Levels of Mercury in the Sediments of some Swiss Lakes Including Lake Geneva and the Rhone River

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ABSTRACT

Sediment samples taken from Lakes Bienne, Brienz, Joux, Tuma, Saoseo, Bodan and Geneva have been analysed for total mercury. Other than Lake Brienz all of the lakes show some evidence of mercury contamination from atmospheric or industrial/municipal sources with levels of mercury above the accepted background level of 200 ppb. The most south easterly lakes, Tuma and Saoseo, show the effects of the precipitation of atmospheric mercury derived from the industrial complexes of Northern Italy. Higher levels are observed in Lake Saoseo than in Lake Tuma due to its geographic location relative to prevailing westerly and south westerly winds. Sediment mercury concentration profiles in the Rhone River identify three canal systems, X, Y and Z and the La Drance tributary as the sources of industrial mercury contamination of the Rhone River and Lake Geneva. Repetative sampling from 1964 to 1971 suggests that significant industrial input to the Rhone River commenced between 1965 and 1967 and has increased annually to 1971.

RÉSUMÉ

Les sédiments récoltés dans les lacs de Bienne, Brienz, Joux, Tuma, Saoseo, Bodan, Léman et dans le Rhône ont été analysés pour déterminer leur teneur en Hg/total. A l'exception du lac de Brienz tous les lacs présentent une contamination mercurielle due soit à la pollution atmosphérique soit à des sources industrielles ou urbaines. La teneur en mercure provenant de l'environnement géologique a été estimée comme étant au maximum de 200 ppb. Les lacs de Tuma et de Saoseo situés sur le versant sud des Alpes sont probablement pollués par les émissions dans l'atmosphère des complexes industriels de l'Italie du Nord, les vents prédominants venant de l'ouest et du sud-ouest. Le profil du Rhône montre des concentrations en mercure dans les canaux X, Y et Z et dans un affluent, la Drance, qui sont les sources industrielles de la contamination par le mercure du Rhône et du Léman.

La répétition des campagnes d'échantillonnage entre 1964 et 1971 montre un apport important de mercure d'origine industrielle entre 1965 et 1967 et dès cette date un accroissement régulier des teneurs jusqu'en 1971.

Introduction

The levels of mercury concentrations recorded in wildlife from many parts of the world during the past decade have demonstrated the wide scale effects of mercury contamination in the environment.

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The industrial discharge of mercury in some restricted aquatic systems has resulted in elevated levels of mercury in the food chain destroying the utility of the system as a food resource for human consumption. In two well documented instances the utilization of contaminated sea food has resulted in the direct poisoning of local inhabitants. At Minimata in Japan between 1953 and 1959, 126 persons were poisoned resulting in 46 deaths. These cases included 19 infants suffering from congenital poisoning born to mothers showing no symptoms of mercury intoxication. At Niigata, Japan, 26 cases of mercury poisoning with 5 deaths were recorded in 1965.

In both of these Japanese epidemics the chemical industries responsible released organic methylmercury, together with mercuric chloride during the manufacture of vinyl chloride and acetaldehyde by means of the catalytic conversion of acetylene. This resulted in the accumulation of methylmercury in shellfish and fish subsequently consumed by the local populations.

Up until the late 1960s it was generally accepted that mercury compounds introduced to the aquatic environment would be diluted and assimilated by the environment with no deleterious effects. Fujiki (1963), during investigations in Minimata Bay, postulated a biological conversion of mercury compounds to the highly toxic methylmercury to account for the high levels of thiomethylmercury in the shellfish of the bay. This concept was discarded when it was discovered that the chemical plant responsible was discharging methylmercury.

Investigations of mercury concentrations in fish in Sweden (see Lofröth 1969) revealed high levels of methylmercury in fish, potentialy hazardous for human consumption, in regions where no introduction of methylmercury had occurred. This led Jenson and Jernalöv (1967, 1968 and 1969) to the important discovery that microbial conversion of inorganic mercury to highly toxic methylmercury occurs in bottom sediments and is transferred to the aquatic food chain.

From the subsequent work of Jernalöv (1968, 1969 and 1971), Wood (1972) and Wood et al. (1968 and 1971) a great deal is now known about the mechanism and on the controlling parameters of the microbiological methylation of mercury. This knowledge is summarized very briefly as follows.

1. No matter what compound of mercury is introduced to the aqueous environment it will degrade and oxidise to mercuric ion (Hg^{2+}) and will be adsorbed by negatively charged, fine grained inorganic or organic particles, e. g. Fe/Mn hydroxides, clays, plankton. In this manner the mercury is transported, dispersed and deposited in the water system.

2. The bottom sediments serve as a store making mercury available for microbial conversion to methylmercury for an extended period of time. The rate of methylation is estimated by Jernalöv (1969) to be one to ten percent per annum.

3. Mercury is not available for methylation when bound as the sulphide without undergoing a prior oxidation step.

4. Jernalöv (1969) estimated that methylation from bottom sediments is significant when the mercury concentration in the sediment exceeds one ppm. This threshold value is arbitary and dependent on bacterial activity. Wood (personal communication) believes that, under high bacterial activity, values as low as 0.3 ppm in bottom sediments may become deleterious to the food chain.

5. The bacterial methylation of mercury is brought about by the transfer of methyl (CH_3) groups with methylcobalamin (methyl-vitamin B_{12}) serving as the methyl donor.

Mono- or di-methylmercury may be formed dependent on the pH. Alkaline conditions favour the formation of di-methylmercury ($CH_3Hg\ CH_3$) with mono-methylmercury (CH_3Hg) forming under acidic conditions.

6. Methylcobalamin is a common coenzyme in bacteria occurring in sediments under both aerobic and anaerobic conditions. The aerobic chemical methylation of mercuric ion (Hg^{2+}) proceeds by the electrophilic attack by Hg^{2+} on methylcobalamin. Hg^{2+} is a pre-requisite for the reaction which is inhibited by the reduction of Hg^{2+} to Hg_2^{2+} or $Hg°$. Anaerobic methylation is an enzymatic process and occurs only in the presence of native mercury ($Hg°$). Mercurous ion (Hg_2^{2+}) is never methylated.

7. Di-methylmercury is volatile (B.P. 94 °C) and is rapidly lost to the atmosphere where it degrades to $Hg°$ and is precipitated with rain or snow. Higher concentrations of mercury are thus observed in fish exposed to monomethylmercury than when exposed to di-methylmercury.

8. The rate of methylation is a direct function of the availability of methylcobalamin and hence is related to the bacterial population and activity. Since the bacterial population and activity is a function of the availability of organic nutrient to the sediment then lake productivity in terms of plankton growth is a controlling factor. A eutrophic lake system will thus have an accelerated methylation rate compared to a lake of lower trophic level. It thus follows that lower levels of mercury concentration in sediment may become deleterious to the lake biota at the higher trophic levels. This is indeed a potent argument for maintaining high water quality standards in lake basins utilized by man in which elevated levels of sediment bound mercury are known to exist.

An understanding of the relationships outlined above at a level sufficient for the predictive modelling of lake systems is dependant on the aquisition of an adequate data base. Such data should include sediment mercury concentrations, mercury concentrations in the food chain and an adequate description of the trophic level in discreet lacustrine situations.

The present paper is intended to provide base level data on mercury concentrations in the sediments of a number of Swiss lakes which may subsequently be related to fish data currently being compiled at the Eidg. Anstalt für Wasserversorgung, Abwasserreinigung und Gewässerschutz research institute in Zürich.

Methods

Samples were collected using a clam type bottom sediment sampler. Samples in Lake Geneva were collected in 1970 and 1971 whereas samples of the Rhone River and other Swiss lake sediments were taken in 1971. Sub-samples for mercury analysis were carefully removed from the top 5 mm of sediment and wet sieved with distilled water to pass a Tyler 80 mesh (175μ) nylon screen. The less than 80 mesh fraction was oven dried at 50 °C, lightly ground in an agate pestle and mortar, and analysed for mercury by the BARRINGER (1966) method. The determinations were carried out using a total combustion procedure to volatalize the mercury into a patented inter-

ference free spectrometer. The precision of the analytical method is given by BARRIN-GER (1966) as 10 percent or better at mercury concentrations in excess of 100 ppb[3]), and 20 percent at concentrations below 100 ppb. As an estimate of the accuracy of the method 26 duplicate samples were sent to the "Bureau des Recherches géologiques et minières" (B. R. G. M.) Orléans, France for mercury determination by acid extraction and flameless atomic absorption. B. R. G. M. is an active member of Geolem which is an international organization for environmental geological studies on Lake Geneva (Léman). The results of the duplicate analyses are given in Table 1 and show generally good agreement between the two methods. It is likely that some of the variation is due to a lack of homogeneity in the sediment samples. The average values for the 26 samples (Table 1) are, however, in excellent agreement with a variation of 3.9 percent.

Sample Number	Barringer Research Total Combustion Hg. / p.p.b.	B. R. G. M. Orléans Flameless A. A. S. Hg. / p.p.b.
L 75	467	325
L 85	1237	1100
L 90	858	930
L 94	1613	1400
L 105	1126	830
L 109	231	230
L 120	1462	1400
L 175	100	80
L 198	476	440
L 214	140	120
L 266	92	150
L 268	2061	1820
L 295	323	325
L 361	1302	1250
L 374	1173	1280
L 383	1247	1400
L 395	1071	1200
L 405	719	840
L 415	1227	1150
L 419	263	550
L 441	270	400
L 445	1404	1320
821	121	300
825	828	450
829	524	400
833	504	350
Mean Values for 26 Samples	802	771

Table 1

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[3]) ppb (parts per billion) as used in this paper relates to the North American system in which 1000 ppb = 1 ppm (part per million).

The determination of mercury by the BARRINGER (1966) method can only be carried out on dried samples due to interference by excess water vapour. The oven drying of samples is open to some criticism due to the fact that some of the mercury may be lost by volatilization. Losses incurred by oven drying have been given as 8 to 10 percent by KENNEDY et al. (1971) at a temperature of 110 °C and in the order of 16 percent by SIVASANKARA PILLEY et al. (1971) after oven drying for 50 hours at 60 °C. The values for total mercury given in this paper may thus be assumed to be low by a factor of 8 to 16 percent. At the general levels of mercury concentration in the sediments examined the mercury loss during sample preparation is not considered to be significant as it is close to the precision of the analytical method.

Results and discussion

It has been shown by CRANSTON and BUCKLEY (1972) that less than one percent of the total mercury in a sample from the Le Have River, Nova Scotia was held in the size fraction greater than 60 microns. Studies by THOMAS (1972) in the North American Great Lakes also demonstrated the association of mercury with the fine fraction of the sediment in those lakes. Total mercury concentrations will thus, in part, vary relative to the sedimentological characteristics of the host sediment. Results from Lakes Ontario and Erie (THOMAS 1972; unpublished data) show that contaminated sediment areas maintain high mercury values regardless of grain size effect.

Since the current study of Swiss lakes is of a comparative nature it was decided to partially eliminate grain size variation by analysing sieved sample to remove the coarse sediment fractions. An 80 mesh sieve was selected due to the fact that this is a commonly used mesh size in geochemical exploration studies. It should be noted, however, that even though values derived from a sieved fraction are of more value for direct inter-sample comparison the grain size effect is not totally eliminated. Sample material less than 80 mesh still contains variable percentages of clay and inert detrital silicates (predominantly quartz) in the silt and fine sand size ranges. True elimination of these compositional variations can only be achieved by analysis of the less than 4 microns size fraction. This size fraction was not utilized due to the insufficient quantity of material and the time involved in separation by sedimentation procedures. Additionally, the use of a very fine size fraction would result in the loss of a substantial quantity of the total mercury, in the order of 57 percent (CRANSTON and BUCKLEY 1972). This would invalidate any future attempt to calculate mercury budgets for the lake systems under investigation. At present, such calculations can be easily carried out by the application of a correction factor to account for the size fraction removed by pre-analysis sieving.

Mercury levels in some Swiss lakes

Samples were collected and analysed for mercury from Lakes Joux, Bienne, Brienz, Bodan, Tuma, Saoseo and Geneva. The locations of the lakes with associated drainage patterns are given in Figure 1. The number of samples collected and analysed for each lake are shown in Table 2 together with the range of mercury values, mean values and standard deviations.
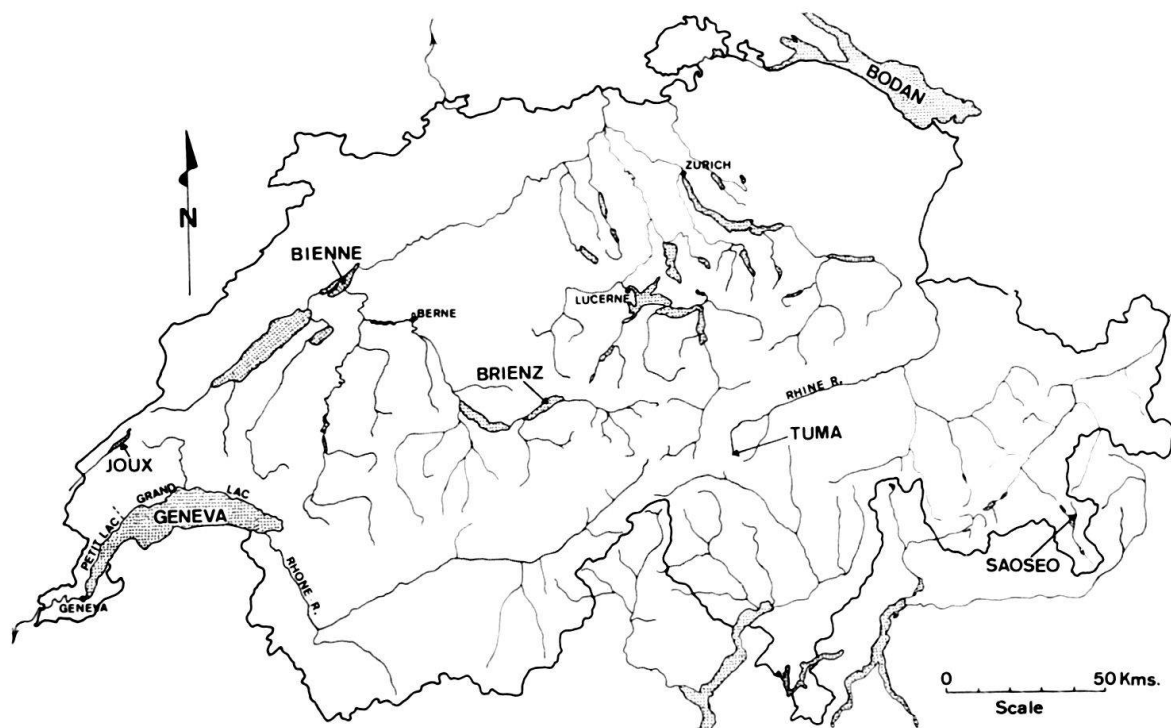
Fig. 1. Plan of Switzerland showing the locations of the lakes sampled and their associated drainage.

Lake	Number of Samples	Range of Values p.p.b.	Mean p.p.b.	Standard Deviation p.p.b.
JOUX	15	205 - 1924	970	391
BIENNE	15	120 - 1731	546	426
BRIENZ	13	34 - 684	190	182
BODAN	10	66 - 1694	765	684
TUMA	8	108 - 602	379	157
SAOSEO	7	748 - 2231	1056	526
GENEVA	213	24 - 2232	675	471
RHONE RIVER	21	20 - 2437	594	651

Table 2

The interpretation of these levels, other than in Lake Geneva and the Rhone River, on a regional or environmental basis is difficult at the present time due to the

lack of data on regional background concentrations and biological sampling. The lowest values for mercury are seen in Lake Brienz with a mean of 190 ppb and a standard deviation of 182 ppb. The analysis of samples from the upper reaches of the Rhone River and associated tributaries (see Table 3, Rhone River Block A and tributaries upstream of La Drance) give mean values of 107 and 48 ppb respectively. If Lake Brienz is considered to be a non-polluted system with respect to mercury then a mean regional Swiss background level of 190 ppb would be a reasonable value. The range of values for Lake Brienz (Table 2) up to 694 ppb suggests that the lake is not wholly uncontaminated and the mean value for the upper Rhone River of 107 ppb is probably a more realistic background level for the Swiss Alpine drainage system. However, for the purpose of this initial investigation the regional background is taken to be 200 ppb or less. This value is probably high but is also lower than the minimum sediment levels which might, under the right circumstances, be deleterious to the aquatic biota (see Introduction, mercury methylation, point 4).

On the basis of a background level of 200 ppb all of the lakes examined show some evidence of mercury contamination. The high altitude alpine lakes, Tuma and Saoseo are of particular interest. Lake Saoseo is situated in the southeastern part of Switzerland in the southern Alps at an altitude of 2028 m and draining out of the country to the southeast (Fig. 1). Lake Tuma is in a more central situation (Fig. 1) at an elevation of 2345 m at the headwaters of the Rhine draining north eastwards to Lake Bodan. Lake Tuma is situated in a glacial cwm (cirque) above the tree line. The immediate basin is subject to rapid physical erosion resulting in a relatively high rate of sedimentation in the lake. Lake Saoseo is situated below the tree line ponded by a glacial morraine. The lake bed is composed of rock blocks with sediment accumulating in the intervening spaces. The lake basin is vegetated with slow erosion resulting in low rates of sediment accumulation in the lake.

The mean levels of mercury in the sediments of the two lakes show that concentrations in Lake Saoseo are approximately three times the levels observed in Lake Tuma. Lake Tuma with a mean of 379 ppb shows only slight evidence of mercury contamination which is verified to some extent by the maximum value of 602 ppb. This is in direct contrast to Lake Saoseo which shows a range of values from 748 to 2231 ppb with a mean of 1056 ppb. In both of these lakes there is no evidence for a direct input of mercury and the contamination is believed to be the result of atmospheric fallout. The variation in mercury levels may be related in part to the postulated difference in the sedimentation rates of the two lakes. To a greater extent, however, the variation is believed to be a function of their geographic location.

Assuming prevailing south westerly and westerly winds in the region and the derivation of the atmospheric mercury from the industrial complexes of Northern Italy in the region of Turin and Milan then the higher levels of mercury would be carried past the region of Lake Saoseo. Additionally, since Saoseo is situated on the southern flanks of the Alps it will receive the initial precipitation which is likely to purge the atmospheric mercury with resulting higher concentrations in rain or snow than would be expected in precipitation further north in the region of Lake Tuma.

The reasons for the high levels of mercury in Lake Joux (Table 2) are not, as yet, understood. It is possible that some industrial contamination may have occurred from small watch making factories or sawmills though this does not seem to be a

satisfactory explanation for the observed mean value of 970 ppb. The cause of these values must await future detailed investigations.

The high levels observed in Lake Bodan, Bienne and Geneva are probably due to the industrial and municipal discharge of mercury. This is discussed later with reference to Lake Geneva and the Rhone River.

The mercury data for the Swiss lakes is summarized in Figure 2 which shows the mean values and the spread of ± one standard deviation. The very large standard deviation observed for Lake Bodan is due to the fact that samples were taken both from the more polluted western part of the lake (Untersee) and the larger eastern section (Obersee) giving a wide range of mercury values from 66 to 1694 ppb. Additionally the values given for Lake Bienne in Table 2 and in Figure 2 may be relatively low
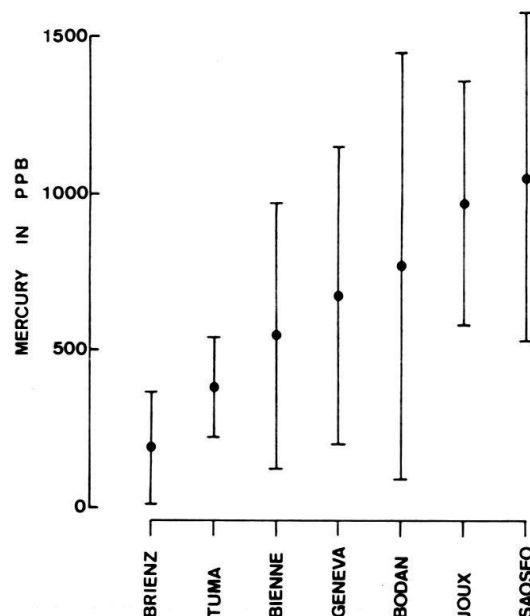

Fig. 2. Mean mercury concentrations ± one standard deviation of the Swiss lakes examined.

compared to the other lakes due to the fact that sample values from this lake refer to a composite sample of approximately the top 10 to 15 centimeters of the sediment column. All other values quoted in this text are for the top 5 mm of sediment.

Until detailed fish analyses become available the environmental effects of the sediment mercury levels discussed above must remain conjectural. From the results of fish analyses (BLIGH 1971) sediment mercury levels in Lake Ontario are resulting in deleterious effects on the food chain. In the eastern part of the lake some of the fish levels are in excess of the permissable 0.5 ppm and restrictions have been placed on commercial fishing. The mean total sediment concentration in Lake Ontario is 651 ppb (THOMAS 1972). When corrected for sand and gravel content (greater that 64 microns) the mercury concentration in the silt and clay fractions stands at 944 ppb (VERNET and THOMAS 1972). This corrected value is a little high to compare directly with the Swiss lake mercury levels since no correction for the dilution by the 64–175 micron size fraction can be made. However, on the basis of the Lake Ontario values given above it can be suggested that elevated fish values may be found in Lakes Joux, Bodan, Saoseo and possibly Geneva. It should not be overlooked, however, that in

addition to the sediment concentrations of mercury the following four factors will have on influence on the fish levels.

1. The species of fish and its position in the aquatic food chain.

2. Age class of the fish. There is a direct correlation between fish weight and mercury concentration (BLIGH 1971).

3. The trophic level of the lake and its effect on bacterial density and activity.

4. The pH of the lake system as a control on the preferential formation of di- or mono-methylmercury.

Mercury levels in the Rhone River and Lake Geneva

The geochemical exploration for gold and base metal deposits using mercury as a tracer element is a well known technique (JONASSON 1971). In this context the most useful characteristic of the element in the fresh water environment is related to its basic lack of mobility. Mercury introduced to the fresh water system, either from natural or industrial sources, is rapidly chelated or adsorbed by fine grained particulate inorganic or organic material. In this manner the mercury is transported, dispersed and deposited relative to the hydraulic conditions within the system. With dispersion there is a decreasing concentration in a downstream direction which may be utilized to identify the source point or region.

In order to attempt to locate the primary sources of industrial mercury input to the Rhone River and Lake Geneva, mercury analyses were carried out on sediment samples taken from the Rhone River and its associated tributaries and canal systems. Approximately 100 kilometers of river were sampled from Lake Geneva upstream to Naters.

The concentration profile of sediment bound mercury in the Rhone River is shown in Figure 3. From sample 1 at Naters downstream to sample 11 mercury values are low ranging from 64 to 336 ppb. These sample values comprise block A (Fig. 3) and with a mean value of 107 ppb represents the Rhone River background value. After sample 11 the mercury concentration increases dramatically to 1818 ppb at sample 13 downstream of a canal input. This canal has been designated Canal X in Figure 3. From sample 13 to sample 24 mercury levels oscillate but show a progressive decrease to approximately 300 ppb. Between samples 24 and 26 a second canal system (Canal Y) enters the Rhone River again elevating mercury levels above 1000 ppb. Values again decrease downstream to between samples 30 and 32 where a final peak in mercury concentration can be seen to occur in association with Canal Z (Fig. 3).

The high value of mercury (2437 ppb) seen at the mouth of the river at sample 40 is believed to be due to the deposition of fine material with decreasing stream velocities as the river enters eastern Lake Geneva.

The samples used in the profile described above were collected in 1971 and can be seen to contain consistantly higher levels of mercury than for samples taken in the lower reaches of the river in 1970 (Fig. 3). This would seem to suggest an increase in the mercury loading to the river over the one year interval between sampling.

The large increase in mercury concentrations between 1970 and 1971 may in addition be due to the exceptionally dry conditions and low river levels in 1971. The
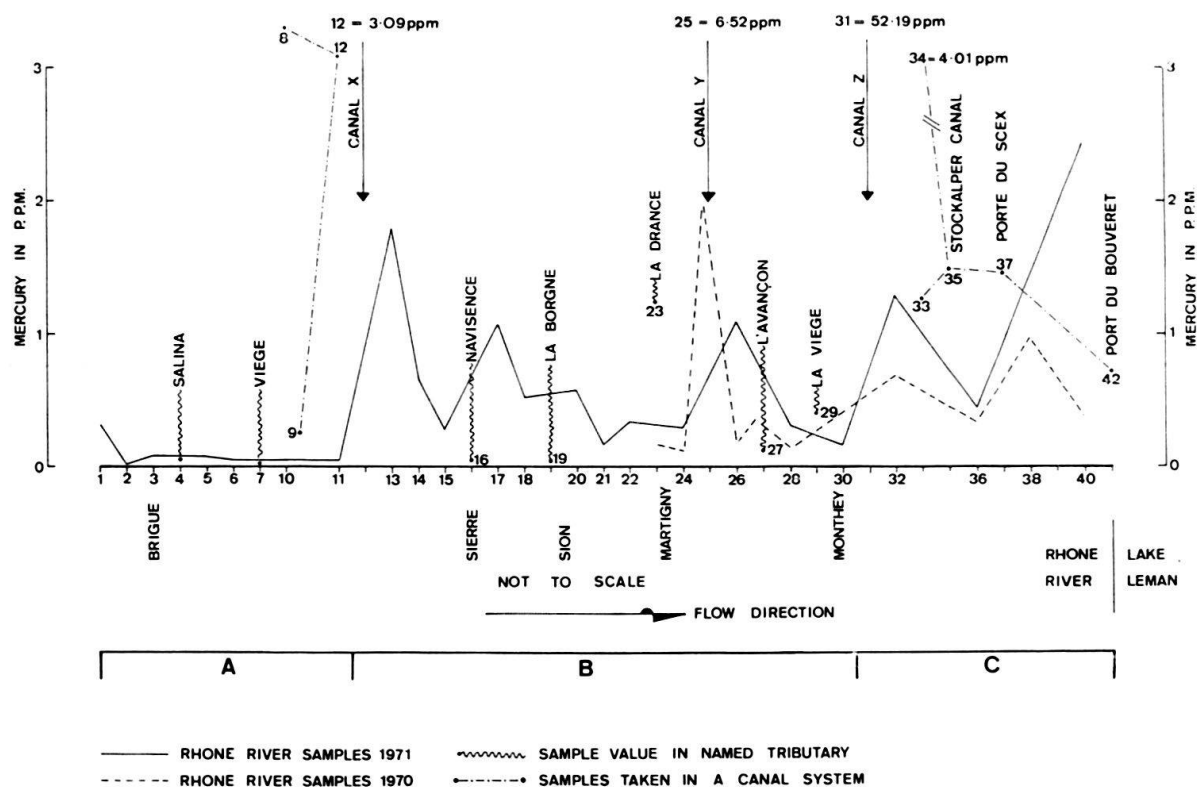
Fig. 3. Mercury profiles in the sediments of the Rhone River.

sequential sampling of sample 38 (Fig. 3) at Porte du Scex from 1964 to 1971 however confirms that an increase in mercury loadings to the sediments of the Rhone River has been occurring during this time interval. The results are summarized as follows:

Year	1964	1965	1967	1970	1971
Hg concentration in ppb	169	171	512	970	1404

Prior to 1967 mercury values at sample 38 were only marginally higher than the background levels observed in the upstream section of the Rhone River, block A described above. Between 1965 and 1967 a substantial increase in mercury levels occurred which may be related to some form of industrial input to the river. From 1967 to 1971 the mercury input to the river has increased sufficiently to raise the sediment mercury to a level 7 times the values recorded in 1964 and 1965.

From the mercury profile in the river sediments there appears to be three major sources of mercury to the Rhone River and Lake Geneva. Each source is identified as a canal system. This is confirmed by the analysis of sediments taken from Canals X, Y and Z the values for which are illustrated in Figure 3 and quoted in Table 3. From Table 3 it can be seen that the average mercury value for the canal systems is 8070 ppb or approximately 14 times the average concentration for the Rhone River.

The mercury values for sediments taken from seven tributary streams are also given in Figure 3 and Table 3. Tributaries entering the Rhone River upstream of

Martigny give low background values with an average concentration of 48 ppb. The Drance entering the Rhone at Martigny gave a value of 1238 ppb suggesting strongly that this river may be an additional source of mercury to the Rhone River. The remaining tributaries downstream of La Drance that were sampled gave low values, 116 ppb for l'Avançon and 394 ppb for La Viège neither of which can be making a significant contribution to the mercury loading of the Rhone River.

Area	Number of Samples	Range p.p.b.	Mean p.p.b.	Standard Deviation p.p.b.
RHONE TRIBUTARIES	7	31 - 1,238	277	-
Tributaries upstream of La Drance	4	31 - 57	48	-
La Drance and down-stream tributaries	3	116 - 1,238	583	-
RHONE RIVER				
All Samples	21	20 - 2,437	594	651
Block A	6	20 - 336	107	115
Block B	11	170 - 1,818	570	493
Block C	4	434 - 2,437	1,389	821
LAKE GENEVA				
Grand Lac	132	41 - 2,232	735	674
Petit Lac	98	24 - 1,274	622	321
RHONE RIVER CANAL SYSTEMS				
All Samples	9	68 -52,192	8,070	-
Canal System X	3	68 - 3,302	2,154	-
Canal System Y	1	-	6,525	-
Canal System Z	5	725 -52,192	11,928	-

Table 3

Basic statistics relative to the data presented in Figure 3 are given in Table 3. The Rhone River has been divided into three main stretches A, B and C covering the area upstream of Canal X (Block A), Canal X to Canal Z (Block B) and Canal Z to Lake Geneva (Block C). The mean mercury values and the spread of ± one standard derivation for blocks A, B and C are illustrated in Figure 4 together with the mean values for the Grand Lac (Eastern basin of Lake Geneva) and the Petit Lac (western basin of Lake Geneva). Figure 4 illustrates very well the progressive increase in sediment mercury concentrations down the Rhone River to the Grand Lac. Dispersion of the mercury in the large lake system of Lake Geneva results in a decrease in the average mercury concentration in the Grand Lac with a further decrease into the
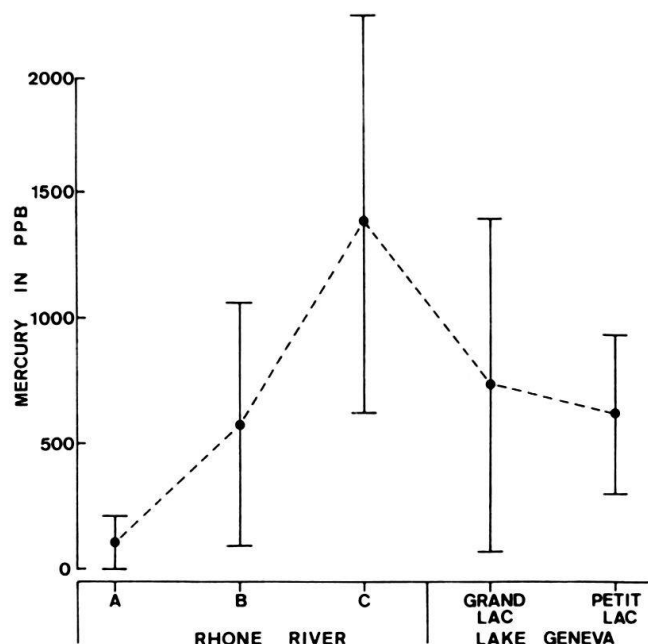
Fig. 4. Mean mercury concentrations ± one standard deviation in the sediments of the Rhone River and Lake Geneva.

Petit Lac away from the source of mercury to the lake from the Rhone River. The mean mercury concentrations of 735 and 622 ppb in the Grand Lac and Petit Lac respectively, when compared to the background level of the Rhone River of 107 ppb (Block A, Table 3) gives some concept of the extent of the contamination of the lake.

Conclusions

The results of an initial survey of the mercury concentrations in the sediments of some Swiss lakes demonstrates that some contamination by industrial mercury has occurred. The extent of this pollution is difficult to estimate as there is insufficient data to determine a precise and realistic regional background level. For the purpose of this paper however a value of 200 ppb has been utilized as a sensible, if somewhat high, background level for the interpretation of the lake data.

All of the lakes examined gave some individual sample values indicative of mercury input in excess to that which might be considered to be of natural geological origin. The mean values confirm this supposition with all lakes other than Lake Brienz having a mean sediment mercury concentration in excess of 200 ppb. The levels of mercury concentration are variable and the mercury is believed to be derived from two sources, atmospheric and industrial/municipal.

The two most southeastern lakes, Saoseo and Tuma, both situated at high elevations, show evidence of atmospheric mercury contamination which is probably derived from the industrial complexes of Northern Italy. Lake Saoseo has a mean concentration of 1056 ppb approximately three times the level observed in Lake Tuma with a mean of 379 ppb. This variation in concentration is believed to be due to the geographic location of the lakes with Lake Saoseo exposed to greater concentrations of atmospheric fallout in rain and snow in the prevailing south westerly winds.

The contamination of the remaining lakes, Bienne, Joux, Bodan and Geneva, is believed to be due to variable mercury discharge from industrial and municipal sources.

A more detailed examination of the sediments of Lake Geneva and the Rhone River shows positive evidence for the industrial contamination of the river with consequent elevated mercury concentrations in the sediments of the lake downstream. High levels of sediment bound mercury give conclusive evidence that three canal systems, designated X, Y and Z, associated with the Rhone River, are the primary sources of industrial mercury contamination. An additional though less significant source of mercury to the river may be related to the La Drance tributary entering the Rhone River at Martigny. Samples taken over a period from 1964 to 1971 suggest that the major input of industrial mercury commenced between 1965 and 1967 and has been increasing annually to 1971.

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