GEOLOGIJA 21, 93—164 (1978), Ljubljana

UDK 552.143+550.4+628.54(285.2)(497.12)=20

Lakes Bled and Bohinj

Origin, Composition, and Pollution of Recent Sediments

Franc Marcus Molnar

Limnološka postaja Bled, Kemijski inštitut Borisa Kidriča, 61000 Ljubljana, Hajdrihova 19, Jugoslavija

Peter Rothe

Abteilung für Geologie, Geographisches Institut der Universität Mannheim, 6800 Mannheim 1, Schloss, B. R. Deutschland

Ulrich Förstner

Institut für Sedimentforschung der Universität Heidelberg, 6900 Heidelberg 1, Im Neuenheimer Feld 236, B. R. Deutschland

Janez Štern and *Bojan Ogorelec*

Geološki zavod Ljubljana, 61000 Ljubljana, Parmova 33, Jugoslavija

Alojz Šercelj and *Metka Culiberg*

Slovenska akademija znanosti in umetnosti, 61000 Ljubljana, Novi trg 3, Jugoslavija

Abstract

Fifteen grab samples and two shallow cores were studied from Lake Bled. Their carbonate contents are in the range 55—79 %. Calcite prevails but dolomite may occasionally amount up to 38 % of the carbonate compound. The non-carbonates seem mostly to be diatoms besides some quartz and traces of feldspar and clay minerals. Chemical analysis of the core sediments revealed a general increase of the heavy metals Zn, Cd and Pb in the uppermost layer. The highest content of Zn (up to 970 ppm) and Pb (up to 160 ppm) were found within nearshore grab samples thus indicating sewage input. The increased eutrophication of Lake Bled is evident.

Eight grab samples and one core from Lake Bohinj are also carbonate rich sandy silts and clays with total carbonate contents ranging from 53—91 %. Calcite prevails especially in the western part of the lake. Dolomite content is, in the average, higher than in Lake Bled. The non-carbonates seem essentially similar to the Bled sediments. The core samples contain an increase of the heavy metals Zn, Cu, and Pb within the uppermost 10 cms. In addition, Fe-, Mn-, Cr-, and Ni-contents are unusually high compared to Bled.

Kratka vsebina

V poročilu so prikazani začasni podatki o sedimentoloških in geokemičnih parametrih iz raziskav sedimentov v Blejskem in Bohinjskem jezeru. Iz Blejskega jezera smo preiskali vzorce 15 zajemov s površja jezerskega dna ter dveh jeder sedimenta do globine 45 cm. V sedimentu prevladuje karbonatni glinasti melj, ki vsebuje v zgornjih 10 cm pod površjem obilo organskih snovi. Zaradi menjavanja organskih in anorganskih sestavin je sediment laminiran. V preiskanih vzorcih je znašala celokupna količina karbonatov 55 do 79 %; bistvenih razlik med vzorci s površja in iz globine ni bilo. Prevladuje kalcit, vendar vsebuje ponekod karbonatna frakcija do 38 % dolomita. Med nekarbonatnimi sestavinami prevladujejo skeleti diatomej, v manjših količinah pa so zastopani še kremen, glinenec in minerali glin. Karbonatni sedimenti Blejskega jezera so v glavnem detritičnega izvora, saj sestoji tudi okolica jezera večidel iz triadnih karbonatnih kamenin. To velja predvsem za delež dolomita v sedimentu, medtem ko za kalcit ne moremo izključiti možnosti avtohtonega nastajanja ob udeležbi vodnih rastlin. Kemične analize jedrskih vzorcev kažejo splošno povečane količine cinka in kadmija, posebno pa svinca v zgornjih centimetrih profilov ponekod do 160 ppm. Najvišje koncentracije Zn in Pb smo našli v vzorcih sedimenta blizu obale, kar kaže na dotoke odpadnih voda. S tem v zvezi je postajala jezerska voda vedno bolj eutrofična.

Iz sedimenta Bohinjskega jezera smo preiskali vzorce 8 zajemov z jezerskega dna in eno jedro. Tudi v tem jezeru sestoji sediment v glavnem iz karbonatnega melja in gline. Vsebuje 53 do 91 % karbonatov; med njimi prevladuje kalcit, vendar je ponekod v karbonatni frakciji dolomita do 69 %. Količine dolomita v sedimentu Bohinjskega jezera so v celoti višje kot v Blejskem jezeru. Dolomit je nedvomno detritičnega izvora. To velja tudi za glavni del kalcita, vendar domnevamo, da je tudi v Bohinjskem jezeru del kalcita avtohton. Nekarbonatne sestavine sedimenta obeh jezer se ne razlikujejo bistveno. Kemične analize jedra kažejo, da količine Zn, Cu in Pb v zgornjih centimetrih sedimenta postopno naraščajo.

Pelod v jedrih sedimenta iz Blejskega in Bohinjskega jezera kaže, da so usedline v obeh profilih relativno mlade in niso starejše od 400 do 500 let.

Zusammenfassung

Es wird über vorläufige Ergebnisse einer Untersuchung der Sedimente aus den Seen von Bled und Bohinj in Slowenien (Jugoslawien) berichtet; dabei werden sedimentologische und geochemische Parameter diskutiert.

Fünfzehn Greiferproben und zwei kurze Sedimentkerne mit einer max. Eindringtiefe von 45 cm wurden aus dem Bled-See untersucht. Es handelt sich um karbonatreiche Silte und Tone, in deren oberflächennahen 10 cm organisches Material häufig auftritt; entsprechend dem Wechsel von mineralischen und organischen Komponenten sind sie im mm-Bereich laminiert. Der Gesamtkarbonatgehalt der untersuchten Proben reicht von 55 bis 79 %, wobei keine wesentlichen Unterschiede zwischen Oberflächenproben und Kernproben bestehen. Es überwiegt Calcit, doch kann die Karbonatfraktion gelegentlich bis zu 38 % Dolomit enthalten. Die Nicht-Karbonate sind überwiegend Diatomeen-Skelette; ausserdem treten geringe Mengen an Quarz, Feldspat und Tonmineralien auf. Die Karbonatsedimente in Bled-See sind im wesentlichen als detritische Bildungen aufzufassen, da die Umgebung des Sees aus Karbonatgesteinen von meist triassischen Alter besteht. Dies gilt insbesondere für den Dolomitanteil, während beim Calcit eine autochthone Bildung unter Mitwirkung von Wasserpflanzen nicht ausgeschlossen werden kann. Die chemischen Analysen an den Sedimentkernen erbrachten einen allgemeinen Anstieg der Schwermetalle Zink, Cadmium und besonders Blei, der sich

in den obersten Profilzentimetern vollzieht, wobei Bleigehalte von z. T. 160 ppm erreicht werden. Die höchsten Konzentrationen für Zink und Blei wurden in den ufernahen Proben gefunden, was auf abwasserhaltige Zuflüsse hinweist. Im Zusammenhang damit muss auch die beobachtete Zunahme der Eutrophierung des Sees gesehen werden.

Aus dem Bohinj-See wurden acht Greiferproben und ein Sedimentkern untersucht. Auch in diesem See handelt es sich im wesentlichen um karbonatreiche Silte und Tone mit Gesamtkarbonatgehalten von 53 % bis 91 %. Dabei überwiegt im allgemeinen Calcit, doch wurden in Einzelfällen Dolomitgehalte bis 69 % der Karbonatfraktion angetroffen. Insgesamt sind die Dolomitgehalte des Bohinj-Sees höher als die von Bled. Dolomit ist eindeutig detritisch und wird durch die Zuflüsse in den See transportiert. Dies gilt auch für die Hauptmenge des Calcits, obwohl auch dafür ein geringer Anteil durch autochthone Bildung vermutet werden kann. Die Nicht-Karbonate unterscheiden sich nicht wesentlich von denen der Bled-Seesedimente. Die chemischen Analysen der Kernsedimente ergaben einen annähernd kontinuierlichen Anstieg der Schwermetalle Zink, Kupfer und Blei innerhalb der obersten Zentimeter zur Oberfläche hin.

Palynologische Untersuchungen zweier Bohrkerne von Boden der Seen von Bled und Bohinj haben gezeigt, dass die Ablagerungen, die zwei Bohrkerne erfassen, ziemlich jungen Alters sind, nicht älter als 400 bis 500 Jahre.

Contents

1. Preface

The quality of waters in many regions has greatly suffered as a result of the increasing impact on our environment by waste materials from industries, communities and agriculture. This development is especially conspicuous in a great number of fresh water lakes, that not only serve as drinking water and nutrient sources, but have a very high value for recreation purposes. Examples from all parts of the world have shown that lakes are very sensitive ecosystems that can be destroyed within a period of mere decades, and can then be regenerated only with very strenuous efforts.

Meanwhile ambitious, large-scale research programs have been introduced at several locations in order to evaluate the causes, extent and future consequences of the pollution, and to prepare appropriate counter measures. In this respect, the investigation of sediment has become increasingly important, since the distribution of pollutants that are only sparingly soluble is, both in their spatial and temporal development, relatively easy to ascertain from such sediment deposits. An example is the research program begun in 1975, for heavy metal distribution in the Sava catchment area in Slovenia, above all in the sediment in the heavily polluted Moste dam, for which the first research results have recently been published (J. Štern and U. Förstner 1976). In the scope of a long-term cooperation between the Geološki zavod Ljubljana and the Institute for Sediment Research of the University of Heidelberg/Dept. of Geology, University of Mannheim, detailed sampling of sediment from Lakes Bled and Bohinj and their affluents was carried out in late summer 1976, in order to be able to more closely examine various aspects of the sedimentological and geochemical conditions of these lakes (see figs. 1, 2 and 3).

The results of the team investigations are presented in six chapters relating to the different consideration aspects.

2. Limnological features of Lakes Bled and Bohinj

Franc Marcus Molnar

The Alpine lakes of Bled and Bohinj in Upper Carniola are characterized by two different environmental conditions. The latter is pure enough to maintain a natural biological equilibrium as the Savica River supplies it with water and air. Conversely, the ecological relations of Lake Bled are disturbed to a degree demanding a restoration. To overcome the lack of a natural aeration, a flushing project has been accomplished introducing a part of the Radovna River water through a pipeline into the lake (M. Rejic, 1973). The water

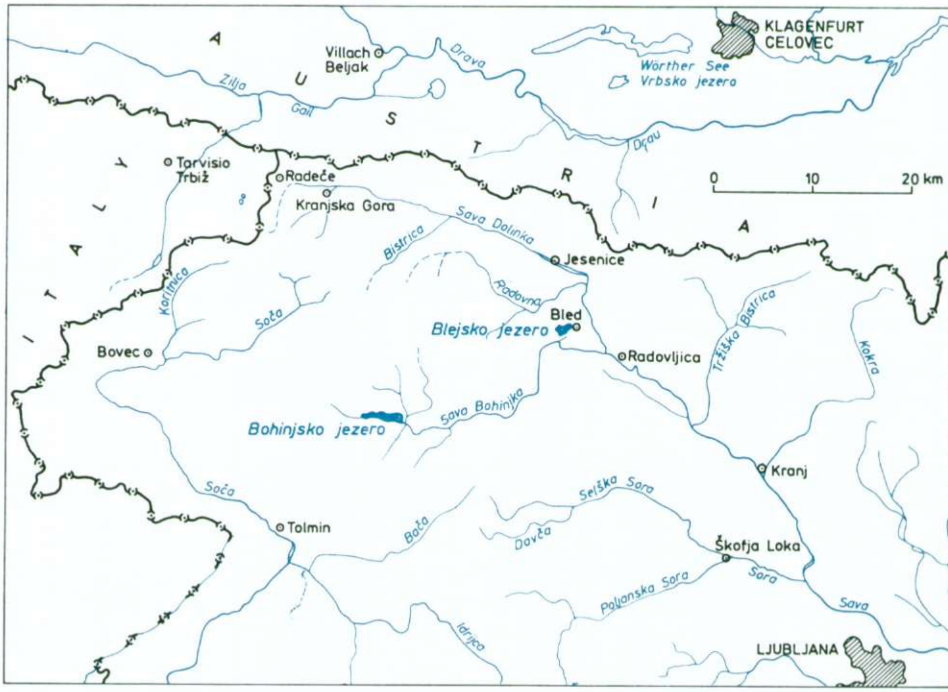
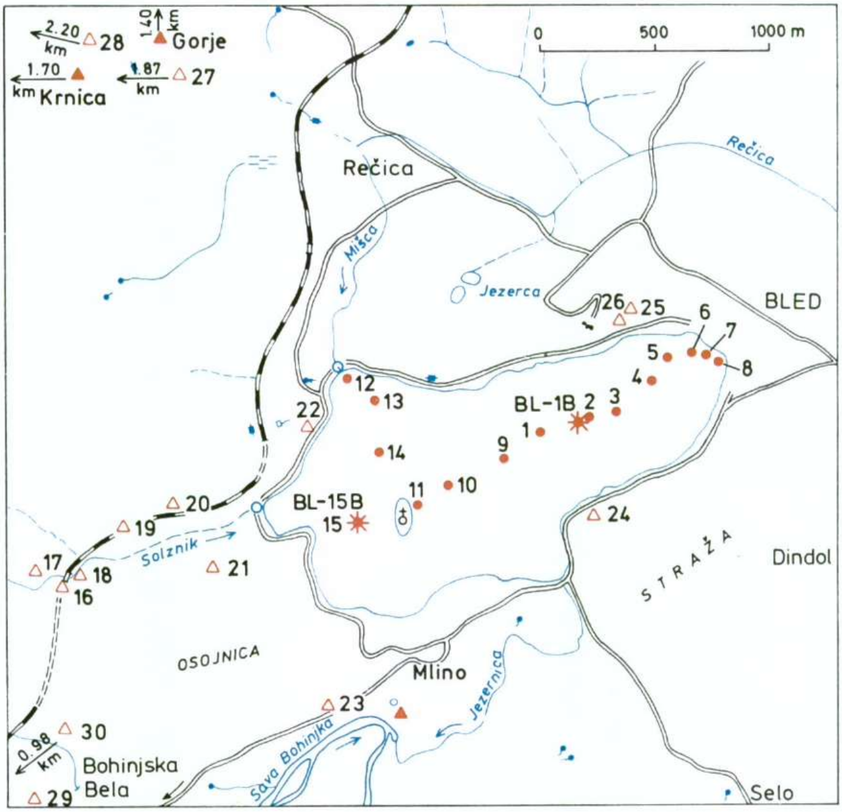


Fig. 1. Lakes Bled (Blejsko jezero) and Bohinj (Bohinjsko jezero). Location map

pipeline went into operation in 1965, and since then the annual inflow of fresh water has been approximately 0,5—17 mio m³. In 1973 a permanent control of the lake started with the foundation of the Limnological station Bled, which was in 1974 incorporated into the Kemijski inštitut Borisa Kidriča Ljubljana.

The lake remains eutrophic in spite of the flushing. The reason could be either that the amount of exchanged water is too small, or that the loading with phosphorus and nitrogen is too high. Neither excludes the other. Figures 4 and 5 show the variations of the oxygen content as well as temperatures and Secchi disc transparency in vertical water profiles at the two deepest points BL-1B and 15B of Lake Bled (fig. 2) during the year 1976. It is evident that in the summer and fail periods the hypolimnion remains anaerobic. There are eumictic or even dimictic periods. The temperature of the cool hypolimnic layer increases due to the inflow of the slightly warmer Radovna river water. An increase of some 3 °C influences the autumn and spring turnover. The lake is becoming holomictic. This can be dangerous for the consumption of oxygen. The Secchi disc transparency is smaller in winter when *Oscillatoria rubiscens* rises to the upper, cooler water layers.

Limnophysical and limnochemical data from Lake Bled was obtained from vertical profiles at the same points BL-1B and BL-15B on September 28 and September 30, 1976 simultaneously with sediment sampling. A concentration of

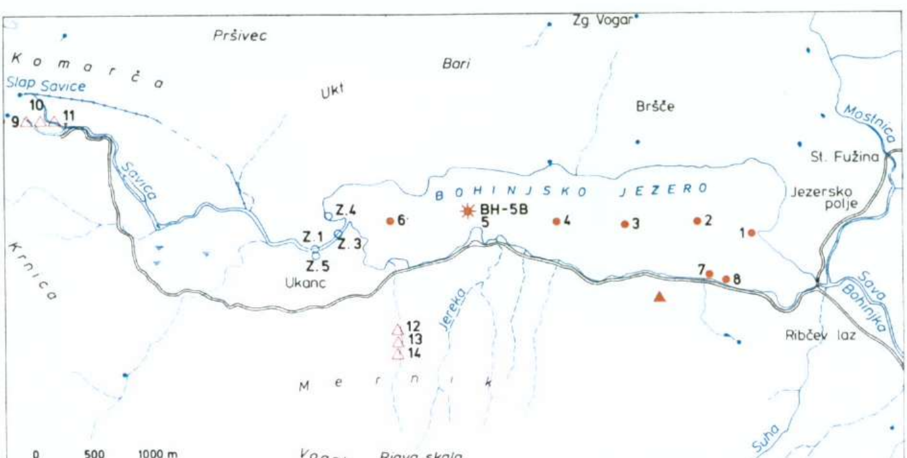


• 1 ✳ 2 ○ 3 △ 4 ▲ 5

Fig. 2. Lake Bled and surroundings. Sampling sites

1 Grab sample } lake sediment
2 Core profile }

3 Fluvial sediment
4 Rock sample
5 Glacial lacustrine chalk



• Grab sample } lake sediment
✳ Core profile }

○ Fluvial sediment
△ Rock sample
▲ Glacial lacustric chalk

Fig. 3. Lake Bohinj and surroundings. Sampling sites

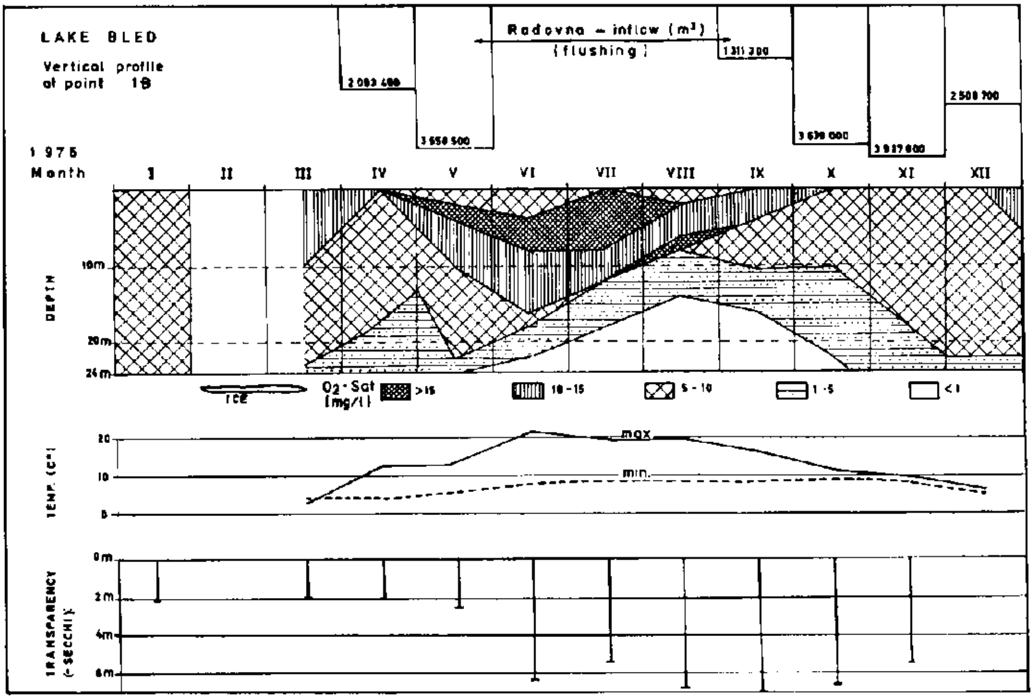


Fig. 4. Lake Bled, vertical profile at point 1B
Diagram showing the oxygen saturation, temperature and transparency dependent on the artificial flushing, during 1976

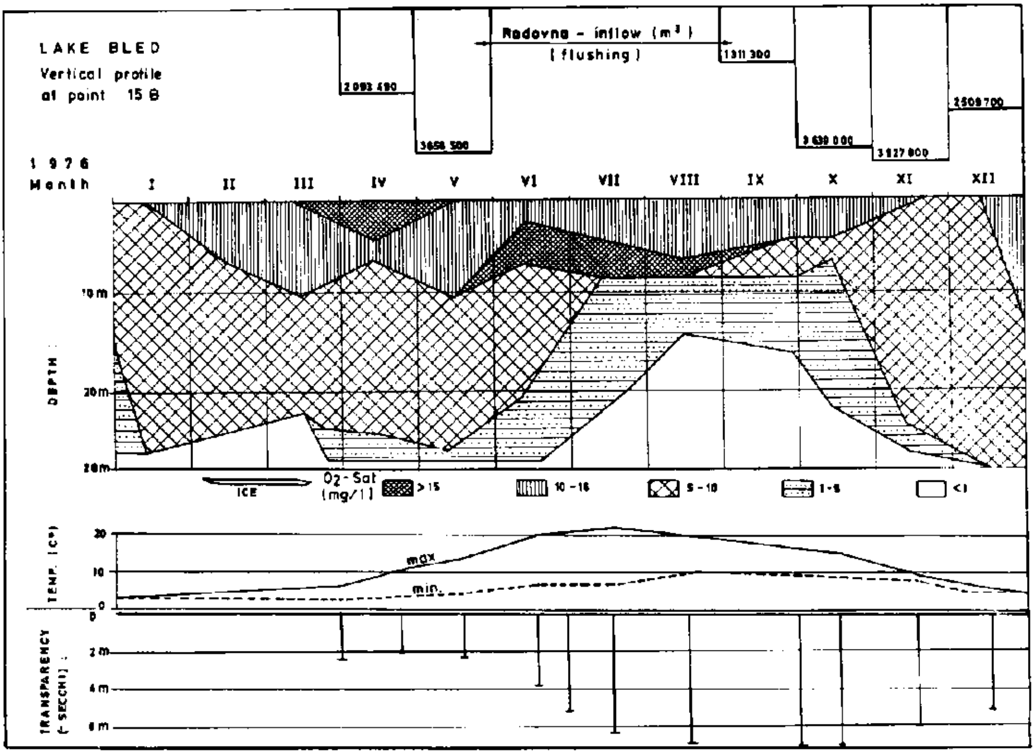


Fig. 5. Lake Bled, vertical profile at point 15B
Diagram showing the oxygen saturation, temperature and transparency dependent on the artificial flushing, during 1976

Table 1. **Lake Bled, vertical profile at point BL-1B (fig. 2.)**
Limnophysical and limnochemical data, 1976 — 09 — 28

Depth m	Temp. °C	Oxygen Diss. mg/l	Oxygen Sat. %	NH_4 mg/l	NO_3 mg/l	PO_4 mg/l	NO_2 mg/l	HCO_3 °dH	Ca+Mg °dH	CO_2 mg/l	H_2S mg/l	pH	Redox pot. (dE) mV	Redox pot. rH_2	Tot. P mg/l
0	16.5	12.4	131	0.1	0.5	0.01	0.02	8.7	9.1	0.0		8.5	-330	33.2	0.01
2	16.4	11.9	125	0.1	0.5	0.06	0.01	8.7	9.1	0.0		8.7	-330	33.2	0.01
4	15.5	11.7	121	0.1	0.5	0.03	0.01	9.0	9.5	3.2		8.2	-325	33.0	0.01
6	15.0	9.1	93	0.1	0.5	0.02	0.01	9.2	9.5	6.4		7.7	-300	32.2	0.01
8	13.7	5.5	55	0.2	0.5	0.02	0.01	9.2	9.9	8.6		7.4	-290	31.8	0.01
10	12.2	1.7	16	0.2	0.5	0.02	0.01	9.8	10.4	10.8		7.3	-260	30.8	0.01
12	10.5	0.9	8	0.4	0.5	0.02	0.01	9.8	10.5	10.8		7.2	-260	30.8	0.02
14	10.0	0.1	1	0.9	0.5	0.03	0.03	9.8	10.5	15.1	<0.01	7.1	-260	30.8	0.01
16	10.0	0.1	1	1.0	0.5	0.04	0.04	10.3	10.7	16.2	<0.01	7.1	-260	30.8	0.01
18	9.7	0.0	0	1.1	0.5	0.04	0.02	10.3	11.0	18.3	<0.01	7.1	-210	29.1	0.02
20	9.5	-	-	1.7	0.5	0.06	0.06	10.3	11.1	21.6	0.02	7.0	+190	18.3	0.03
22	8.8	-	-	6.6	0.5	0.15	0.03	12.3	12.0	23.8	0.48	7.0	+290	11.9	0.13
24	8.2	-	-	14.7	0.5	0.61	0.02	14.6	13.8	37.7	2.30	6.9	+310	11.2	0.61

Remarks: Partly cloudy, windy, three days after rainfall; air temperature = 17° C; transparency (Secchi) = 7.0 m. Total P measurement have been done in laboratories of Kemijski inštitut Borisa Kidriča, Ljubljana

Table 2. **Lake Bled, vertical profile at point BL-15B (fig. 2.)**
Limnophysical and limnochemical data, 1976 — 09 — 30

Depth m	Temp. °C	Oxygen Diss. mg/l	Oxygen Sat. %	NH_4 mg/l	NO_3 mg/l	PO_4 mg/l	NO_2 mg/l	HCO_3 °dH	Ca+Mg °dH	CO_2 mg/l	H_2S mg/l	pH	Redox pot. (ΔE) mV	Redox pot. rH_2	Tot. P mg/l
0	16.4	11.9	125	0,2	0.5	0.01	0.01	8.4	9.0	0.0		8.4	-175	28.8	0.01
2	16.4	11.9	125	0,3	0.5	0.01	0.01	8.4	9.0	3.2		8.4	-300	33.1	0.01
4	15.5	10.9	112	0.4	0.5	0.01	0.01	9.0	9.2	3.2		8.2	-300	33.1	0.01
6	15.0	8.1	83	0.2	0.5	0.01	0.01	9.0	9.2	5.4		7.7	-290	32.8	0.01
8	13.7	5.3	53	0.4	0.5	0.01	0.04	9.8	9.6	5.4		7.4	-290	32.8	0.02
10	12.2	1.2	12	1.1	0.5	0.01	0.01	10.1	9.9	8.6		7.2	-250	31.4	0.03
12	10.2	0.5	5	2.0	0.5	0.01	0.02	10.1	10.3	10.8		7.2	-245	31.3	n.d.
14	10.0	0.1	1	2.3	0.5	0.02	0.02	10.1	10.5	16.2		7.2	-255	31.6	0.01
16	9.8	0.1	1	1.5	0.5	0.02	0.04	10.1	10.5	16.2		7.1	-245	31.3	0.02
18	9.6	0.0	0	2.3	0.5	0.02	0.03	10.4	10.5	16.2		7.1	-245	31.3	0.02
20	9.4	-	-	2.5	0.5	0.02	0.04	10.4	10.5	16.2		7.1	-250	31.4	0.03
22	8.3	-	-	2.6	0.5	0.05	0.03	10.6	10.5	20.5	0.27	7.0	-235	30.9	0.04
24	8.3	-	-	3.9	0.5	0.05	0.02	10.6	11.0	21.6	0.16	7.0	+300	12.5	0.02
26	8.2	-	-	6.6	0.5	0.05	0.04	12.3	11.7	26.9	2,20	6.9	+340	11.1	0.20
28	8.2	-	-	13.0	0.5	0.13	1.40	14.0	12.8	33.4	2,50	6.9	+340	11.1	0.39

Remarks: Cloudy, thunderstorm; air temperature = 17° C; transparency (Secchi) = 7.0 m. Total P measurement have been done in laboratories of Kemijski inštitut Borisa Kidriča, Ljubljana

Table 3. **Temperature and oxygen dissolved in Lake Bohinj,**
1975 — 08 — 13

Depth m	Temp. °C	Oxygen mg/l
0	20.2	11.3
1	18.4	11.1
2	15.4	13.1
3	13.2	13.8
4	11.7	14.0
5	10.9	14.3
10	9.0	14.6
15	7.3	14.4
20	6.1	13.7
23	5.9	13.0

Depth m	Temp. °C	Oxygen mg/l
0	19.0	11.2
1	18.2	11.4
2	15.1	13.3
3	13.4	14.0
4	12.4	14.5
5	11.1	15.0
10	9.0	15.4
15	7.5	15.2
20	6.9	14.8
25	5.8	13.8
30	5.5	13.2
35	5.0	13.2
40	5.0	12.6
41	4.9	13.2
42	4.8	11.6
43	4.7	10.6
44	4.6	10.2

Left: profile between sediment sampling sites 1 and 8
Right: profile at sediment sampling site 2
Measured by F. M. Molnar and D. Vrhovšek

PO_4, NH_4 accumulated at the bottom water layer, is evident from the enclosed tables 1 and 2. The decomposition of dead organisms, be it plant or animal, takes place. There is a stronger rain-like precipitation of organic matter in the warmer summer months. During the decomposition the oxygen is used up and chemical changes set in to form hydrogen sulfide and other noxious substances.

Until now little has been reported about the water conditions of Lake Bohinj. R. Gradnik (1946) examined the seasonal changes of the lake water temperature with respect to depth. This lake is not polluted and its crystal-clear water abounds in fish. It has the advantage of the Savica river flowing through its whole length. Thereby the natural conditions are improved. The river springs from the foot of the Julian Alps below Komarča. The spring is 3.5 km away from the lake. There a small power plant is erected.

From the eastern side of the lake the river Sava Bohinjka flows out. The passage of the Savica-Sava Bohinjka through the lake, and the temporary torrential affluents, produce strong oscillations of the water level up to 3.0—3.5 m, as well as a certainly beneficial mixing and aeration of the lake (table 3 and fig. 3). As yet the urban and tourist development has not endangered the water quality and the ecological conditions, and Lake Bohinj remains oligotrophic.

3. Geological setting of the surroundings of Lakes Bled and Bohinj

Bojan Ogorelec

3.1. Lake Bled

The Bled depression with its lake occupies the western part of the Radovljica basin filled in by fluvioglacial deposits (D. Kuščer, 1955). A characteristic feature of the Bled landform is the frontal moraine at the north-east edge of the lake, where the Alpine resort of Bled is now situated. Even more conspicuous are some monadnocks rising above the general level of the glacial deposits. The most attractive is Grad with its cliff-like southern slope made up of Middle Permian reef limestone and breccia. The island in the lake consists of Anisian dolomite (A. Grimšičar, 1955). Outcrops of Lower Triassic marly shale (H. Vetters, 1935) occur in a narrow belt at the northern edge of Zaka. On the lake shore and its hinterland there prevail Anisian and Ladinian dolomites and limestones containing nodular chert. At several places Pleistocene lacustrine chalk occurs associated with sandy and conglomeratic glacial deposits.

The lake does not significantly benefit from surface streams. Different manmade changes have altered the natural drainage. The most important permanent influent is the Mišca creek traversing Pleistocene deposits of the near-shoreland north of the lake. The Solznik creek, is, however, of lesser length and volume and is fed by heavy rainfall and melting snow. Thereby it has the character of a torrent.

3.2. Lake Bohinj

The basin of Lake Bohinj is also of glacial origin as is confirmed by the moraines and the steep-sided Bohinj Valley modified by the former Bohinj glacier. To the north the lake is bordered by the steep slope of Pršivec Mt. and at the south by the ridge of Vogel which extends towards the west into the Komna high plain.

On the western and northern shoreland of the lake the Upper Triassic, slightly dolomitized, limestone prevails, showing some karst phenomena with small bauxite pockets, residual clay and nodular limonite. The southern border of the lake is composed of Middle Triassic dolomite (R. Fabiani and others, 1937). On the Komna high plain and on Vogar Mt., erosion remnants of red Jurassic limestone including manganese nodules occur.

The main affluent carrying sediment into Lake Bohinj is the river Savica. It is able to transport even cobbles and boulders as can be observed in the valley of Ukanc. However, these large rock fragments do not reach the lake. In a small delta mostly pebble size waterworn stones are accumulated. From the southern slope some torrents are seen to descend. One of the biggest is Jereka. The surface waters coming from the northern slope flow into the lake beneath or within a talus accumulated all along the shore. During the last glaciation the torrent of the river Mostnica issued into Lake Bohinj as can be deduced from the gravel deposited on the lake shore at Jezersko polje. Subsequently the stream has changed its course in such a manner that it became a tributary of the river Sava Bohinjka flowing out of the lake. As in the case of Bled there are also, at the southern border of Lake Bohinj, outcrops of Pleistocene lacustrine chalk.

For a geochemical comparison a total of 20 rock samples of different ages were taken from the surroundings of both lakes (table 4 and figs. 2 and 3).

3.3. Pleistocene lacustrine chalk from the surroundings of Lake Bled

For the purpose of comparison with the recent sediment of Lake Bled, some mineralogical and chemical data of lacustrine chalk from its surroundings are presented (see tables 5 and 6). In the neighbourhood of Bled there are some large outcrops of lacustrine chalk at Gorje, at Krnica, and on the banks of the river Sava Bohinjka near Mlino (A. Šercelj, 1970).

Lacustrine chalk is laminated and yellowish gray in colour. The chalk from Gorje and Krnica belongs to the early Würm interstadial and contains more carbonate than that from Mlino, which belongs to the younger stadial.

3.4. Sediments of the streams flowing into Lakes Bled and Bohinj

Samples were taken from the sediment of the main affluents close by their issues into the lakes (figs. 2 and 3). The grain size distribution of the samples examined is shown in figure 6.

Considerable differences were found between the affluents of two lakes. Sediment recently deposited by the Bled streams of Solznik and Mišca consists mostly of poorly sorted coarse sand containing fine pebbles, some silt (7—10 %), and clay (2—5 %). The sediment accumulated by the affluents of Lake Bohinj is considerably coarser than that of the Bled streams.

The mean value of the sphericity index after Th. Zingg (1935) of 150 pebble samples taken from the mouth of the Savica amounts to 0.72. The pebbles are well rounded, although they have only been transported over a short distance of 4 kms.

The mineral composition of the samples taken from the affluents of both Lakes Bled and Bohinj is shown in fig. 7. In the fine grained sediment of the creek Mišca dolomite prevails (72—94 %). Among the non-carbonate minerals present are quartz, illite, chlorite, and smectite. In the river Solznik there is a smaller amount of carbonate (40—75 %). Within the coarse fraction calcite prevails, whereas dolomite is more abundant within the finer fractions. The river Radovna in its turn carries mostly carbonates (68—85 %) with approximately the same proportion of calcite and dolomite. The sediment carried into Lake Bled by an artificial conduit, made for bringing fresh water from the Radovna river, has already been discussed by D. Vrhovšek and A. Brezigar (1976). A sediment charge of 2—5 mg/l (low water) and 10—15 mg/l (high water) has been determined. The particle size held in suspension in the water pipeline is 0.1—0.3 mm (low water) and 0.5 mm (high water).

In the gravel transported by the Savica limestone prevails. Dolomite is abundant (up to 20 and at most 40 %) in the fractions finer than 0.1 mm only. The torrential sediment of Jereka close to the lake shore, consists of limestone and dolomite except the fraction < 0.063 mm. Dolomite prevails, both because of its abundance within the drainage area and its concentration due to hardness within the finer grain size fractions.

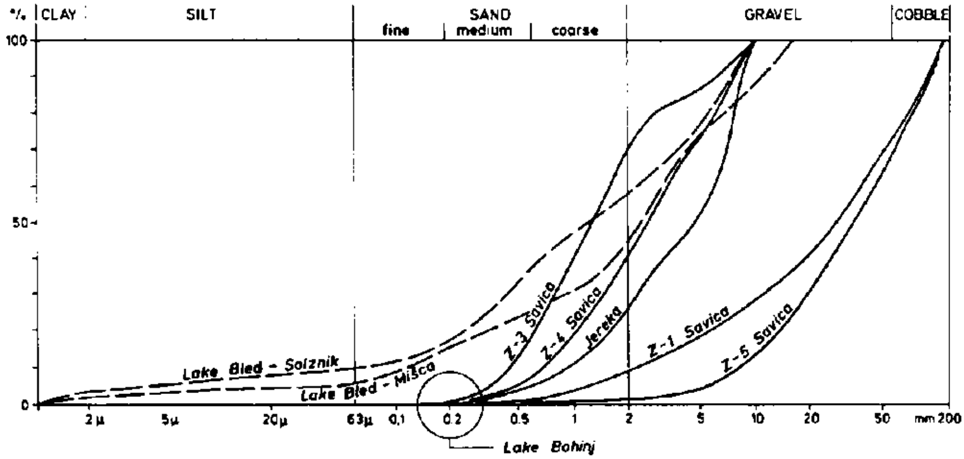


Fig. 6. Cumulative grain size curves of sand and gravel from the affluents of Lakes Bled and Bohinj

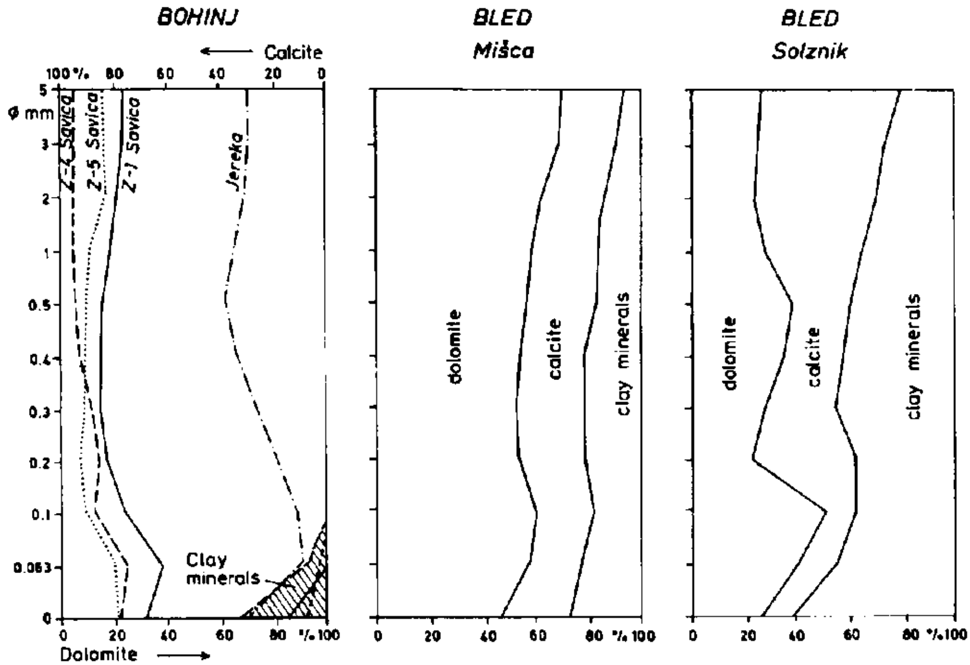


Fig. 7. Relation between the mineral composition and the grain size of sand and gravel from the affluents of Lakes Bled and Bohinj

Table 4. **Chemical analyses of the rock samples from the surroundings of Lakes Bled and Bohinj**

Sampling point	Age	Rock type	Mg %	Ca %	Sr ppm	Fe ppm	Mn ppm
BLED							
16	Anisian	dolomite	13.0	22.0	45	300	320
17	Ladinian	limestone	0.26	36.0	1300	2450	450
18	Anisian	dol.limestone	4.8	34.0	95	480	130
19	Scythian	marly shale	0.52	19.0	540	2400	240
20	Ladinian	dolomite	12.8	22.0	110	120	40
21	Ladinian	limestone	0.3	39.6	170	100	40
22	Ladinian	limestone	0.4	39.4	235	120	40
23	Anisian	dolomite	13.0	21.7	30	125	75
24	Anisian	dolomite	12.8	21.6	25	110	150
25	Permian	limestone	0.25	39.6	150	90	30
26	Permian	limestone	0.25	39.4	200	80	20
27	Ladinian	dolomite	13.0	22.0	45	60	150
28	Ladinian	limestone	0.2	39.6	240	55	50
29	Permian	limestone	0.3	39.6	135	420	105
30	Permian	limestone	0.35	39.8	140	220	15
BOHINJ							
9	Norian-Rhaetian	dol.limestone	7.5	30.0	120	120	15
10	Norian-Rhaetian	dol.limestone	0.8	38.6	130	50	10
11	Norian-Rhaetian	dol.limestone	4.5	34.0	110	120	20
12	Ladinian?	dolomite	12.6	22.0	85	55	10
13	Ladinian?	dolomite	12.8	21.8	40	50	20
14	Ladinian?	dolomite	12.6	22.0	60	40	25

Table 5. **Mineral composition of lacustrine chalk from the surroundings of Lake Bled**

Location	Total carbonate %	dolomite %	calcite %	quartz %	clay minerals illite	chlorite	smectite
Gorje	84	28	56	3	xx	xx	trace
Krnica	88	17	71	3	x	x	-
Mlino	61	15	46	5	xx	xx	x

Table 6. **Chemical analyses of lacustrine chalk from the surroundings of Lake Bled**

Location (total sample)	Mg %	Ca %	Sr ppm	Fe %	Mn ppm	Zn ppm	Cr ppm	Ni ppm	Cu ppm	Pb ppm	Cd ppm	Hg ppm	Co ppm
Gorje	3.87	23.2	212	0.56	220	50	6.5	67	35	42	0.03	0.14	0.4
Krnica	2.12	26.0	212	0.70	130	37	8.5	70	28	57	0.01	0.26	0.4
Mlino	2.45	18.2	175	1.68	420	62	24.5	151	62	30	0.01	0.10	1.0

Analyzed by I. Krüll, Heidelberg

4. General properties of the sediments taken from Lakes Bled and Bohinj

Janez Štern

4.1. Sampling methods

In the period from September 20 to 25, 1976 preliminary sampling of sediments from lakes Bled and Bohinj were carried out. The samples were taken at 15 sampling points in Lake Bled and 8 sampling points in Lake Bohinj along longitudinal sections. The distances between the sampling points were 20—200 meters in Lake Bled and 150—750 meters in Lake Bohinj (figs. 2 and 3).

From both lakes a total of 43 samples were obtained from the lake bottom by a grab sampler of the Van Veen type. Subsequently the samples were divided (a) into an upper part corresponding to a depth of 0—3 cms, and (b) a lower part representing the layer from a depth of 5—10 cms. The midpart was usually cast away to prevent contamination. In this way 13 samples (a), 13 samples (b), and two bulk samples were gathered from Lake Bled and six samples (a), six samples (b), and two bulk samples from Lake Bohinj. Additionally a sample from the midlayer (aprox. 3—5 cms depth) was taken at sampling point 5 in Lake Bohinj.

The sites BL-1B and BL-15B were sampled in Lake Bled by means of a Züllig type corer. The cores were divided into 9 and 19 samples, respectively. Likewise the site BH-5B was cored in Lake Bohinj. The core was subsequently divided into 14 samples.

4.2. Field description

4.21. Grab samples

The macroscopic characteristics of the lake sediment are recorded from the grab samples taken from the bottom. The upper part of the grab sample differs considerably from its lower part. The difference is even more evident in Lake Bled than in Lake Bohinj. Furthermore, the depth of the lakes is likewise of great importance. Namely the difference is greater in deep waters compared to nearshore regions. The upper part of grab samples from Lake Bled is characterized by flocculent to jelly-like sediment of liquid to very soft consistency. In general the sediment abounds in organic admixture, particularly in the top part which is gray, dark gray to almost black in colour.

The midlayer 3—8 cm is often distinctly laminated. The sample Bled 14 for instance shows about 30 laminae within a total thickness of approx. five centimeters (fig. 8).

The lower part of the grab samples (depth 5—10 cms) is mainly a brownish gray sludge of a soft consistency. Infrequently indistinctly developed bedding occurs.

The grab samples 12 and 13, taken from the northwestern nearshore of Lake Bled, are dark gray to greenish-black in colour, rich in decayed leaves, cloddy to mashed, and of liquid consistency. The grab samples 5 to 8, taken from the northeastern shore of Lake Bled, are likewise extremely rich in organic admixtures and characterized by a mainly very dark, greenish brown to greenish black colour.

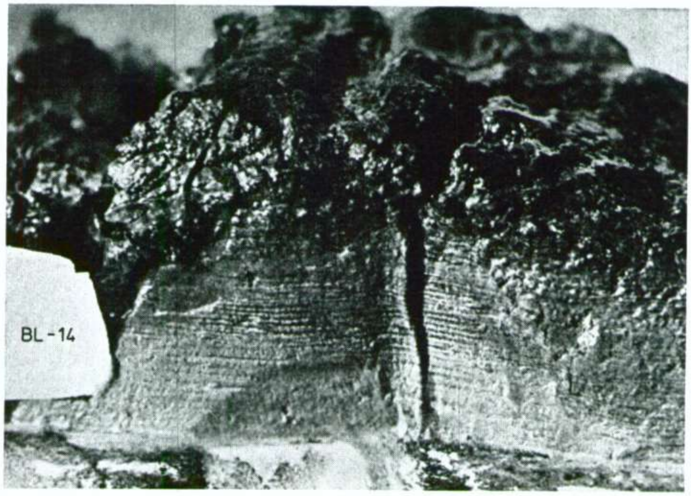


Fig. 8. Grab sample BL-14 from Lake Bled

Upper part is dark gray, homogeneous, and rich in organic matter. Lower part is laminated and rich in carbonate. Vertical scale is approximately 10 cms

Photograph and description by P. Rothe

All sediment samples taken from the bottom of Lake Bled, had an distinct odor resulting from decay of sewage, particularly the sediment close to the shore. A repulsive faeces odor was exuded by the sediment from the eastern nearshore in the area of the densely populated Bled holiday resort. Abundance of white shells of recent *Anodonta* forms 12 cm large has been found in sampling site 8.

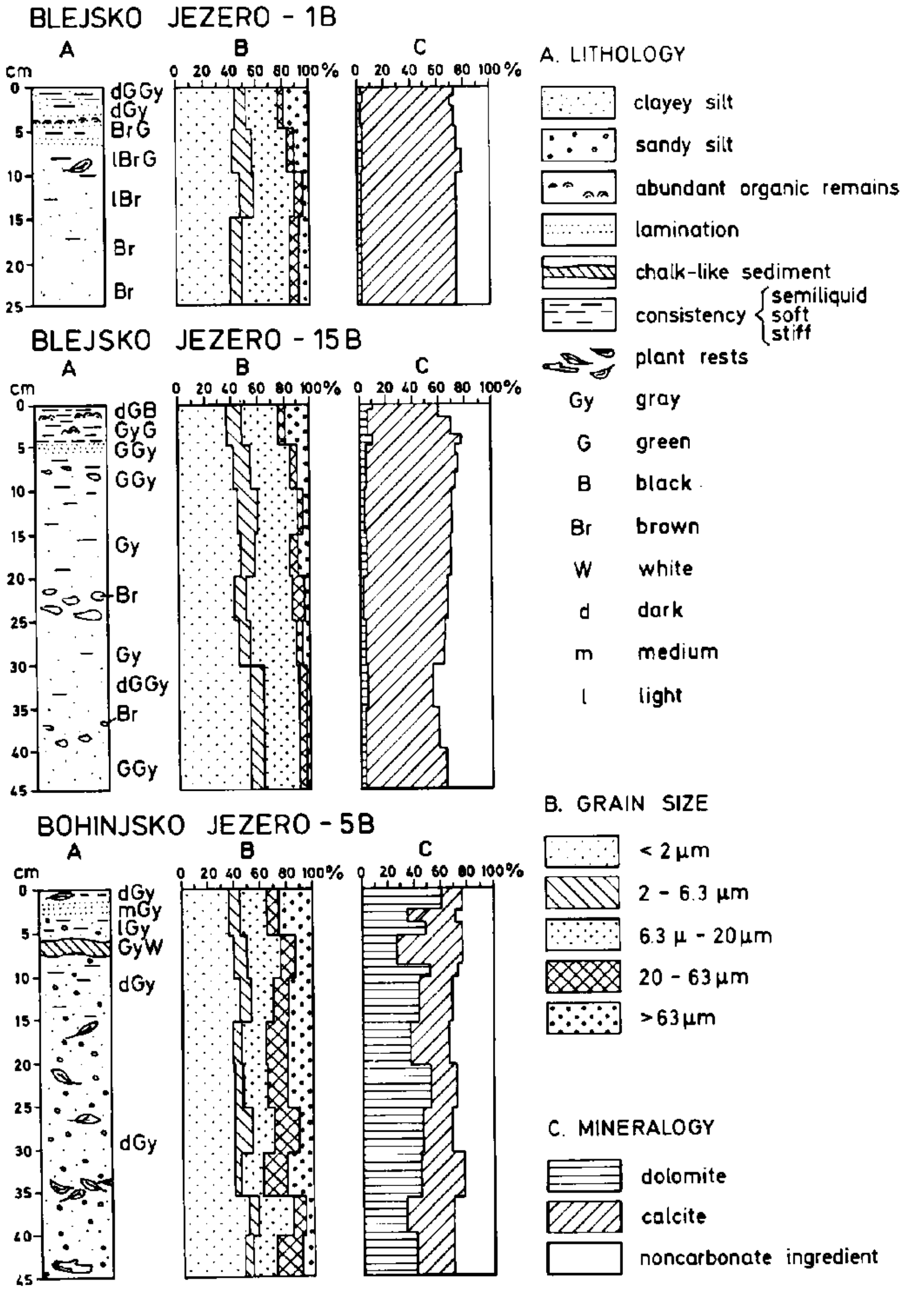
The upper part of the grab sample from Lake Bohinj is less liquid sandy-silty mud. It is brownish gray to gray, showing lighter bands and reddish spots, indicating a lower organic content compared to Bled. The lower part of the sample shows a somewhat homogeneous and massive structure of rather dry consistency. The sediment is light gray in colour, at places greenish in deeper waters.

In the Lake Bohinj nearshore sediment an increased sandy content is observed. Sample 1, taken along the eastern shore is light brownish gray, sandy-silty clay, soft to stiff in consistency. In its top part soft material prevails, including abundant leaves and other plant remains.

The grab samples 7 and 8, taken along the southern shore, are rather pure to almost white clayey and sandy chalky sediment.

Fig. 9. Lithological and mineral composition, and grain size of the core samples BL-1B and BL-15B taken from Lake Bled and BH-5B from Lake Bohinj

Drawn up by B. Ogorelec; mineralogy after P. Rothe, tables 11, 12 and 14


BLEJSKO JEZERO - 1B
A
B
C
cm
0 20 40 60 80 100%
dGGy
dGy
BrG
lBrG
lBr
Br
Br
BLEJSKO JEZERO - 15B
dGB
GyG
GGy
GGy
Gy
Br
Gy
dGGy
Br
GGy
BOHINJSKO JEZERO - 5B
dGy
mGy
lGy
GyW
dGy
dGy
A. LITHOLOGY
clayey silt
sandy silt
abundant organic remains
lamination
chalk-like sediment
consistency semiliquid soft stiff
plant rests
Gy gray
G green
B black
Br brown
W white
d dark
m medium
l light
B. GRAIN SIZE
< 2 μm
2 - 6.3 μm
6.3 μ - 20 μm
20 - 63 μm
>63 μm
C. MINERALOGY
dolomite
calcite
noncarbonate ingredient

4.22. Core samples

The sediment was cored at points BL-1B and BL-15B in Lake Bled (see fig. 2) and at the site BH-5B in Lake Bohinj (see fig. 3). The thickness of sediment penetrated is 25—45 cms. The top (0—1.5 cm) of the two Bled cores is brownish and dark greenish gray liquid and slimy sediment, having an apparent waste odor. The sample BL-1B had at first a characteristic odor, releasing bubbles of hydrogen sulfide. Subsequently a repulsive sewage smell remained. Proceeding downwards in core BL-1B a brownish shaded sediment prevails showing a semiliquid jelly consistency which passes over into a sludge with cloddy inclusions. At a depth of 15—25 cms these inclusions gradually tend to increase. Simultaneously the colour changes into reddish brown and more and more the sewage smell increases. Noteworthy is the laminar structure at a depth of 3—7 cms. As to the core BL-15B, no difference occurs in its composition and consistency compared to BL-1B. They differ in colour only. From the depth 1.5 cm the sediment of the BL-15B becomes gray and greenish gray. In the interval 10—20 cms a bluish shaded sediment occurs and at a depth from 20 to 40 cms brownish spots are observed. The laminated interval is somewhat thinner there: it occurs at a depth of 2—3 cms.

The core BH-5B from Lake Bohinj differs widely from those from Bled. First of all the Bohinj sediment contains fairly more sandy and silty fractions; therefore its water content is lower. Furthermore its fine-grained organic admixture is low. It abounds, however, in leaves. On the contrary the Bled sediment contains no remains of leaved plants. In general the Bohinj sediment is medium gray. At a depth of 5—7 cms a grayish white chalk-like intercalation occurs. The samples obtained possess no particular odor.

4.3. Grain size distribution

Sieve and sedimentation analysis has been undertaken to determine the particle-size distribution in the sediment from lakes Bled and Bohinj (see tables 7, 8 and 9).

A total of 54 samples were examined. After the preparation of the sample with water, each sample was sieved wet through the sieve screen, 0.063 mm DIN 4188. The oversize was dried at 105 °C and the undersize at 60 °C. Subsequently a part of the undersize $< 63\ \mu m$ was dried at 105° C for sedimentation analysis. The majority of the samples were examined using the Sartorius sedimentation balance. For the core samples the sedimentation vessel after Andreasen-Börner was used (table 9). The grain size variation in bottom sediment is shown in figure 9.

In comparison with Lake Bohinj the sediment from Lake Bled is more fine-grained and well sorted in both vertical and lateral directions. The grab samples from the depth 5—10 cms, as well as the core samples from the same depth, contain about 95 per cent particles $< 20\ \mu m$. In the samples taken from the corresponding depths of Lake Bohinj the size grade $< 20\ \mu m$ drops to 70 per cent. It is noteworthy, however, that the fraction $< 2\ \mu m$ lies within the same range (35—55 %) in both lakes Bled and Bohinj. The specific gravity of the sediment from Lake Bohinj is somewhat higher due to less organic matter and a higher dolomite content compared to Lake Bled.

Table 7. **Grain size of the grab samples taken from the depth (a) 0—3 cms and (b) 5—10 cms from the bottom of Lake Bled**

Sample Nr.	Grain size in µm					Medium grain size µm	Sp. gravity of grain size <63 µm
	>63	20–63 18–63*	6.3–20 5–18*	2–6.3 2–5*	<2		
	weight percent						
1a	8.75	23.75	33.50	13.00	21.00	10.0	2.46
1b	0.55	7.90	37.09	21.16	33.30	5.2	2.50
2a	6.54	11.05*	35.76*	20.46*	26.19*	6.0*	2.40
2b	0.86	4.73	30.83*	19.54*	44.04*	2.6*	2.48
3a	4.63	14.20	40.56	21.50	19.11	9.0	1.54
3b	0.89	5.27	35.34	17.40	41.10	4.2	2.52
4a	5.68	21.07	26.54	21.47	25.24	7.3	2.51
4b	3.41	3.58	41.61	28.09	23.31	5.7	2.54
5a	5.68	21.56	36.58	21.02	15.16	9.0	2.54
5b	1.58	13.09	28.23	24.59	32.51	4.7	2.56
6a+7a	19.30	18.04	26.60	14.28	21.78	10.1	2.59
6b+7b	3.69	24.58	21.48	18.75	31.50	5.9	2.59
8a+b	16.90	26.60	19.50	14.50	22.50	12.0	2.53
9a+10a	20.97	12.64	27.31	17.08	22.00	9.7	2.50
9b	2.34	7.59	36.01	25.20	28.86	5.3	2.51
10b	4.49	2.53	38.09	30.98	23.91	4.9	2.50
11a	17.81	16.17	28.38	16.14	21.50	12.0	2.52
11b	1.50	7.33	38.27	31.20	21.70	5.6	2.55
12a+b	13.94	5.96*	24.50*	7.20*	48.40*	2.5*	2.45*
13a	7.22	14.90*	22.66*	6.69*	48.53*	2.5*	2.50*
13b	5.13	7.27*	31.58*	21.72*	34.30*	4.2*	2.53*
14a	13.91	11.44	29.75	19.41	25.49	8.8	2.55
14b	4.40	5.08	33.03	27.29	30.20	4.5	2.47
15a	22.86	12.32*	32.82*	19.26*	12.74*	12.1*	2.41*
15b	10.86	3.04*	29.80*	16.40*	39.90*	3.8*	2.50*

Data obtained by the sedimentation balance and by the Andreasen-Börner* sedimentation vessel

Table 8. **Grain size data of the grab samples taken from the depth (a) 0—3 cms and (b) 5—10 cms from the bottom of Lake Bohinj**

Sample Nr.	Grain size in µm					Medium grain size µm	Sp. gravity of grain size <63 µm
	>63	20–63	6.3–20	2–6.3	<2		
	weight percent						
1a+b	21.82	13.30	19.30	13.70	32.05	7.9	2.28
2a	10.32	8.10	24.33	20.15	37.10	3.9	2.55
2b	7.06	7.42	18.72	17.80	49.00	2.3	2.52
3a	11.42	5.66	20.24	27.68	35.00	3.8	2.51
3b	6.84	4.00	17.36	16.00	55.80	1.8	2.50
4a	7.71	15.70	18.63	17.96	40.00	3.8	2.56
4b	5.92	12.98	23.50	14.60	43.00	4.0	2.55
5	(see: core samples 5 B)						
6a	16.90	22.09	22.96	17.55	20.50	13.2	2.61
6b	10.20	30.10	19.20	10.70	29.80	9.1	2.63

Data obtained by the sedimentation balance

Table 9. **Grain size data of sediment samples from core profiles of Lakes Bled and Bohinj**

Depth in cms.	Grain size in µm (weight percent)					Medium grain size µm	Sp. gravity of grain size <63 µm
	>63	18–63 / 20–63*	5–18 / 6.3–20*	2–5 / 2–6.3*	<2		
BLEJSKO JEZERO – Core 1 B:							
0–5	19.10	1.07*	27.05*	9.48*	43.30	4.9	1.58
5–10	11.81	2.80*	17.79*	25.65*	41.95	3.8	2.58
10–15	4.12	6.11	31.82	10.38	47.57	3.0	2.47
15–25	6.37	7.85	37.62	6.67	41.49	5.6	2.49
BLEJSKO JEZERO – Core 15 B:							
0–5	16.13	2.74*	26.85*	16.01*	38.27	5.3	2.54
5–10	9.83	4.24*	21.72*	22.76*	41.45	4.1	2.54
10–15	4.68	2.46	29.38	17.76	45.72	3.1	2.54
15–20	7.42	6.50	23.92	12.55	49.61	2.0	2.51
20–25	3.23	8.89	34.05	9.42	44.41	3.1	2.52
25–30	5.06	4.95	34.54	7.73	47.72	2.8	2.50
30–45	1.88	4.94	29.18	8.19	55.81	1.8	2.51
BOHINJSKO JEZERO – Core 5 B:							
0–5	24.19	9.88*	20.70*	10.00*	35.23	8.1	2.63
5–10	12.78	10.02*	21.09*	16.79*	39.32	4.8	2.61
10–15	18.31	12.00	15.50	9.02	45.17	3.6	2.53
15–20	19.26	16.02	18.40	3.22	43.10	7.0	2.61
20–25	19.26	14.45	18.50	4.78	43.01	6.0	2.63
25–30	10.00	17.97	17.35	11.52	43.16	3.7	2.58
30–35	19.08	16.52	17.43	4.02	42.95	6.4	2.61
35–40	4.24	8.31	27.07	7.00	53.38	1.9	2.58
40–45	7.64	18.61	19.22	4.71	49.82	2.0	2.54

Data obtained by the Andreasen-Börner sedimentation vessel

5. Pollen contents in sediments from Lakes Bled and Bohinj

Alojz Šercelj and *Metka Culiberg*

Samples for pollen analysis have been taken and analyzed from the cores BL-15B and BH-5B at an interval of 5 cm.

The main purpose of this investigation has been to gather some information about the paleoecology of the surroundings of the lakes and about the age of the sediments on the base of well known stages of vegetational development or special plant indicators of man's activity (A. Šercelj, 1971, 1975). Complete pollen analyses reveal about 50 taxa represented in different spectra. Since it is evident that not all plant taxa have equal meaning in interpreting vegetational history and hence stratigraphy, only the characteristic ones have been picked out (figs. 10 and 11). As they are different from each other, the explanations of each are given separately for the most important points.

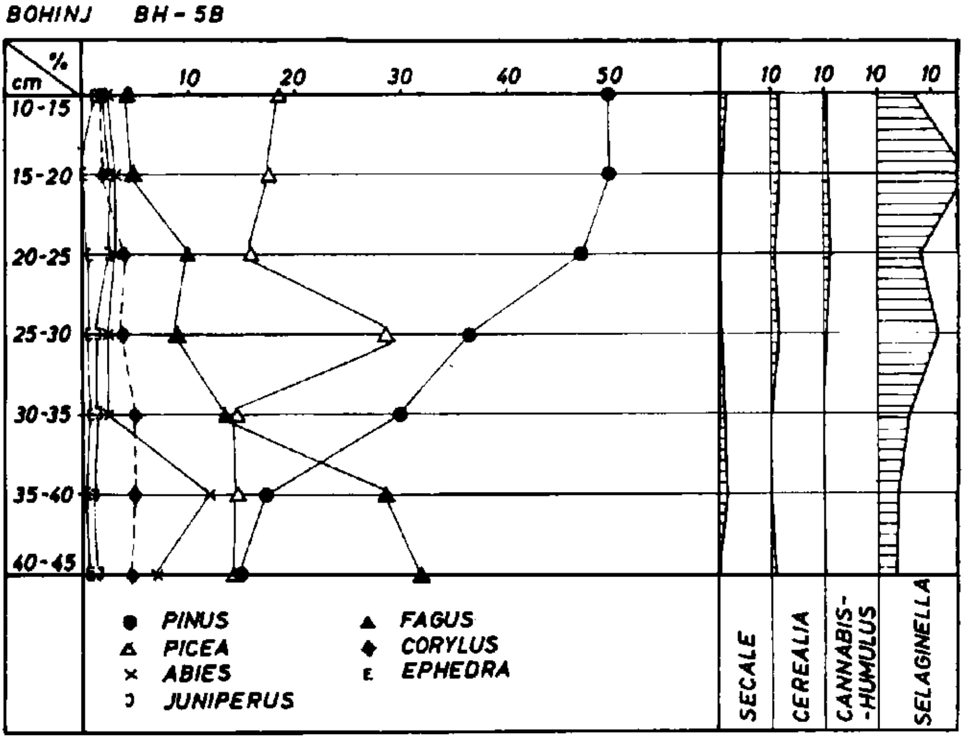


Fig. 10. Pollen diagram of the sediment core BH-5B from Lake Bohinj

5.1. Bohinj BH-5B

The pollen curves of various forest trees follow different, partly opposite courses. But the most characteristic ones are those of *Pinus*, *Fagus* and *Picea*. The *Pinus* curve increases from an initial 15 % to 50 % on the top of the diagram, meanwhile the *Fagus* curve decreases in the same direction from 30 % to 5 % tree pollen. This peculiar change in vegetation is certainly not due to climatic events. Originally this valley had been covered by woods of *Abieti-Fagetum* (depth 45—35 cm), and on the mountain slopes intermixed with fairly high percentages of *Picea*. Then cutting of beech forests for burning charcoal, used in melting iron, started, especially during the Middle Ages. This could be the point of decline of *Fagus* pollen curve. On the contrary, continuous rise of the pollen curve of *Pinus* suggests that the destroying of deciduous forest has continued by grazing, especially in the subalpine belt.

The presence of *Secale* pollen, other cereals, and of *Cannabis-Humulus*, though in low percentages, also indicates that the radical change in vegetation is due to extensive land use for farming.

Selaginella selaginoides, the subarctic small fern, is present in relatively high percentages, though it did not thrive in the valley, but on the deforested mountain plateaus.

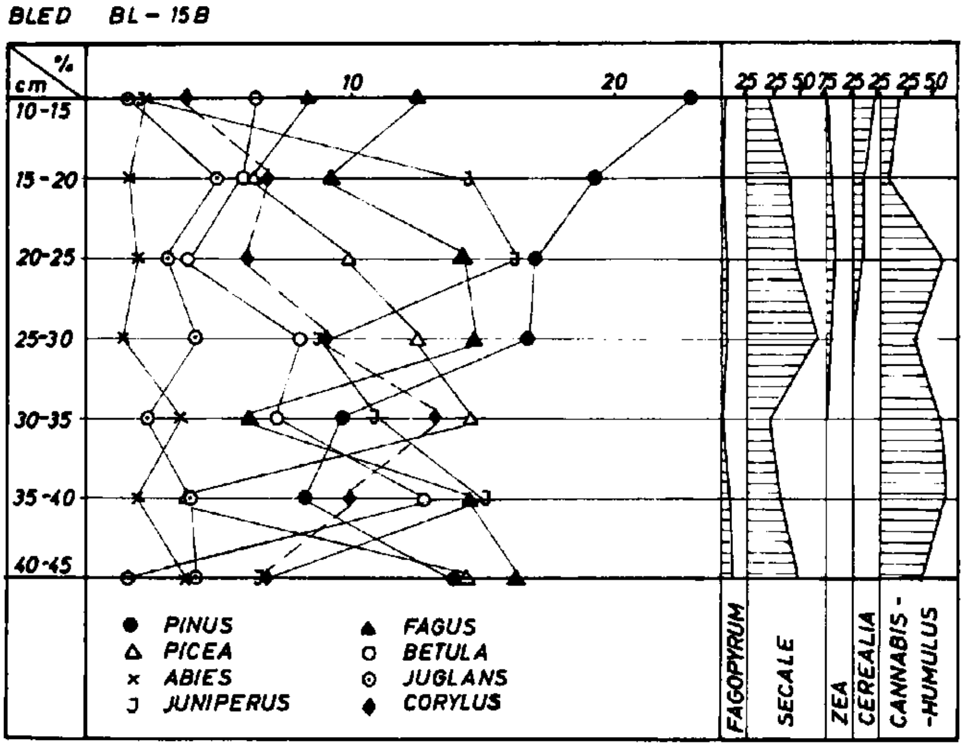


Fig. 11. Pollen diagram of the sediment core BL-15B from Lake Bled

5.2. *Bled BL-15B*

The surroundings of Bled is a more opened landscape and there are no steep mountain slopes within the immediate neighbourhood. As a result the forest picture, as shown by the pollen diagram, is a little more intricate.

The pollen diagram reflects two declines of the natural forest (*Abieti-Fagetum*). The curve of *Fagus* shows two oscillations which are not very pronounced, with a decreasing tendency. Opposite to that of *Fagus*, the *Pinus* curve rises up to 23 %. *Pinus* forests are to be regarded here as a pioneer vegetation on previously highly degraded soils. More indicative about the general aspect of landscape may be the unusually high percentage of *Juniperus* (juniper) pollen in the middle of the diagram. This indicates heavy sheep grazing, juniper being the only resistant element.

Direct indicators of man's activity are: *Juglans* (walnuttree), present with relatively high pollen values, obviously having been much cultivated here.

High pollen values of *Secale* and other cereals, besides *Humulus* and *Cannabis*, which theoretically could have been cultivated here since eneolithic times, suggest that this country had been densely settled.

There are two more cultivated plants that yield us also a reliable dating: *Fagopyrum* and *Zea*. Buckwheat has been introduced to Europe from Asia and reached this country about 1490, and corn has been brought to Spain in 1519. There is no doubt that this profile cannot be older than 500 years, but could be younger.

6. Mineral association in sediments from Lakes Bled and Bohinj

Peter Rothe

6.1. Introduction

Lake sediment consists of components of detrital, chemical, or biogenic origin. Within most lakes more than one of these components are found.

It has been amply shown that many factors such as climate, geographical position, geological conditions, etc. are influencing the final composition of lake sediment. Carbonates within lakes may either be of detrital origin or they are formed authigenically within the lake due to biological activity, chemical conditions, or both.

The surroundings of both Lakes Bled and Bohinj (Blejsko jezero and Bohinjsko jezero) consist almost entirely of limestones and dolomites of Permian and Triassic age.

The aim of this chapter is to provide a preliminary description of the sediments within both lakes. The main part of these sediments has a clearly detrital origin. Carbonate mud and silt prevail. Autochthonous formation of some of the carbonates may be suggested from the fact that abundant Ca^{++} is supplied by affluents from the drainage area. Precipitation of calcium carbonate by means of changing physico-chemical conditions or photosynthetic activity of macro- and microphytes within the lakes is possible.

6.2. Analytical procedure

Samples already split, for chemical analysis (see chapt. 7.2.), into fractions $< 2\,\mu m$, 2—6.3, 6.3—20, and 20—63 μm were used for X-ray mineralogical determinations. Powdered samples were run with a Philips PW 1310 diffractometer at 36 kV and 24 mA. Nickel-filtered $CuK\alpha$-radiation was applied. Total carbonate content was determined by the "bomb"-method (G. Müller & M. Gastner, 1971); a smaller type of "bomb" was used where only small amounts of the samples were left. Within the tables 10—14 some data are not complete; in this case no material was available since it was entirely used for chemical analysis.

6.3. Lake Bled

Fifteen grab samples taken from the lake bottom, already split into upper and lower parts on board ship, and samples of two cores were analyzed. Upper and lower parts represent a top sediment layer of 0—3 cm (a) and a deeper layer of approximately 5—10 cm (b) below the bottom surface. Results out of a total of 58 samples $15 \times 2 = 30 + 9$ (= core BL-1B) + 19 (= core BL-15B) are discussed below (tables 10—12). In regard to both regional sample distribution (see maps fig. 12—13, figs. 1—4) and vertical penetration of the corer (fig. 9) the results must be regarded preliminary.

6.31. Grab samples

Total carbonate content. The samples taken from the lake bottom have carbonate contents averaging about 70 % (54.5—78 % range). Carbonate contents are different within different grain size fractions. A general increase

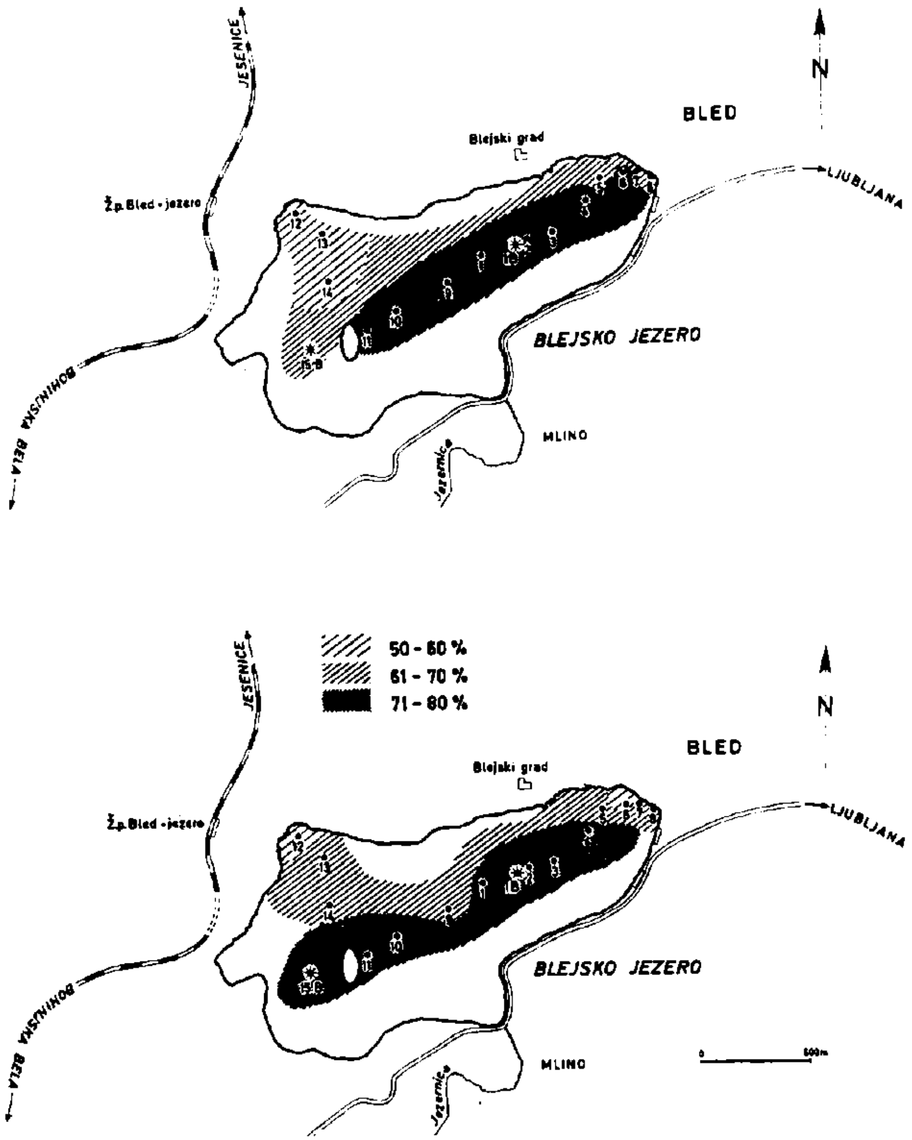


Fig. 12. Lake Bled. Total carbonate content
Above: Grab samples, upper part
Below: Grab samples, lower part

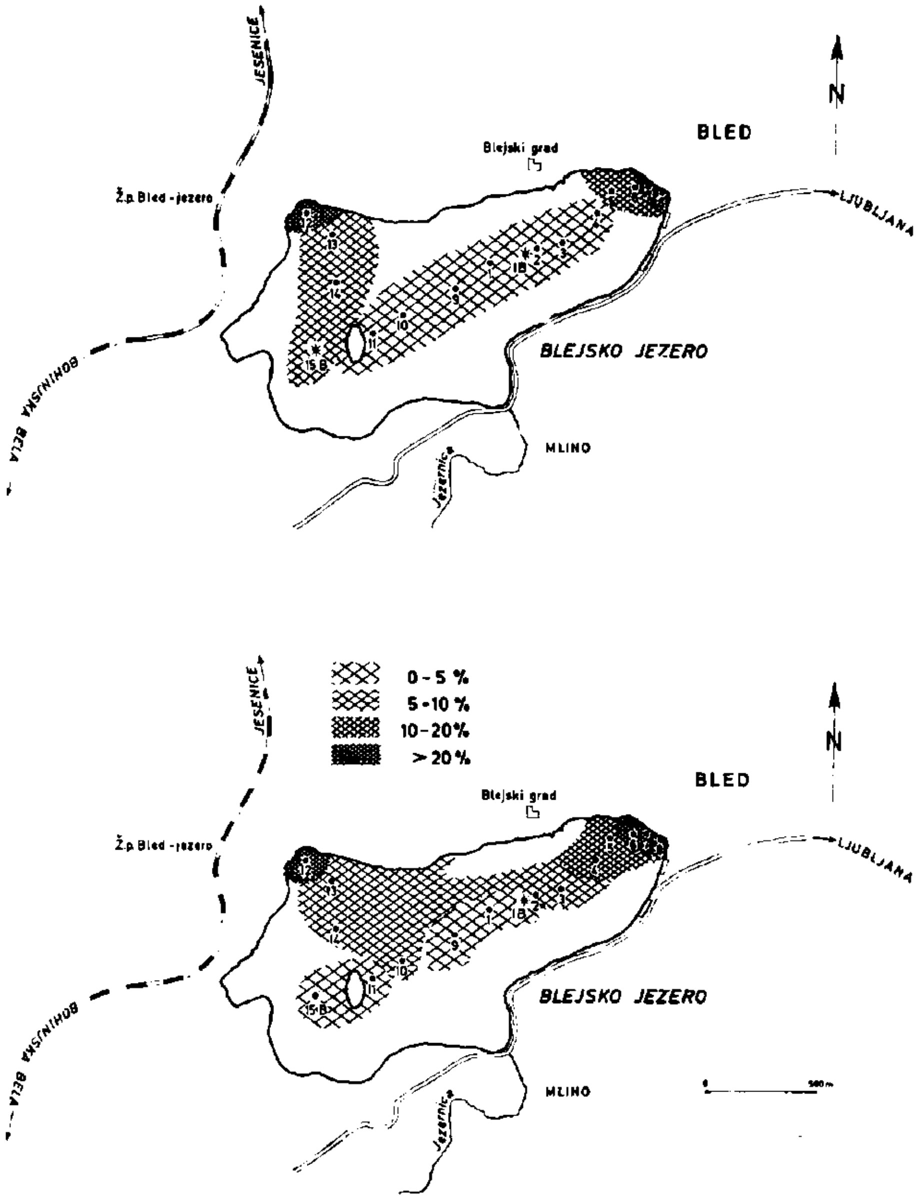


Fig. 13. Lake Bled. Dolomite within carbonate fraction

Above: Grab samples, upper part

Below: Grab samples, lower part

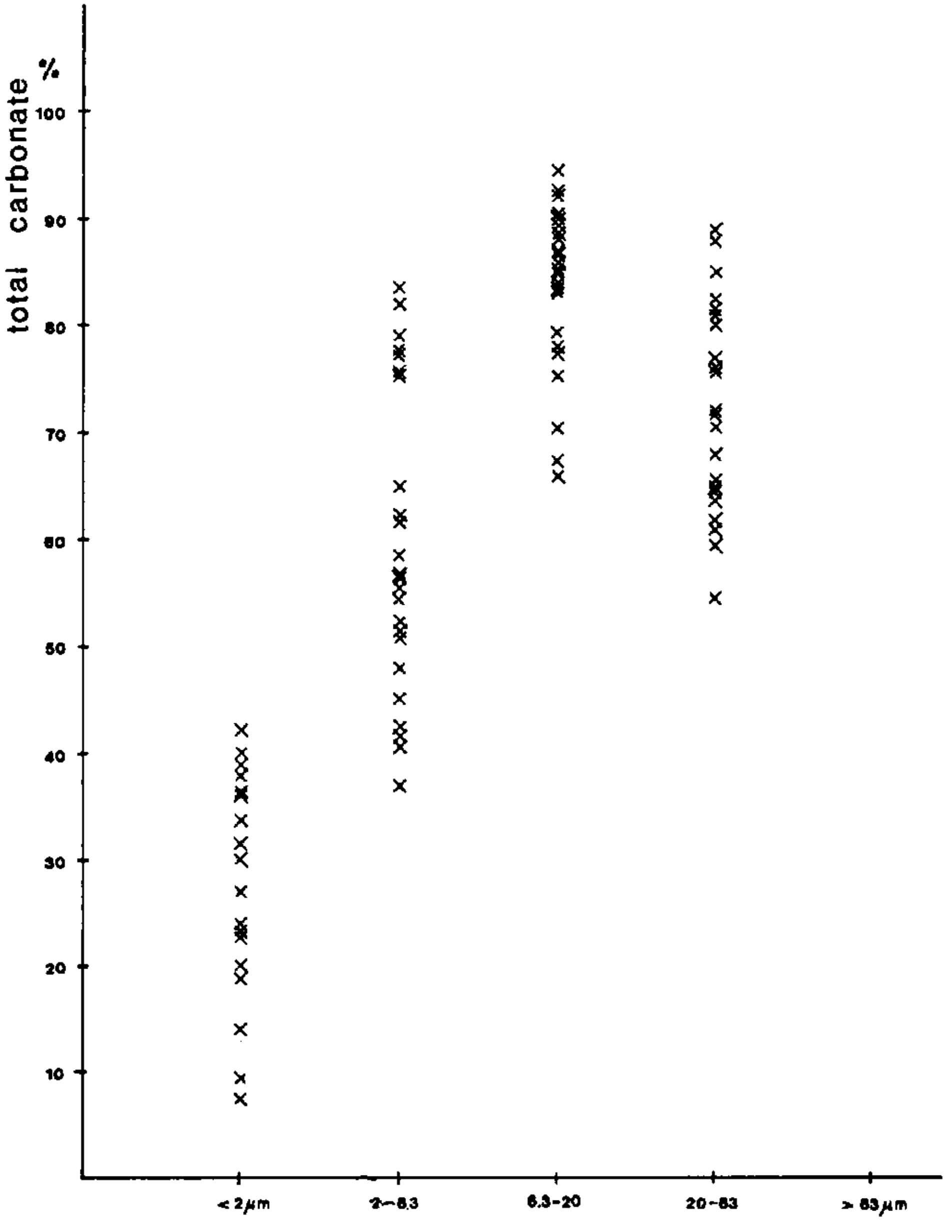


Fig. 14. Grab samples from Lake Bled
Total carbonate content versus grain sizes < 63 µm

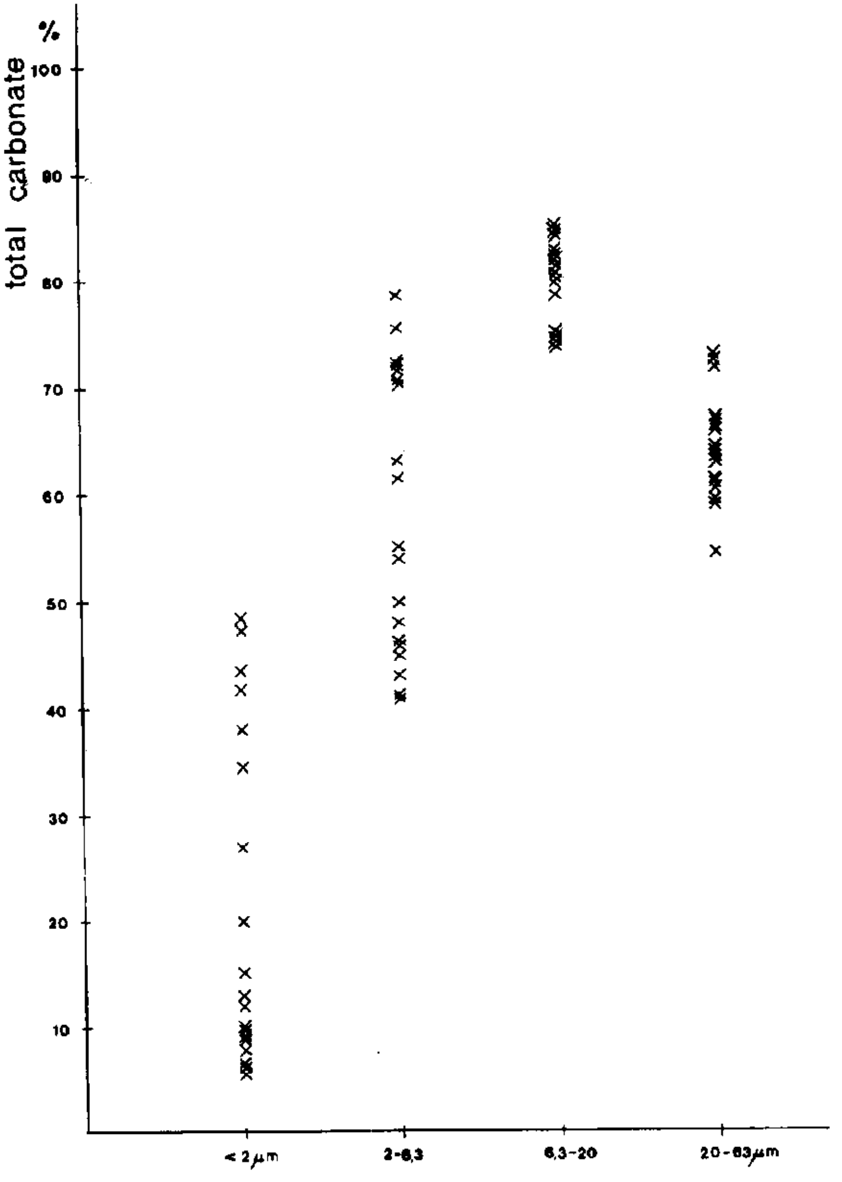


Fig. 15. Core samples of BL-15B from Lake Bled
Total carbonate content versus grain sizes < 63 μm

of total carbonate with increasing grain size is observed from the < 2 μm fraction to the 6.3—20 μm fraction whereas it decreases significantly within the 20—63 μm fraction (fig. 14). Since clay mineral analysis from the < 2 μm fraction failed to give definite results it must be assumed that most of the non-carbonate is probably biogenic material. This applies also to the other grain size fractions.

Carbonate mineralogy. Most of the carbonate is low magnesium calcite but dolomite is also present throughout and is abundant within some of the samples; 2—38 % of the carbonate fraction was found to consist of dolomite. An obvious difference of regional distribution of dolomite was found. Dolomite contents within the carbonate fraction are highest in grab samples 4, 5, 6, 7, 8, 12 and 13.

A difference in dolomite contents was found between the upper and lower parts of the grab samples. Within the lower samples dolomite seems to reach a little further towards the central parts of the lake (fig. 13). This reflects that dolomite input had changed with time.

Probably due to prior sedimentation, not much of the dolomite carried into the lake can reach its deepest, or central, parts.

6.32. Core samples

The two cores BL-1B and BL-15B were separated into 9 and 19 samples, respectively.

6.321. Core BL-15B

Carbonate content. Core BL-15B has an average carbonate-content of about 67 % (56.5—77 % range). Carbonate contents within single samples are extremely variable. They are lowest within the < 2μm fraction ranging from 5.5—48.5 %. Again a general increase of total carbonate with increasing grain size is observed, with the exception of the 20—63 μm and coarser fractions (fig. 15).

A rather good correspondence between the mineral composition of the finest studied fraction (< 0.063 mm) of the Solznik affluent (40 % carbonate, see chapt. 3.4) and the uppermost sample of the core (57.5 % carbonate) reflects more or less the present conditions. Higher carbonate contents within all grain sizes are centered at 5—10 cm depth, reflecting that the sedimentation history of the lake had changed slightly with time.

Carbonate mineralogy. Different amounts of calcite and dolomite were found from core BL-15B. Within most samples, dolomite contents are low (2—6 % or slightly more) but some layers contain more than 10 % dolomite (12—18 %). These higher dolomite contents are paralleled by higher amounts of quartz, thus they represent phases of detrital sedimentation.

6.322. Core BL-1B

Carbonate content. Similar high carbonate contents as in core BL-15B were found from core BL-1B (total samples about 75 % average. Range is 69—79 %). Contrary to BL-15B the composition of the sediment is much more uniform as far as the total samples are regarded. The same pattern of carbonate content versus grain size is observed with highest contents within the 6.3—20 μm fraction (fig. 16).

The difference between sediment composition of both cores may have its origin in the position of core stations. Both cores were taken from similar water depths. Core BL-1B was taken from a central part with equilibrated conditions, whereas BL-15B is more marginal and most probably reflects the influence of the Solznik affluent.

C a r b o n a t e m i n e r a l o g y. Calcite and dolomite are present but within total samples dolomite is rare (about 3 %, range 2—4 %). In the 20—63μm fraction, however, dolomite may reach up to 24 % (see table 11). This seems to be paralleled by the amounts of quartz although quartz-peak heights can reach similar maxima from samples of the < 2 μm fraction without higher dolomite contents. Again, the dolomite seems likely to be of detrital origin.

6.33. *Origin of the Lake Bled sediment*

Most of the sediments within Lake Bled are muds rich in, or entirely consisting of, carbonate material. Both calcite (low magnesium calcite) and dolomite occur. An approach to regional distribution of some parameters (carbonate content, dolomite content) must be regarded very tentative since sampling sites are scarce for such a purpose. Regional distribution of total carbonate content shows highest values in the central part of the lake, decreasing towards the northern shore. The lowest values occur within samples 12, 13 and 14 which can most probably be referred to the influx of non-carbonates from the Mišca affluent in the northwestern corner of the lake (fig. 12).

In the mineral association calcite and dolomite prevail; there is considerably less quartz, and scarce feldspar (see tables 10—12). Most of this material is detrital but some calcite may also be autochthonous. Dolomite, however, is apparently detrital, as can be suggested from both regional distribution and linkage between dolomite and quartz contents of the samples (figs. 13, 17). Although quartz was only determined on a semiquantitative basis by X-ray diffraction, and peak height of the main peak was taken as an arbitrary measure, it is evident that within a similar matrix this gives reliable results.

The regional distribution of dolomite within Lake Bled reflects transport from the north or from the northeastern and northwestern part of the lake surroundings (fig. 13). In the case of the northwestern bay, dolomite was apparently transported by the Mišca affluent; its sand- and gravel fraction was found to contain up to 70 % dolomite (see chapt. 3.4). Contribution from the erosion of the shore rocks, however, is not evident. Likewise, the small island situated in the western part of the lake seems not to have much influence on nearby sedimentation: the adjacent sites 11 and 15 revealed comparatively little dolomite although this island consists of Triassic dolomite.

Little can be said, so far, about the non-carbonates. Beside the scarce quartz and feldspar, abundant diatoms were found, particularly within the smaller grain size fractions. They are very well preserved. Selected samples investigated by scanning electron microscopy revealed several species of circular and elongated shapes which require further studies (figs. 18, 19).

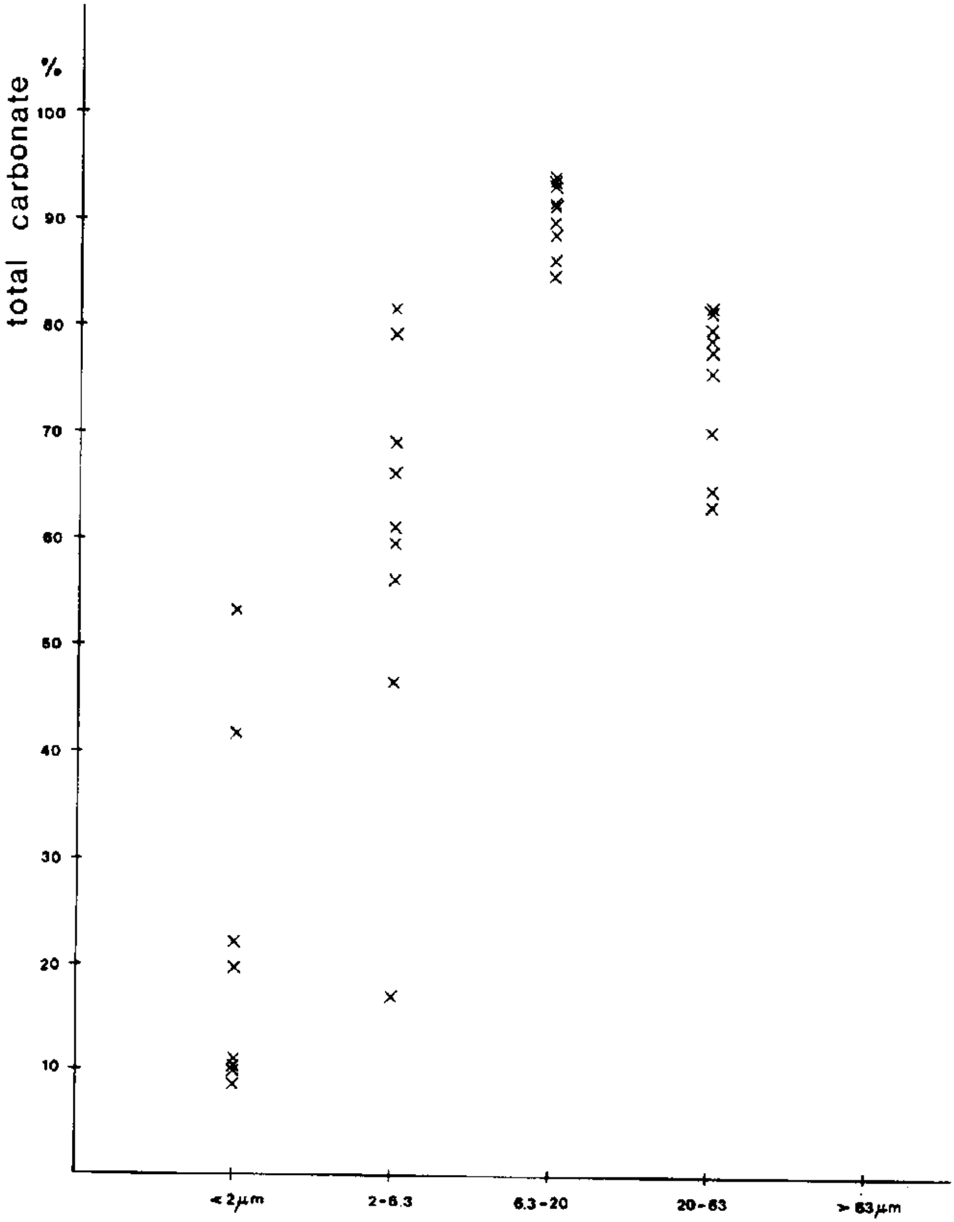


Fig. 16. Core samples of BL-1B from Lake Bled
Total carbonate content versus grain sizes < 63 μm

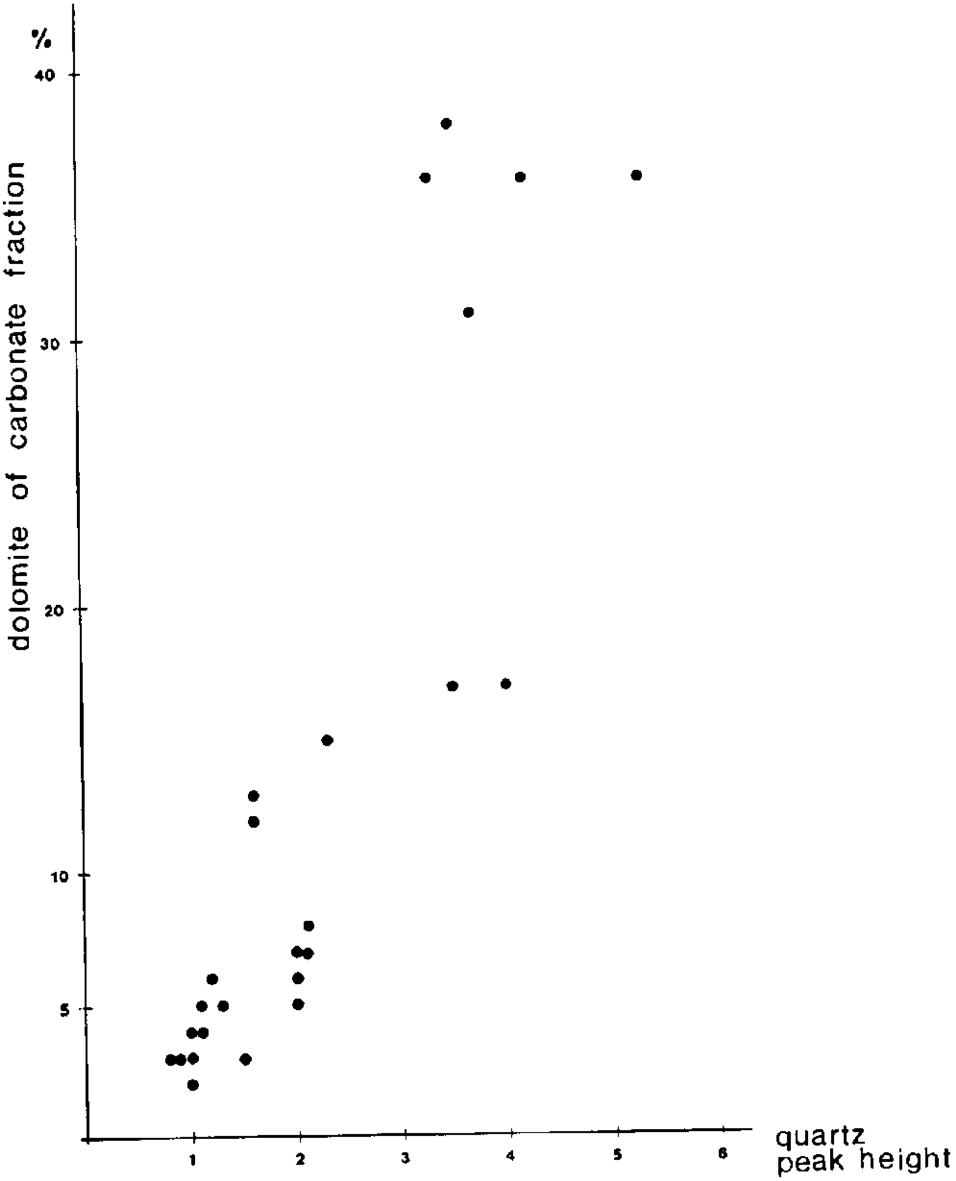
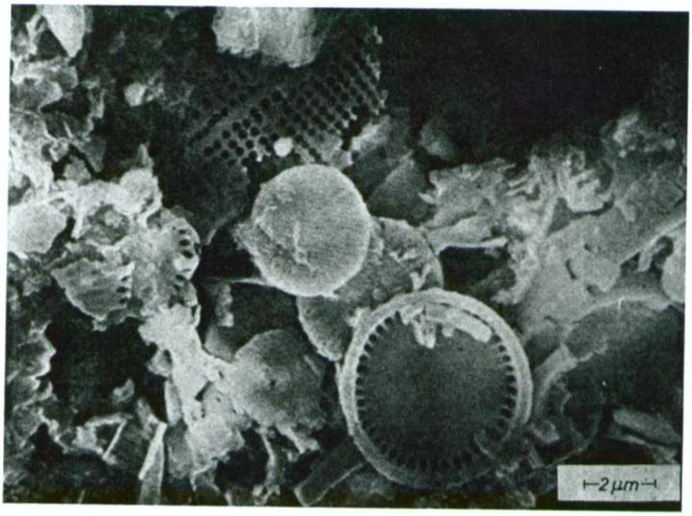
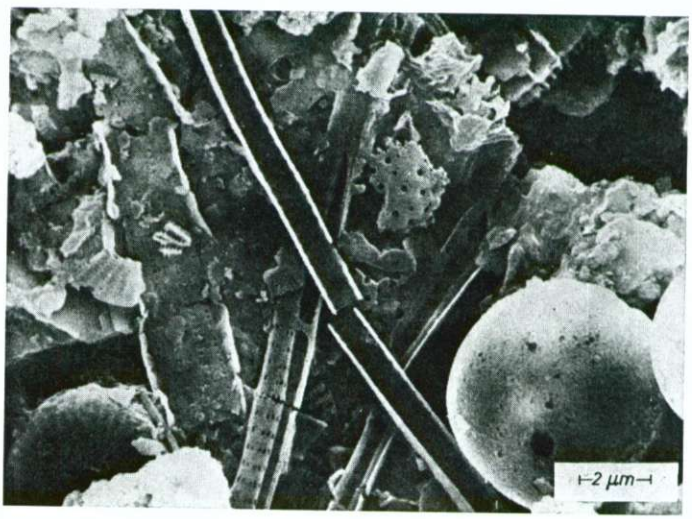


Fig. 17. Total grab samples from Lake Bled
Dolomite content of the carbonate fraction versus quartz peak height





Figs. 18. and 19. Sediment from Lake Bled

Diatoms from the carbonate free part of the $< 2\,\mu m$ fraction, grab sample 14, lower part

Due to the settling tube technique for grain size analysis, particles are usually larger than $2\,\mu m$ because of slower settling of diatoms

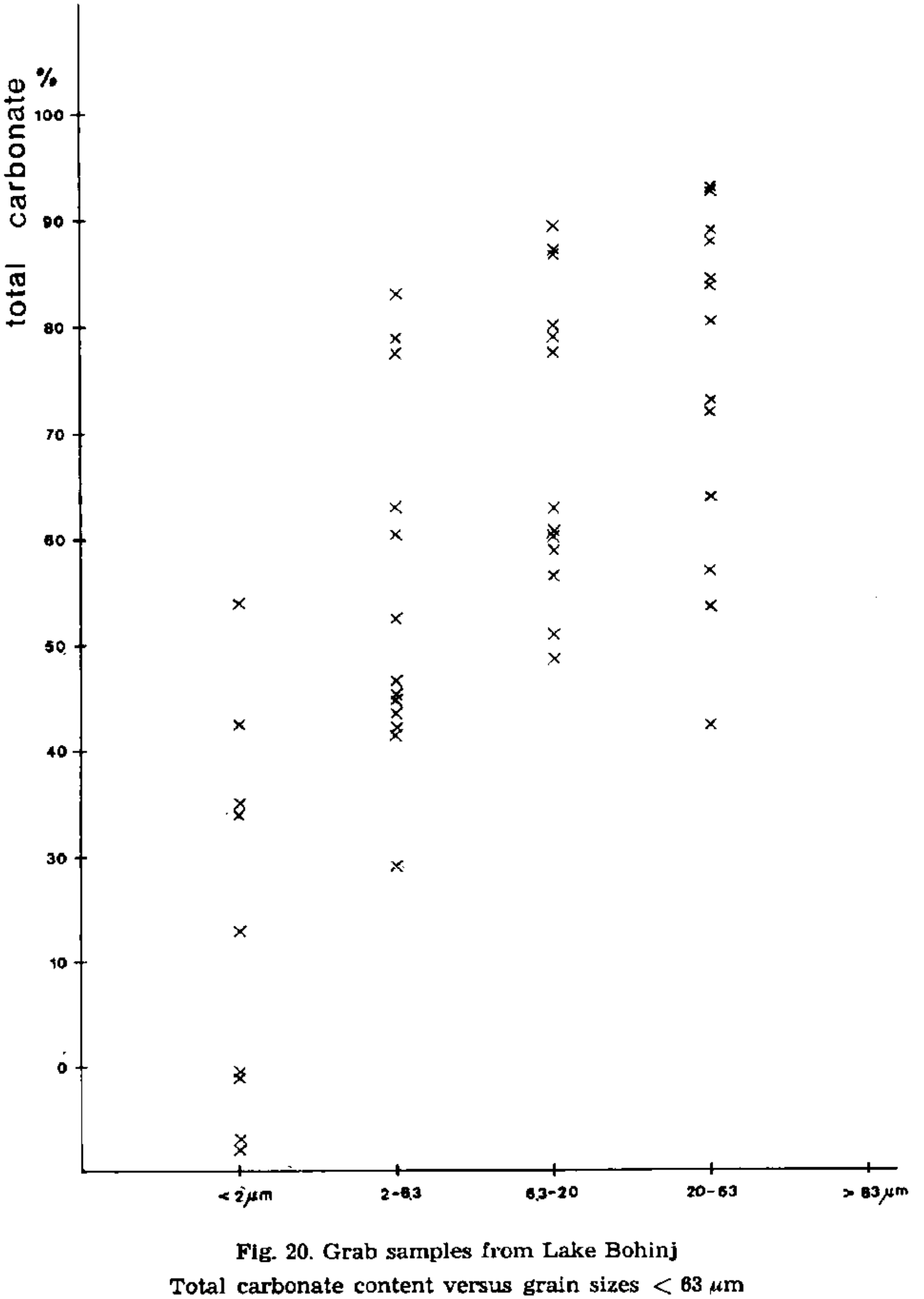


Fig. 20. Grab samples from Lake Bohinj
Total carbonate content versus grain sizes < 63 μm

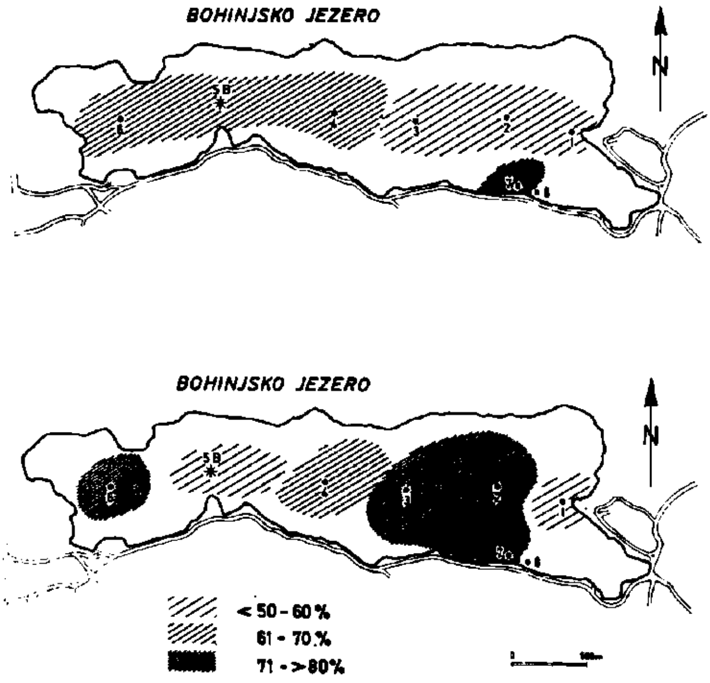


Fig. 21. Lake Bohinj. Total carbonate content
Above: Grab samples, upper part
Below: Grab samples, lower part

Abundant opaline silica was already suggested from the typical "opal bulge" at the diffractograms of carbonate-free samples. The behaviour of clay minerals within the lake remains an open question. From the contribution of B. Ogorelec (see chapt. 3.4) it is evident that illite, chlorite, and smectite are transported by the small streams. Within the lake sediment, however, very little clay minerals could be determined. Although the hydrochloric acid method to remove carbonate was replaced by using cation exchange resin (R. M. Lloyd, 1954), clay mineral peaks remained poorly developed.

A tentative suggestion may be that a break-down of clay mineral structures takes place due to dissolution of silica out of these clays. No data concerning silica concentration of the lake water are available so far but apparently silica concentration must be low in such lakes situated within an area consisting essentially of carbonate rocks. The abundance of diatoms, however, requires a source for silica, and clay minerals seem the most likely material to provide silica rather rapidly according to the results of F. T. Mackenzie et al. (1967).

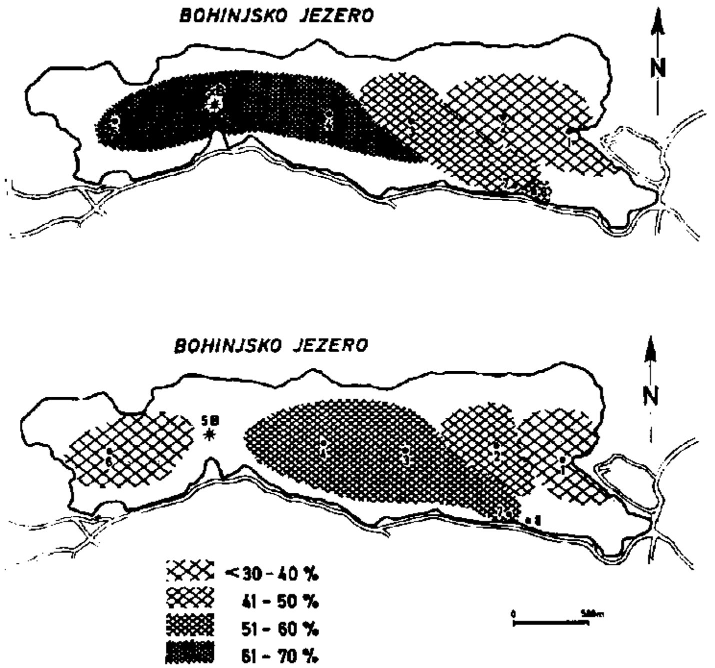


Fig. 22. Lake Bohinj. Dolomite within carbonate fraction
Above: Grab samples, upper part
Below: Grab samples, lower part

6.4. Lake Bohinj

Eight grab samples were taken from Lake Bohinj and were split into upper and lower parts as the samples from Lake Bled. Additionally, one core was taken from the western central part of the lake; the core was split into 14 samples. A total of 30 samples thus represent the sediment of Lake Bohinj discussed here (tables 13, 14 and fig. 20).

6.41. Grab samples

Carbonate content. The upper part of the grab samples have carbonate contents ranging from 53 to 91 percents. Most samples from the lower part have higher carbonate content than their upper counterparts. On a regional aspect, the present bottom surface sediment (if the upper parts of the samples really represent it) is different in carbonate content: the western part of the lake contains more carbonate than does the eastern part. This regional distribution is not valid, however, for the lower part of the surface samples, wherein high contents were found from both parts of the basin. Any suggestions about regional distribution, however, must be regarded tentative sofar because of the few sampling sites.

Carbonate mineralogy. Both calcite and dolomite make up the carbonates of the lake sediment investigated. Little can be said — as was the case in Lake Bled — about their regional distribution. Figs. 21 and 22 represent tentative suggestions only. They also display the distribution within upper and lower parts of the samples. Again, a different input of sediment at different times is evident. This also must be discussed with care, however, since not even the uppermost part of the samples really represents one sedimentation event. This holds true, much less, with the »lower parts« of samples which most probably are not time-equivalent in any case. No "single grain layers" were analyzed, but a mixture of layers representing different time span, instead.

The ratio of calcite/dolomite is fairly uniform throughout all grain sizes. It is, on the average, about 50 : 50 although a range of 70 % calcite: 30 % dolomite to 31 % calcite: 69 % dolomite was found within total samples.

With increasing grain size this ratio seems to shift in favour of dolomite; hence dolomite is, on the average, more abundant within the coarser grain size fractions.

6.42. Core BH-5B

Carbonate content. The total samples range in carbonate contents from 65.5—76.5 %. Sofar, no phases of extremely different sedimentation events are obvious from the core. As within the grab samples of the lake the core samples also show carbonate contents increasing with increasing grain size (see fig. 23).

Carbonate mineralogy. High dolomite contents, as already observed from the grab total samples, are also obvious from the cored sediment of this lake. On the average, both calcite and dolomite are present in similar amounts, although the ratio may reach from 69 % calcite : 31 % dolomite up to 5 % calcite : 85 % dolomite within the carbonate fraction. From the present sampling sites a certain regional distribution of dolomite within Lake Bohinj seems to be evident. The upper part of the grab samples show higher amounts within the western part, reaching from sites 6 to 4 (fig. 3) which decrease — continuously? — towards lower dolomite contents at the eastern part of the basin.

Both affluents Savica and Jereka could be responsible for the transport input of dolomite into the lake. According to B. Ogorelec (see chapt. 3.4) the Jereka sediment contains more dolomite than the Savica sediment and hence the Jereka is more likely the source of dolomite within Lake Bohinj.

6.43. Origin of the Lake Bohinj sediment

Since the geological surroundings and the general sedimentological conditions of Lake Bohinj are partly similar to the neighbouring Lake Bled, a comparable origin of its sediments could be assumed. Accordingly the sediments are dominated by calcite and dolomite, quartz and feldspar being not common. In contrast to Lake Bled, however, no additional water is carried into Lake Bohinj which in Lake Bled could have influenced locally the chemical conditions of the lake water.

A difference exists between both lakes as far as dolomite is concerned: The Bohinj sediment contains considerably higher amount of dolomite than sediment from Lake Bled. Although a relationship between dolomite and quartz contents is generally observed, the higher dolomite concentration of the Lake Bohinj sediment is not paralleled by correspondingly high amount of quartz. Dolomite seems to be derived from the lake's surroundings which consists of Triassic carbonate rocks. At the southern shore dolomite prevails whereas the other frame rock is slightly dolomitized limestone.

Calcite is present throughout and is the dominant mineral phase within most of the sediments. The detrital origin of most of the calcite is beyond any doubt, but a small part may also be autochthonous.

Evidence for calcite precipitation comes particularly from the southern nearshore sites 7 and 8 where the lake floor has a whitish appearance and macrophytes are abundant. Since the southern shore is composed of dolomite, the calcite within the nearshore sediment may have at least partly been precipitated by biogenic activity.

As within Lake Bled, the non-carbonates include abundant opaline silica of very well preserved diatoms (figs. 24, 25).

6.5. Autochthonous formation and dissolution of calcite within Lakes Bled and Bohinj

Although the sediments of both lakes clearly reflect a strongly detrital regime, formation of some autochthonous carbonate is indicated by our data.

It is evident that high input of Ca^{++} into both lakes takes place since the affluence of both surface and ground water from an area consisting mostly of carbonate rocks is likely to contain high Ca-concentrations.

Several mechanisms of $CaCO_3$-precipitation are known: Inorganic chemical precipitation may occur by either evaporation-concentration of the lake water or else by a mixing of water bodies of different composition. Biogenic carbonate precipitation due to the assimilation of plants is another possible mechanism. Evaporation-concentration is unlikely to explain an eventual carbonate precipitation from the lake water in Bled and Bohinj since the climatic conditions are not favorable. Mixing of different water bodies (e. g. the lake water and the Radovna river water) may eventually cause calcite precipitation although the water chemistry of both the river and the lake may not be very different. This model is unlikely, however, for the affluents.

If, nevertheless, some carbonate precipitation occurs within such mixing areas, the small amount would be "masked" by the great amounts of detrital carbonate carried by the affluents. The main, if not exclusive, source of autochthonous calcite could then remain the biogenic activity of plants releasing CO_2. Some of the nearshore environments, particularly at the southern shore of Lake Bohinj, have a whitish appearance, and underwater macrophytes are abundant there.

Eutrophication effects, particularly within Lake Bled, are evident from several limnological data, and are also shown from the present study by U. Förstner (chapt. 7). The uppermost layer (0—3 cm) contains up to 10.4 ‰ organic carbon (U. Förstner, 1977 a in print) whereas the lower layer

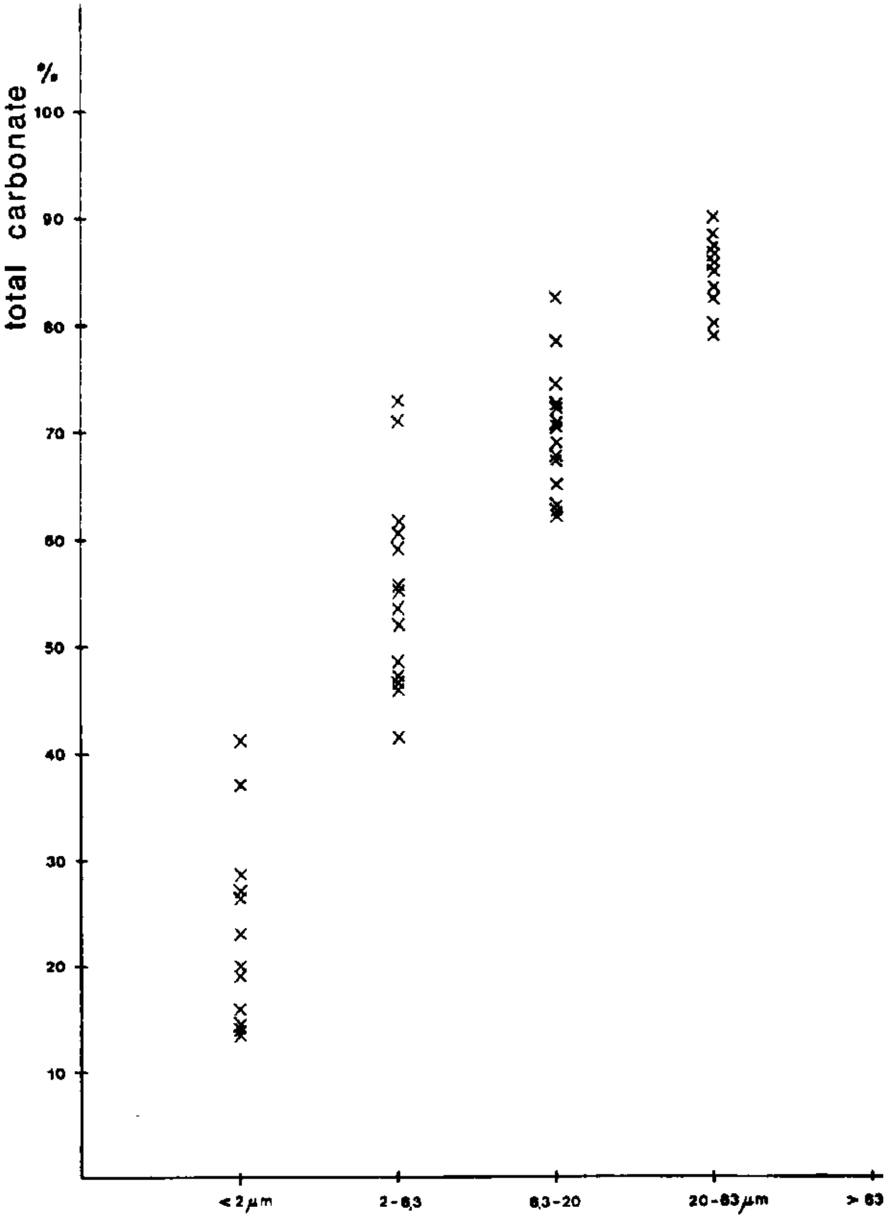
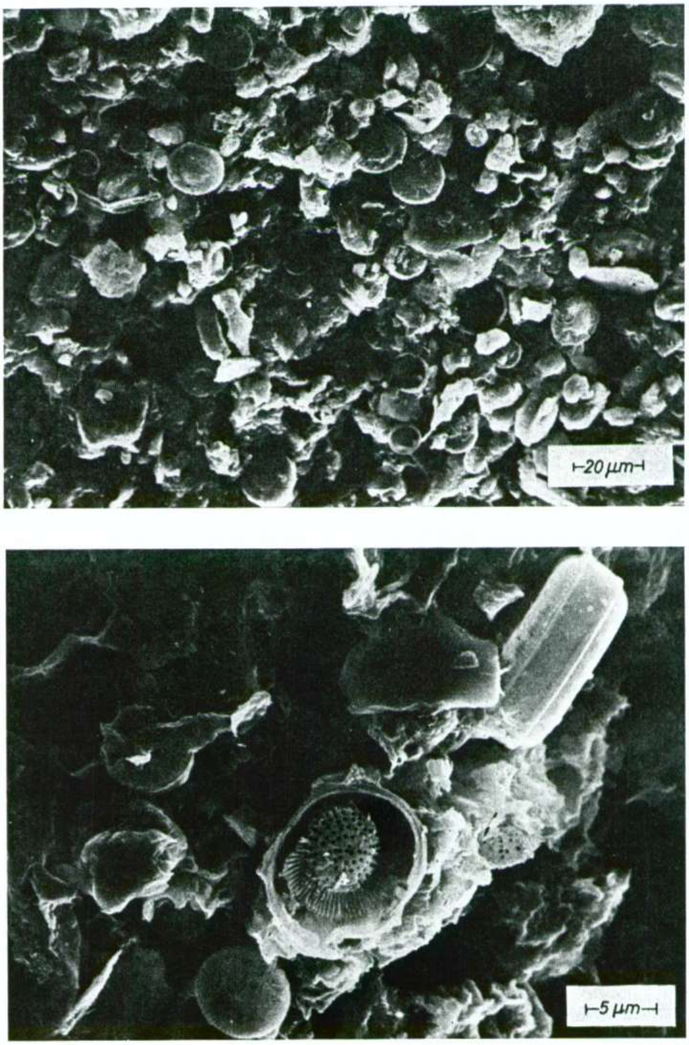


Fig. 23. Core sediment samples of BH-5B from Lake Bohinj
Total carbonate content versus grain sizes < 63 µm



Figs. 24. and 25. Sediment from Lake Bohinj. Diatoms from the carbonate-free part of the grain size 2—6.3 μm

(5—10 cm) revealed only 2.2 ‰ (G. Schmoll, 1977). This high organic carbon content is referred to algal "blooms" which are known worldwide from many other lakes.

Such algal "blooms" may be the most probable factor for autochthonous carbonate formation within Lake Bled and also Lake Bohinj. A certain increase of Ca within the $< 2\ \mu$m fraction, though not always very pronounced, in the uppermost 10 cm of the sediment of the three cores studied (see table 16), may

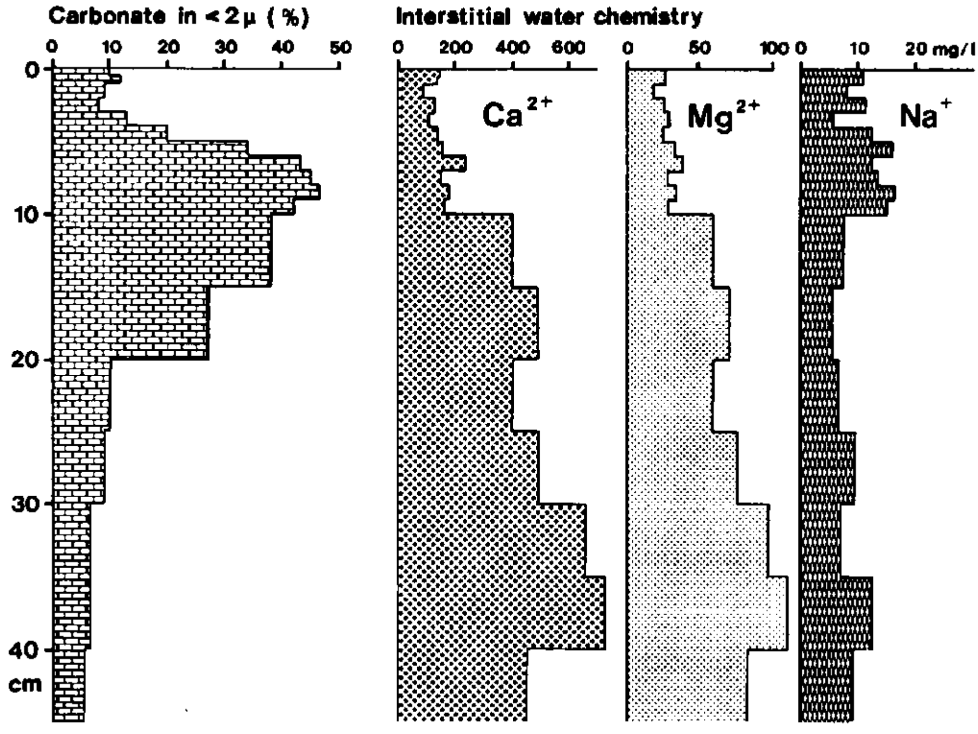


Fig. 26. Sediment core BL-15B from Lake Bled
Chemical composition of the interstitial water

indicate such biogenic precipitation of carbonate. Whereas the deeper layers of the lake sediments have a rather homogeneous appearance, the upper 5—10 cm of almost all samples show a distinct thin lamination (fig. 8), the top few centimeters consist of a textureless soft mud of a dark gray colour. The laminated part contains very thin white laminae of calcite. It is possible that this represents episodically precipitated autochthonous carbonate. Dissolved Ca^{++} is abundantly supplied to the lake water, although little data from the lake water for Ca^{++} were available (30—50 mg/l; unpublished data of the Limnological station of Bled). The uppermost samples from the interstitial water (table 15), however are likely to present slightly higher values of Ca^{++} than the lake water. They range from 100 to 170 ppm and are thus still double that of the lakes of Plitvice where carbonate precipitation takes place (P. Stoffers, 1975).

From chemical analyses of the Lake Bled water at sites BL-1B and BL-15B (tables 1 and 2) it is apparent that already within deeper strata of the open water column carbonate can be dissolved rather than precipitated. A continuous decrease of pH-values from 8.5 and 8.4 at the surface towards 6.9 at 24 m and 26 m, respectively, is observed, and is paralleled by an increase of CO_2, H_2S and HCO_3 (!). Similarly, the temperatures decrease bottomwards, favouring carbonate dissolution.

Chemical composition of the interstitial waters is also in favour of dissolution rather than precipitation of carbonate: An almost continuous increase of Ca^{++} and Mg^{++} is observed at core BL-15B which is independent of the carbonate content of the sediment (fig. 26). Sodium and potassium remain constant although some variations occur.

Within the uppermost 10 cm of the core the decrease of carbonate can be explained by two factors which most probably act together:

1. The sediment is diluted by the high amount of organic matter (up to about 25 %).

2. Decomposition of organic matter provides CO_2 and thus causes dissolution of carbonate.

A decrease of Ca within the uppermost layer is also evident from the other cores as is indicated by the results of U. Förstner (chapt. 7).

Dissolution of carbonate at similar depths (max. 22 m) was suggested from an extremely carbonate-rich part of Lake Constance ("Gnadensee", M. Schöttle, 1969), where about ten times more carbonate is autochthonous biogenic than detrital.

6.6. *Sedimentation rates*

Without further dating comparison with other lakes of a similar setting, and the pollution effects within the uppermost centimeters of sediments can be used for dating purposes. Comparison with dated sediment cores from other lakes can only give approximate values. For the central part of Lake Constance an average of about 1 mm/a seems now reasonably established (G. Müller, 1966, G. Wagner, 1972). In case of a similar sedimentation rate in both lakes Bled and Bohinj the lowermost samples within core BL-15B would not be much older than 400 years (see A. Šercelj and M. Culiberg, chapt. 5.2).

Mass balance of the lake sediment is still an open question since almost no data are available for the input rate of suspended matter. The small affluents, as well as the artificial input of the Radovna water, seem to carry little suspended load (D. Vrhovšek & A. Brezigar, 1976).

Input of further suspended matter was not measured since most of the detrital material seems to be transported by small torrents. Analysis immediately after rainfall is necessary. Probably, a large part of the detrital sediments may also be washed in by surface runoff similar to sheet-flows.

From the few analyses of the chemical composition of the outflowing water of the Jezernica, it is evident, however, that suspended material is extremely scarce (about 10 mg/l, unpublished data of the Limnological station of Bled).

Since the affluents of these lakes are mostly torrents a rather discontinuous influx of detrital components must be assumed. Flood layers should be expected within the sediment column although they have not yet been detected within the uppermost 45 cm studied. Further, and deeper coring is thus required to elucidate the history of Lakes Bled and Bohinj.

Table 10. **Mineral composition of the bottom samples from Lake Bled**

Nr.	total sample: total carbonate	total sample: dolomite %	total sample: calcite %	total sample: quartz (peak-height)	total sample: feldspar (peak-height)	< 2 µm grain size: total carbonate	< 2 µm: dolomite %	< 2 µm: calcite %	< 2 µm: quartz (peak-height)	< 2 µm: feldspar (peak-height)	2-6.3 µm grain size: total carbonate	2-6.3 µm: dolomite %	2-6.3 µm: calcite %	2-6.3 µm: quartz (peak-height)	2-6.3 µm: feldspar (peak-height)
1a	74.5					-	-	100	1.2	-	55.5				
1b	78.0					36.5	5	95	1.2	-	75.5	2	98	0.4	-
2a	76.5	3	97	0.9	-	-	-	100	1.2	-	-				
2b	75.5	6	94	1.2	0.3	9.5	4	96	1.5	-	45.0	48	52	2.4	-
3a	76.5	3	97	1.0	0.4	20.0	-	100	0.5	-	51.0				
3b	75.5	5	95	1.3	-	36.0	8	92	1.0	-	79.0	5	95	0.7	-
4a	76.0	2	98	1.0	-	-	26	74	0.7	-	56.5				
4b	74.5	12	88	1.6	-	42.0	5	95	0.8	-	83.5				
5a	70.5	13	87	1.6	-	-	24	76	1.0	-	56.5				
5b	61.0	17	83	3.5	-	27.0	19	81	1.1	-	61.5				
6a	72.0	15	85	2.3	-	-	23	77	1.2	-	62.2				
6b	59.0	36	64	5.3	0.7	23.5	16	84	3.0	-	58.5				
7a	64.0	36	64	3.3	0.5	38.0	15	85	1.7	-	54.5	20	80	4.6	-
7b	61.5	38	62	3.5	0.3	30.0	7	93	0.9	-	52.5	25	75	4.5	-
8a+b	61.0	31	69	3.7	0.6	23.0	11	89	1.6	-	37.0				
9a	72.0	4	96	1.1	-	-	-	100	1.0	-	65.0				
9b	70.5	3	97	0.8	-	24.0					77.5				
10a	74.0	3	97	1.5	-	-	-	100	0.5	-	48.0	7	93	1.4	0.4
10b	78.0	5	95	1.1	-	40.0	4	96	1.1	-	82.0				
11a	77.5	3	98	0.8	0.4	14.0	8	92	0.4	-	51.5	13	87	2.2	-
11b	78.0	4	96	1.0	0.4	39.0	5	95	1.0	-	75.5				
12a+b	54.5	36	64	4.2	-	19.0	14	86	2.3	0.4	42.5	18	82	6.7	0.6
13a	57.5	17	83	4.0	-	-	8	92	1.4	-	41.5				
13b	69.0	7	93	2.0	-	22.5	5	95	1.1	-	56.5				
14a	60.0	7	93	2.1	-	7.5	17	83	1.6	-	40.5				
14b	69.0	6	94	2.0	-	33.5	4	96	1.4	-	77.5				
15a	60.5	8	92	2.1	0.6	-	18	82	1.6	-	41.5				
15b	71.5	5	95	2.0	-	31.5	5	95	1.4	-	75.5				

Nr.	6.3-20 μm grain size total carbo-nate	dolo-mite %	cal-cite %	quartz (peak-height)	feldspar (peak-height)	20-63 μm grain size total carbo-nate	dolo-mite %	cal-cite %	quartz (peak-height)	feldspar (peak-height)
1a	90.5					85.0				
1b	89.5	4	96	0.5	-	75.5				
2a	94.5	4	96	0.3	-	89.0	18	82	0.8	-
2b	83.0	49	51	2.2	0.5	64.5	55	45	5.0	-
3a	88.5					88.0	4	96	0.7	-
3b	83.0	5	95	0.8	-	64.5	42	58	3.8	0.4
4a	87.0	5	95	0.6	-	82.5				
4b	88.5	8	92	1.2	-	63.5	18	82	2.9	1.1
5a	83.0	11	89	1.0	-	76.0	39	61	2.0	0.7
5b	77.5	30	70	3.0	0.4	64.5	40	60	3.5	0.4
6a	87.0	14	86	1.0	-	77.0	40	60	2.2	0.6
6b	66.0	36	64	3.9	-	65.5	45	55	4.8	1.2
7a	78.0	23	77	3.8	0.6	72.0	47	53	6.0	1.4
7b	75.5	25	75	3.7	0.5	72.0	54	46	7.5	1.2
8a+b	70.5	23	77	4.2	-	64.0	49	51	5.9	0.6
9a	90.0	5	95	0.7	-	81.5	13	87	2.5	-
9b	86.2	4	96	0.9	-	81.0	7	93	1.2	-
10a	84.0	4	96	0.8	-	81.5	11	89	1.7	-
10b	92.5	5	95	0.7	-	70.5	15	85	5.6	2.0
11a	88.0	4	96	0.6	-	80.0	5	95	1.5	-
11b	92.5	4	96	0.6		59.5	28	72	1.4	-
12a+b	67.5	14	86	5.8	0.4	62.0	64	36	9.7	0.6
13a	79.5	11	89	2.0	-	54.5	69	31	3.2	0.8
13b	85.0	4	96	1.3	-	61.0	60	40	3.5	0.6
14a	90.0	8	92	1.6	-	68.0	23	77	1.9	-
14b	88.5	8	92	1.2	-	64.5	48	52	2.6	-
15a	85.0	5	95	1.4	-	75.5	19	81	1.8	1.7
15b	85.0	4	96	1.1	-	64.5	41	59	2.4	-

Table 11. **Mineral composition of the BL-1B core samples from Lake Bled**

Depth in cms.	total sample: total carbo-nate	total sample: dolo-mite %	total sample: cal-cite %	total sample: quartz (peak-height)	total sample: feldspar (peak-height)	<2 µm grain size: total carbo-nate	<2 µm grain size: dolo-mite %	<2 µm grain size: cal-cite %	<2 µm grain size: quartz (peak-height)	<2 µm grain size: feldspar (peak-height)	2–6,3 µm grain size: total carbo-nate	2–6,3 µm grain size: dolo-mite %	2–6,3 µm grain size: cal-cite %	2–6,3 µm grain size: quartz (peak-height)	2–6,3 µm grain size: feldspar (peak-height)
0–0,5	73,0	2	98	0,8	-	-	-	100	0,8	-	17,0	26	74	7,0	-
0,5–1,5	69,0	3	97	1,1	-	11,0	6	94	1,1	0,4	46,5	8	92	4,6	-
1,5–3	73,0	4	96	1,1	-	10,0	10	90	2,1	-	56,0	2	98	0,7	-
3–5	75,0	2	98	1,1	-	10,0	6	94	1,1	0,4	59,5	4	96	1,6	-
5–7	75,0	3	97	1,5	0,3	41,5	6	94	2,5	-	79,0	3	97	1,3	-
7–10	79,0	4	96	1,1	-	53,0	3	97	2,0	-	81,5	-	100	1,0	-
10–15	75,0	3	97	1,7	0,2	22,0	-	100	3,5	0,7	69,0	2	98	0,4	-
15–20	75,0	2	98	1,3	-	8,5	-	100	4,2	-	66,0	2	98	2,2	-
20–25	75,0	2	98	1,1	0,3	19,5	-	100	4,0	-	61,0	2	98	1,8	-

Depth in cms.	6.3–20 μm grain size total carbo-nate	dolo-mite %	cal-cite %	quartz (peak-height)	feldspar (peak-height)	20–63 μm grain size total carbo-nate	dolo-mite %	cal-cite %	quartz (peak-height)	feldspar (peak-height)	>63 μm grain size total carbo-nate	dolo-mite %	cal-cite %	quartz (peak-height)	feldspar (peak-height)
0–0.5	93.0					81.5						5	95	1.5	-
0.5–1.5	84.5	2	98	1.5	-	78.5	5	95	1.7	-					
1.5–3	91.0					81.5	6	94	2.0	-		5	95	1.8	0.7
3–5	89.5	1	99	0.7	-	79.5	6	94	1.5	-		11	89	2.5	-
5–7	86.0	5	95	2.0	-	63.0	24	76	4.4	0.5		13	87	2.8	-
7–10	88.5	4	96	1.4	-	70.0	14	86	2.4	0.6					
10–15	91.0	2	98	1.0	0.6	64.5	24	76	4.7	1.0		5	95	2.2	1.0
15–20	93.5	3	97	0.6	-	75.5	20	80	3.0	-					
20–25	93.5	2	98	2.0	-	77.5	14	86	5.0	0.7					

Table 12. **Mineral composition of the BL-15B core samples from Lake Bled**

Depth in cms.	total sample: total carbo-nate	total sample: dolo-mite %	total sample: cal-cite %	total sample: quartz (peak-height)	total sample: feldspar (peak-height)	<2 μm grain size: total carbo-nate	<2 μm grain size: dolo-mite %	<2 μm grain size: cal-cite %	<2 μm grain size: quartz (peak-height)	<2 μm grain size: feldspar (peak-height)	2–6.3 μm grain size: total carbo-nate	2–6.3 μm grain size: dolo-mite %	2–6.3 μm grain size: cal-cite %	2–6.3 μm grain size: quartz (peak-height)	2–6.3 μm grain size: feldspar (peak-height)
surf.	57.5	18	82	2.0	-	15.3	-	100	0.6	-	41.0	11	89	2.5	-
0-0.5	60.0	13	87	2.1	-	9.8	-	100	1.0	-	41.0	8	92	2.3	-
0.5-1	60.5	9	91	1.4	-	12.0	-	100	1.6	-	48.0	7	93	2.1	0.4
1-2	60.0	8	92	1.9	-	9.0	-	100	2.4	-	43.0	13	87	2.3	0.6
2-3	68.0	6	94	1.1	0.4	8.0	-	100	0.6	-	55.0	9	91	2.0	-
3-4	70.5	14	86	1.1	-	13.0	-	100	0.6	-	63.0	8	92	1.3	-
4-5	77.0	6	94	1.0	-	20.0	-	100	-	-	72.0	4	96	0.9	-
5-6	73.0	6	94	1.2	-	34.5	3	97	2.0	-	71.5	6	94	1.1	-
6-7	74.5	7	93	0.7	0.7	43.5	1	99	0.7	-	78.5	4	96	0.8	-
7-8	75.0	4	96	1.0	0.2	47.5	-	100	1.5	-	75.5	2	98	0.6	-
8-9	72.0	6	94	1.3	-	48.5	-	100	1.2	-	72.0	3	97	0.8	-
9-10	69.0	3	97	1.1	0.4	42.0	-	100	1.2	-	70.5	3	97	1.1	-
10-15	69.5	2	98	0.8	0.3	38.0	-	100	0.9	-	70.5	-	100	1.1	-
15-20	67.5	8	92	1.2	-	27.0	-	100	1.4	-	61.5	3	97	1.3	-
20-25	65.0	2	98	1.7	0.3	10.0	-	100	2.1	-	54.0	-	100	1.8	0.2
25-30	63.0	7	93	1.7	-	9.0	5	95	5.1	-	50.0	7	93	2.0	0.3
30-35	56.5	12	88	2.5	0.6	6.5	7	93	4.8	0.6	45.0	4	96	2.6	-
35-40	60.0	6	94	2.2	0.3	6.5	3	97	5.5	0.4	46.0	8	92	2.9	-
40-45	65.0	6	94	1.9	-	5.5	-	100	3.4	0.4	46.0	-	100	2.1	-

Depth in cms.	6.3–20 μm grain size: Total carbo-nate	dolo-mite %	cal-cite %	quartz (peak-height)	feldspar (peak-height)	20–63 μm grain size: total carbo-nate	dolo-mite %	cal-cite %	quartz (peak-height)	feldspar (peak-height)	> 63 μm grain size: total carbo-nate	dolo-mite %	cal-cite %	quartz (peak-height)	feldspar (peak-height)
surf.	78.5	6	94	2.3	-	60.5					48.5				
0-0.5	74.5	8	92	1.7	-	67.0					48.5				
0.5-1	84.5	4	96	1.0	-	73.0					48.5				
1-2	74.5	7	93	1.8	0.3	63.0					48.5				
2-3	82.5	5	95	1.6	-	72.5					47.5				
3-4	84.5	4	96	1.0	-	72.0					52.0				
4-5	84.5	4	96	0.8	0.3	66.0					-				
5-6	84.5	10	90	1.7	-	59.0					-				
6-7	84.5	8	92	1.2	0.5	63.0					-				
7-8	84.5	6	94	1.0	-	67.0					47.5				
8-9	80.5	6	94	1.6	-	64.0					49.0				
9-10	80.5	3	97	1.8	-	63.0					47.5				
10-15	81.5	3	97	1.1	-	64.0					49.0				
15-20	82.5	5	95	1.4	0.5	64.0					50.0				
20-25	84.5	4	96	1.2	0.3	66.0					51.0				
25-30	81.5	4	96	1.2	-	61.0					-				
30-35	75.0					54.5					46.0				
35-40	74.0	5	95	1.8	-	59.5					-				
40-45	80.0	4	96	1.2	-	61.0					46.0				

Table 13. Mineral composition of the bottom samples from Lake Bohinj

Nr.	total sample: total carbonate	total sample: dolomite %	total sample: calcite %	total sample: quartz (peak-height)	total sample: feldspar (peak-height)	<2 µm grain size: total carbonate	<2 µm grain size: dolomite %	<2 µm grain size: calcite %	<2 µm grain size: quartz (peak-height)	<2 µm grain size: feldspar (peak-height	2-6.3 µm fraction: total carbonate	2-6.3 µm fraction: dolomite %	2-6.3 µm fraction: calcite %	2-6.3 µm fraction: quartz (peak-height)	2-6.3 µm fraction: feldspar (peak-height)
1	45.5	32	68	5.2	-	23.0	23	77	1.2	-	46.5	31	69	3.1	-
2a	56.5	31	69	6.1	0.8	9.5	13	87	1.2	-	52.5	38	62	1.8	-
2b	75.5	41	59	5.7	0.6	-	7	93	1.0	-	77.5	5	95	0.7	-
3a	53.0	43	57	5.5	-	9.5	9	91	1.4	-	45.0	49	51	1.8	-
3b	74.5	51	49	8.1	0.5	35.0	4	96	1.0	-	79.0	6	94	0.8	-
4a	61.0	64	36	5.0	-	2.0	15	85	1.4	0.3	42.0	39	61	2.4	-
4b	65.5	53	47	6.2	-	0	22	78	2.1	-	41.5	31	69	2.0	-
5a	69.5	69	31	6.7	0.3	3.0	14	86	0.8	-	45.0	55	45	1.9	-
5m		47	53	3.7	0.4		16	84	1.0	-		38	62	1.2	-
5b	-					54.0	14	86	0.6	-	83.0	18	82	0.9	-
6a	70.5	68	32	5.4	-	9.0	12	88	0.5	-	43.5	66	34	1.5	-
6b	76.0	30	70	4.6	-	34.0	28	72	1.1	-	60.5	32	68	1.2	-
7a	91.0	45	55	2.3	-	-	-	-	-	-	29.0				
7b	88.0	51	49	2.7	0.5	42.5	31	69	1.3	-	63.0	28	72	1.6	-
8		54	46	3.3	2.6		8	92	0.8	-		12	88	1.3	-

Nr.	6.3-20 µm grain size					20-63 µm grain size					63-125 µm grain size				
	total carbonate	dolomite %	calcite %	quartz (peak-height)	feldspar (peak-height)	total carbonate	dolomite %	calcite %	quartz (peak-height)	feldspar (peak-height)	total carbonate	dolomite %	calcite %	quartz (peak-height)	feldspar (peak-height)
1	51.0	36	64	4.8	0.6	42.5	34	66	4.8	-	-	30	70	4.0	-
2a	59.0	45	55	1.9	-	57.0	45	55	5.6	-	49	31	69	5.2	0.6
2b	87.0	4	96	0.9	-	72.0	47	53	3.5	-	-	24	76	1.6	-
3a	48.5	51	49	2.5	-	53.5	49	51	8.4	-	47.5	51	49	6.0	-
3b	87.0	8	92	0.5	-	64.0	37	63	4.3	0.7	-	22	78	5.8	1.0
4a	56,5	48	52	2.7	0.8	84.0	85	15	1.4	0.7	95.0	95	5	0.3	-
4b	60.5	42	58	2.8	-	73.0	54	46	3.2	0.3	68.0	88	12	1.3	-
5a	60.5	60	40	2.1	-	80.5	66	34	0.8	-	80.0	72	28	2.2	-
5m		47	53	2.0	0.4		59	41	2,1	-		65	35	0.7	-
5b	89.5	18	82	0.8	-	93.0	34	66	0.4	-	76.5	42	58	1.3	-
6a	63.0	42	58	1.8	-	84.5	77	23	1.1	-	67.5	78	22	1.7	-
6b	77.5	40	60	1.5	-	89.0	32	68	0.8	-	79.0	23	77	0.4	-
7a	79.0	41	59	1.5	-	93.0	37	63	0.6	0.7	93.5	41	59	0.5	-
7b	80.0	30	70	1.5	-	88.0	36	64	0.7	0.5	94.0	34	66	0.3	-
8		22	78	1.1	-		63	27	1.1	0.2		44	56	1.2	-

Table 14. **Mineral composition of the BH-5B core samples from Lake Bohinj**

Depth in cms.	total sample: total carbonate	total sample: dolomite %	total sample: calcite %	total sample: quartz (peak-height)	total sample: feldspar (peak-height)	< 2 µm grain size: total carbonate	< 2 µm: dolomite %	< 2 µm: calcite %	< 2 µm: quartz (peak-height)	< 2 µm: feldspar (peak-height)	2-6.3 µm grain size: total carbonate	2-6.3 µm: dolomite %	2-6.3 µm: calcite %	2-6.3 µm: quartz (peak-height)	2-6.3 µm: feldspar (peak-height)
0-1	76.5	85	15	1.3	0.2	-	17	83	-	-	46.0	42	58	1.2	
1-2	74.5	75	25	1.6	-	-	17	83	0.6	0.8	41.5	45	55	0.9	
2-3.5	68.5	47	53	1.0		19.0					52.0	35	65	1.1	
3.5-5	75.5	60	40	1.2	0.1	27.0					61.5	29	71	1.1	
5-7	76.5	31	69	0.9	-	41.0	24	76	0.7	-	71.0	17	83	0.7	
7-8	75.5	35	65	0.7	0.2	37.0	14	86	0.5	-	73.0	15	85	0.6	
8-10	71.5	72	28	1.0		14.0	-	100	0.5	-	53.5	32	68	1.1	
10-15	68.0	61	39	1.5		14.0	-	100	-		46.5	39	61	1.2	
15-20	65.5	54	46	2.0		16.0	15	85	0.6	-	48.5	31	69	1.4	
20-25	71.0	72	28	1.2		20.0	24	76	1.0	-	55.5	33	67	1.2	
25-30	68.5	66	34	0.8		13.5	31	69	1.0	-	47.0	40	60	1.5	
30-35	76.0	58	42	0.6		23.0	27	73	2.8	-	55.0	35	65	1.2	
35-40	69.0	47	53	0.8		28.5	20	80	2.5	-	59.0	27	73	0.9	
40-45	68.0	59	41	1.2		26.5	22	78	2.7	-	60.5	28	72	0.9	

Depth in cms.	6,3–20 µm grain size total dolo- mite	dolo- mite %	cal- cite %	quartz (peak- height)	feldspar (peak- height)	20–63 µm grain size total carbo- nate	dolo- mite %	cal- cite %	quartz (peak- height)	feldspar (peak- height)
0–1	62,5	49	51	1,8	-	85,0	75	25	2,6	0,3
1–2	69,0	49	51	1,4	-	87,0	59	41	4,8	0,4
2–3,5	67,5	35	65	0,7	-	86,0	63	37	1,1	0,2
3,5–5	74,5	36	64	1,2	-	90,0	72	28	0,9	0,1
5–7	78,5	23	77	0,9	0,2	85,0	48	52	0,6	-
7–8	82,5	20	80	1,0		86,0	58	42	1,2	-
8–10	67,5	36	64	1,3	-	85,0	75	25	1,6	-
10–15	62,0	45	55	1,7	-	80,0	60	40	1,1	0,2
15–20	63,0	36	64	2,3	-	79,0	30	70	2,6	-
20–25	70,5	36	64	1,4	-	85,5	75	25	0,8	-
25–30	65,0	47	53	2,1	1,2	82,5	74	26	1,3	-
30–35	72,5	38	62	1,5	-	88,5	76	24	2,7	0,4
35–40	72,5	32	68	1,1	0,1	86,0	53	47	1,0	-
40–45	70,5	36	64	1,3	-	83,5	65	35	1,2	-

Table 15. Sediment cores from Lakes Bled and Bohinj. Chemical data of the interstitial water (in mg/l).

Core BL-1B

Depth in cms.	Ca (mg/l)	Mg (mg/l)	Mg/Ca atomic ratio	Na (mg/l)	K (mg/l)
0–0.5	140	21	0.25	17.0	5.8
0.5–1.5	120	19	0.26	11.5	5.0
1.5–3	140	23	0.27	11.0	5.0
3–5	160	26	0.27	12.5	5.0
5–7	200	35	0.29	16.0	6.0
7–10	160	29	0.45	17.0	5.3
10–15	120	27	0.37	10.0	5.5
15–20	300	42	0.23	6.5	3.5
20–25	310	44	0.24	13.5	3.8

Core BH-5B

Depth in cms.	Ca (mg/l)	Mg (mg/l)	Mg/Ca atomic ratio	Na (mg/l)	K (mg/l)
0–1	100	12	0.20	10.5	2.0
1–2	140	17	0.20	13.0	2.8
2–3.5	120	11	0.15	11.5	2.0
3.5–5	100	9	0.15	13.5	2.3
5–7	70	6	0.14	12.0	2.0
7–8	100	8	0.13	19.0	2.8
8–10	130	9	0.11	15.5	2.5
10–15	80	8	0.17	4.0	1.8
15–20	100	9	0.15	2.5	2.3
20–25	70	6	0.14	5.0	1.8
25–30	60	4	0.11	8.0	2.5
30–35	350	17	0.08	5.0	4.0
35–40	90	7	0.13	5.5	2.5
40–45	90	7	0.13	10.0	3.5

Core BL-15B

Depth in cms.	Ca (mg/l)	Mg (mg/l)	Mg/Ca atomic ratio	Na (mg/l)	K (mg/l)
surf.	170	31	0.3	11.5	5.0
0–0.5	150	25	0.28	11.0	4.8
0.5–1	140	27	0.32	12.5	3.8
1–2	90	18	0.33	8.0	3.0
2–3	130	26	0.33	11.5	4.5
3–4	110	29	0.43	5.5	3.8
4–5	140	27	0.32	12.5	4.0
5–6	160	33	0.34	16.0	5.0
6–7	240	39	0.27	12.5	2.8
7–8	150	28	0.31	13.5	5.0
8–9	180	33	0.30	16.5	5.0
9–10	160	29	0.30	15.0	4.3
10–15	400	59	0.24	7.5	3.0
15–20	490	71	0.24	5.5	2.8
20–25	400	59	0.24	6.5	2.0
25–30	490	77	0.26	9.5	5.8
30–35	660	98	0.24	7.0	3.0
35–40	720	112	0.26	12.5	4.3
40–45	550	83	0.25	9.0	4.3

Analyzed by D Reinhard.

7. Geochemistry of recent sediments from Lakes Bled and Bohinj

Ulrich Förstner

7.1. Introduction

The chemical composition of lacustrine sediments is influenced by a number of internal and external factors, such as the lithofacies of the surrounding areas, precipitation and sorption processes and diagenetic redistribution of elements after the deposition of the sediment material. During the last few decades, many lakes in the more densely populated and industrialized areas are becoming increasingly affected by human activities, in particular from sewage inputs and air-borne contamination.

Initial observations of cultural effects from communities and agriculture on lakes, indicated in the variations in the sediment stratigraphic records, were made on Lake Zürich and described by H. F. Nipkow (1920). Increased rates of eutrophication in lakes were first studied by G. E. Hutchinson & A. C. Wollack (1940) from Linsley Pond, Conn. and C. H. Mortimer (1941) from Lake Windermere, England. These reports and the subsequent findings of R. C. Murray (1956) from Wisconsin Lakes and W. Ohle (1956) from lakes in Northern Germany suggested that lake sediments "may be regarded as a response of the conditions in an aquatic system" (H. Züllig, 1956). Characteristic man-made contamination effects have been evaluated by investigating the distribution of phosphorous (A. Livingstone & J. C. Boykin, 1962; M. C. Whiteside, 1965), of iron monosulfide (G. Müller, 1967) and of changes of diatom assemblages (J. G. Stockner & W. W. Benson, 1967; H. C. Duthie & M. R. Sreenivasa, 1971). Pollen variations in recent lake sediments have been found to reflect historical changes in land use of areas in North America and Europe (J. Vuorela, 1970; A. M. Solomon & D. F. Kroener, 1971; T. W. Anderson, 1973; A. L. W. Kemp et al., 1974). During the last decade lake sediment analyses have increasingly been employed as a tool to trace sources of less degradable pollutants, such as halogenated hydrocarbons (H. O. Leshniowsky et al., 1970) and heavy metals (R. L. Thomas, 1972; R. J. Allan, 1974; U. Förstner & G. Müller, 1974, L. Håkanson, 1977).

One field of sedimentary investigation, which is particularly useful in the present context, is marked by the study of vertical profiles from fine-grained deposits in lakes. Sediment cores provide a historical record of events occurring in the watershed of a particular lake and enable a reasonable estimate of the background level and changes in input of any pollutant over an extended period of time. This approach is especially valuable if the rate of sedimentation is known.

The present study deals with the distribution of major cations (sodium, potassium, magnesium, calcium, and iron) and trace elements (manganese, strontium, lithium, zinc, chromium, nickel, copper, lead and cadmium) in the pelitic fractions of grab samples and core samples from Lakes Bled and Bohinj (Blejsko jezero and Bohinjsko jezero) in Slovenia.

7.2. Analytical methods

From both lakes a total of 82 sediment samples, obtained by the grab sampling, was investigated geochemically; 28 surface (0—3 cm) and subsurface (5—10 cm) samples from Lake Bled, 14 surface and subsurface samples from Lake Bohinj and 28 core samples were analyzed.

In order to reduce the grain size effects as much as possible and compare the different samples, the grain size $< 2\,\mu m$ (pelitic fraction) was separated, in each case with distilled water in settling tubes. The suspended solids were recovered by evaporation in porcelain bowls at 60 °C. For the metal analyses, the dry material was treated with aqua regia (conc. $HNO_3 : HCl = 1 : 3$). The elements lithium, sodium, potassium, magnesium, calcium, strontium, iron, manganese, zinc, chromium and copper were determined by conventional (flame-) atomic absorption spectroscopy and the elements nickel, lead and cadmium by means of flameless AAS according to the usual setting we use in this institute (U. Förstner & G. Müller, 1974).

7.3. Interpretation of metal data

The analytical data of the elements investigated are registered in tables 16, 17 and 18. Mean values, standard deviations and variation coefficients for both areas of investigation are summarized in table 19. The distribution of the major and trace elements in the three core profiles are graphically presented in figure 27.

7.31. Mean values

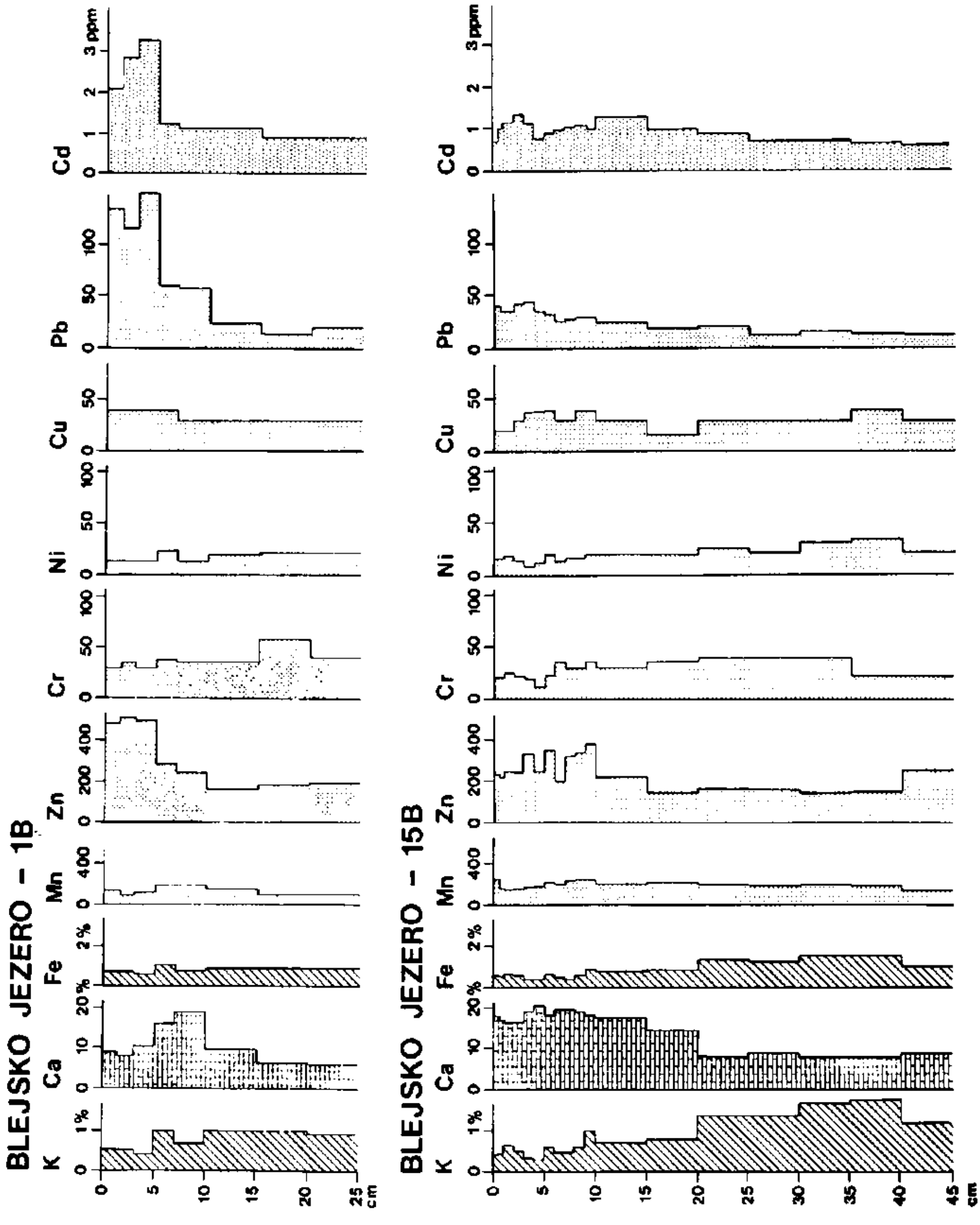
The comparison of the mean values (table 19) and variation coefficients of the metal data from the sediments of Lake Bled and Lake Bohinj indicates characteristic differences between both areas under consideration. There is a significant higher amount of calcium (30 %), lithium and potassium (50 %) and magnesium (100 %), in the sediment of Lake Bohinj when compared with the pelitic fractions of the Bled sediment. Even stronger enrichment (150 to 300 % more than in Lake Bled) of iron, chromium, manganese and nickel has been found in the sediment of Lake Bohinj. The only significant exception with regard to the metals studied here, are the values of zinc, which are on the average, approximately 50 % higher in the sediments from Lake Bled than in those taken from Lake Bohinj. Variation coefficients are relatively low for sodium, magnesium and calcium in both test areas, as well as for copper in Lake Bled and cadmium in Lake Bohinj; in contrast, the values of cadmium, nickel and lead from the sediments of Lake Bled indicate particularly strong variations, as the manganese concentrations likewise do in Lake Bohinj. With regard to the latter effect, it can be seen from the data of the grab samples that the top layers (0—3 cm) of Lake Bohinj are characteristically enriched in manganese as compared with the analytical values obtained from subsurface sediments (5—10 cm).

From the present data of average values and variation coefficients of major and trace elements it would appear that there is a predominant lithogenic influence — from basic rocks — on the sediment composition of Lake Bohinj, whereas the elevated concentrations of zinc and the higher variability of the cadmium and lead values of Lake Bled point to anthropogenic influences. According to available knowledge (see chapt. 3.2.), however, basic source rocks have not been found in the catchment area of Lake Bohinj.

The extremely high variation coefficient of manganese in Lake Bohinj is probably indicative of the presence of diagenetic effects that are brought about by changes in the redox conditions. The increase of manganese in near-surface sediments has been explained by processes of diagenetic dissolution of manganese compounds in the lower reducing part of the sedimentary column, upward migration of dissolved manganese ions and subsequent precipitation at the oxidizing sediment/water interface (E. Bonatti et al., 1971). These processes are considered important mechanisms in the formation of manganese concretions in the lacustrine environment (E. M. Kindle, 1932; R. Rossmann & E. Callender, 1968). Enrichment of manganese within the top surface sediment layers have been observed in Lake Constance (U. Förstner et al., 1974) and lakes of Upper Bavaria as well (U. Förstner, 1977 b).

7.32. *Core profiles*

The metal data from core profiles (fig. 27), which were taken from the eastern basin (BL-1B, water depth 24 m) and from the western basin (BL-15B, 29.6 m) of Lake Bled and from a water depth of 35 m of Lake Bohinj, confirm the findings described above. Within the upper part of the sedimentary sequence of the eastern basin of Lake Bled, we can note a distinct increase of the concentrations of zinc, lead and cadmium. Compared to the "background" data, presented by the respective metal values from the lower parts of the core profiles (approximately 150 ppm for zinc, 15 ppm for lead and 0.8 ppm for cadmium), there is a maximum enrichment in the surface sediment layers of the eastern part of Lake Bled by factors of 3.5 for zinc, 4 for cadmium and 10 for lead. In the western basin of Lake Bled, the surface enrichment is much lower for these metals, ranging between 2 for zinc and cadmium and 3 for lead. It seems quite probable from the core data that the enrichment of zinc, cadmium and lead in the surface sediments is due to the increased input of wastes from human activities. Similar effects can also be evaluated from the sediment core taken in the central part of Lake Bohinj. Significant enrichment in the surface sediment layers occurs: for copper, with concentrations up to 110 ppm (background 55 ppm) and zinc (420 ppm — 200 ppm). In contrast to the findings from Lake Bled, there is no characteristic increase of the cadmium concentrations within the upper portion of the core profile from Lake Bohinj. Decreasing values of chromium, nickel, and to a lesser extent, iron and potassium concentrations are found in the upper layers of the sediments in the middle of the lake; since there is a simultaneaous increase of the calcium concentration, we conclude that the depletion of Cr, Ni, Fe and K is due to the dilution effect by higher carbonate contents in the near-surface sediments.


BLEJSKO JEZERO - 1B
BLEJSKO JEZERO - 15B
Cd
3 ppm
Pb
Cu
Ni
Cr
Zn
Mn
Fe
2%
Ca
20%
K
1%
cm

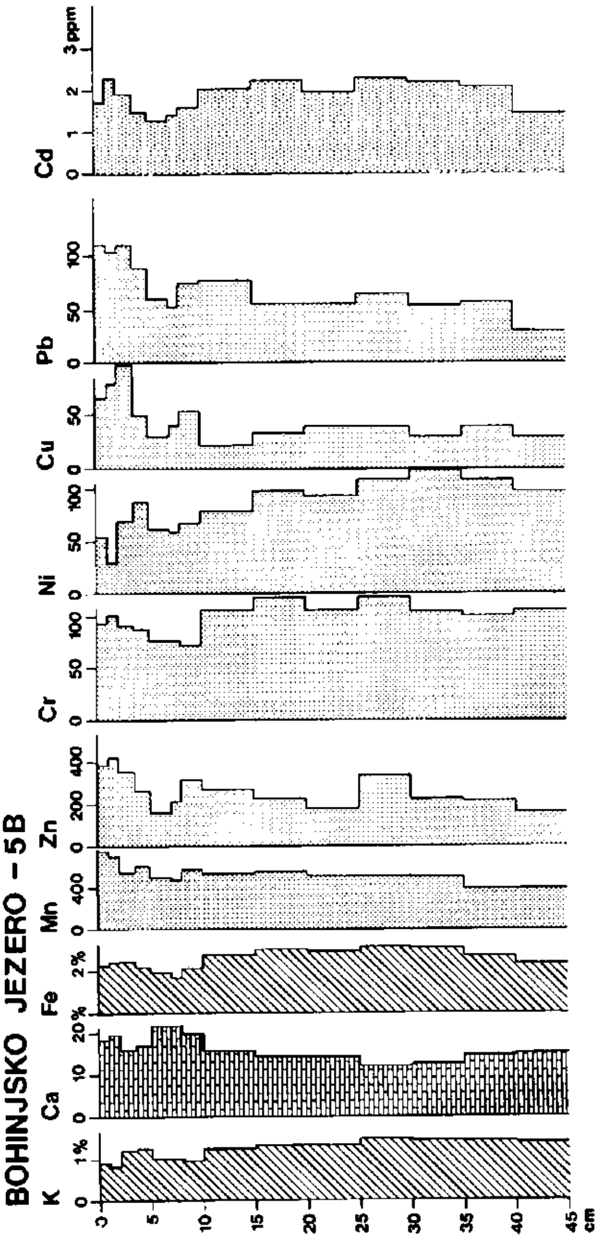


Fig. 27. Vertical distribution of major and trace metals in the clay-sized fractions of sediment cores from Lakes Bled and Bohinj (for location see figs. 2. and 3.)

7.33. Inter-element relations

Further insight into the factors influencing the distribution of major and trace metals could be expected from a statistical evaluation of the analytical data. Tables 20 and 21 indicate the correlation coefficients from linear regression analysis of possible element pairs for 28 samples from Lake Bohinj and 54 samples from Lake Bled. Values of more than 95 % significance are simply underlined; "r"-coefficients of > 99 % significance show double underlining.

Lake Bohinj. With respect to the last-mentioned effect of depletion of Cr, Ni, Fe and K and simultaneous increase of calcium concentrations in the core profile from Lake Bohinj, the calculation of the "r" coefficients seems to confirm our interpretation of carbonate dilution: there is a significant negative correlation between calcium on the one side and the metals lithium, potassium, iron, chromium, nickel and cadmium on the other. The latter elements form a first group of metals, which are positively interrelated, each to one other, with a probability > 95 %. Particularly high correspondence of the pairs K-Ni, Li-Fe, K-Cr and Li-Cr point to a common source of these metals from basic rocks; the presence of potassium and lithium in the strongly associated element pairs suggests that clay minerals might be the dominant carriers of elements, such as chromium, nickel, iron and cadmium into the sediment of Lake Bohinj. A second group of metals is formed by the elements zinc, copper and lead, which are correlated at more than 98 % significance. Although a common source of these elements from Zn-Pb-Cu mineralizations cannot be excluded, it seems more likely from their distinctly simultaneous enrichment in the upper part of the core profiles, that these three metals originate from increased anthropogenic inputs into the lake.

Lake Bled. Significant dilution effects by carbonate components are restricted to the elements lithium, potassium and iron. The copper contents of pelitic sediments from Lake Bled are related both to the group of lithogenic elements, such as magnesium, iron, chromium and nickel, and surface-enriched elements such as cadmium, lead and zinc, which are positively interrelated with a particularly high degree of significance (> 99.9 %).

Enrichment of the latter elements is considered to be predominantly induced by human-activities. Particularly heavy anthropogenic enrichment of Cd, Zn, Pb and Cu has been found by U. Förstner & G. Müller (1973) in sediment from the lower Rhine, by A. L. W. Kemp et al. (1976) from sedimentary core investigation in Lake Erie and by L. Håkanson (1977) from metal studies in the four largest Swedish lakes. This group of metals fully coincides with the frequency sequence of trace elements emitted in the atmosphere from burning fossil fuels (H. Erlenkeuser et al., 1974), which subsequently forms a characteristic "coal-residue-assemblage" in aquatic sediments (E. Suess, 1977).

It has already been shown by H. Hellmann (1972) that elevated zinc and lead contents are indicators of increased input of sewage. After a review of lacustrine sediment studies from highly industrialized regions, it was suggested by U. Förstner (1976) that a moderate increase of the above-mentioned combination of heavy metals (Cd, Zn, Pb, Cu and Hg) is typical for mixed sewage inputs from urban sources.

7.4. *Human effects on the metal composition of sediments from Lake Bled*

The distribution of the last-considered elements zinc, lead and cadmium in top layer samples from Lake Bled is shown in fig. 28. The dotted caption on the bottom part of each graph depicts the probable background values, as represented by the minimum metal contents in the deeper parts (15—25 cm) of the core profile BL-1B from the eastern basin of Lake Bled; dashed lines indicate metal concentrations of the subsurface samples from 5—10 cm depth and the solid lines show the actual levels of zinc, lead and cadmium in the pelitic fractions of the surface sediments of 0—3 cm.

According to the present graph, a major source of enriched concentrations of zinc and lead must exist at the eastern shore of the lake. Typical increases of lead and zinc strongly point to the influence of sewage, which is most probably derived from the community of Bled. In contrast to that, the distribution patterns of cadmium values do not indicate a very distinct influence from the shore, and seem to be rather more affected by diffuse sources, such as characterized by atmospheric emissions. Another explanation for the distribution of cadmium could lie in the lithogenic influences from the north-western inflow to the lake, since the subsurface samples (5—10 cm) show a distinct decrease in cadmium between that point and the eastern shore. Finally, it cannot be excluded that soluble waste materials containing elevated cadmium concentrations are dispersed in the lake water and are partly coprecipitated with carbonate minerals.

7.5. *Metal contents associated with the lake carbonate sediments*

Sediment analyses are not only useful when evaluating local sources of pollution and selecting critical sites for routine water sampling, they can also reveal the fate of contaminants under varying environmental conditions. In connection with the problems rising from the disposal of contaminated dredge material, methods of sediment partitioning have been developed. The most advanced techniques presently include the successive extraction of the metal contents in interstitial water and of ion exchangeable, easily reducible, organic and residual sediment fractions (e. g. R. E. Engler et al., 1974).

Here we are concerned mainly with the effects of carbonate associations of trace metals, since the sediments of both Lake Bled and Lake Bohinj predominantly consist of carbonate minerals. Table 22 gives the data of carbonate-associated metal contents from Lake Bled and — for comparison — of other lakes; examples from Central and Southeastern Europe, are analyzed after selective extraction, using strongly acid cation exchange resin (R. Deurer et al., 1978). By comparing the total carbonate percentage (in table 22 increasing from top to bottom) with the corresponding carbonate-associated metal content (given as percent from the total metal concentration), it is possible to deduce the effects of either enrichment or depletion caused by the carbonate component. If the metal content associated with carbonate is lower than the total carbonate, a dilution effect results, even when — as in the case of the result for iron — the metal content increases along with the carbonate percentage of the sample. It appears that the carbonate fraction is generally capable of bonding only up to 1/3 to 1/5 of the iron associated with the other sediment

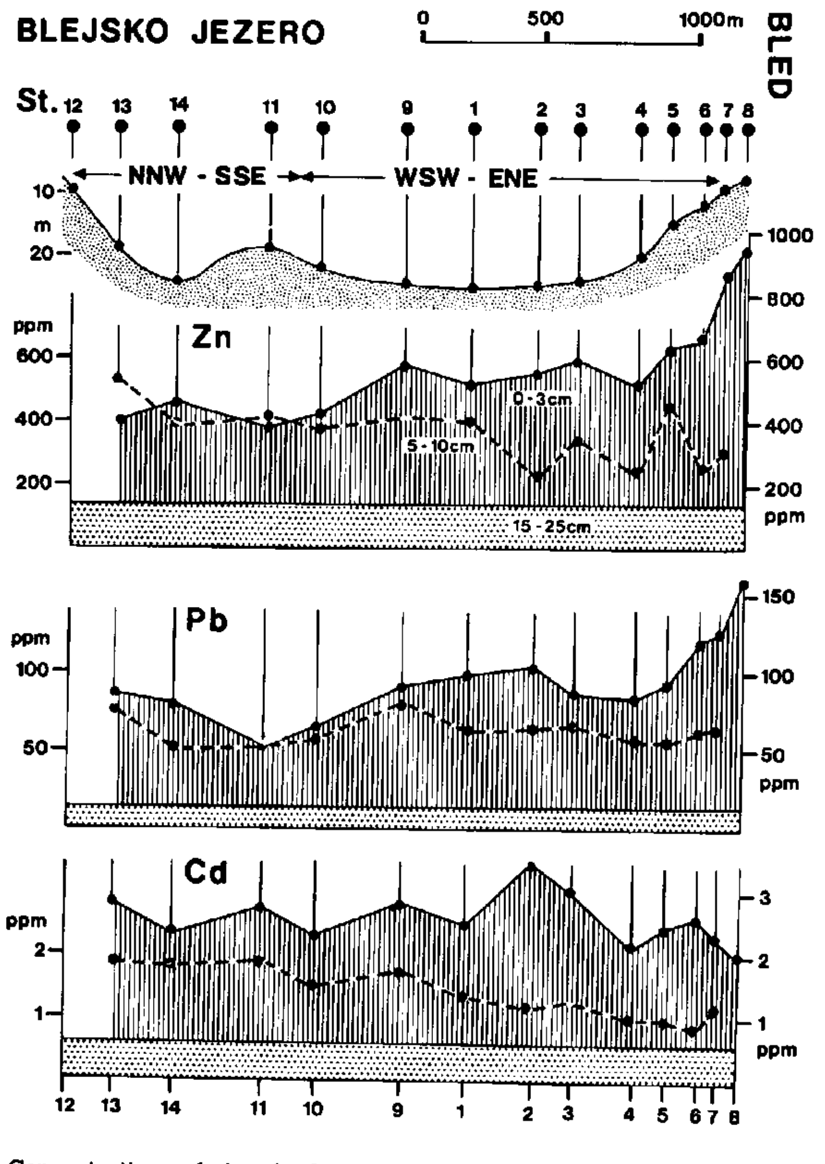


Fig. 28. Concentrations of zinc, lead and cadmium in the clay-sized fractions of sediment samples from Lake Bled (top layer 0—3 cms and subsurface 5—10 cms)

The dotted areas represent the geochemical background of the elements, as determined from the deeper layers of core 1B

Table 16. Metal data of pelitic sediment samples from core profiles of Lakes Bled and Bohinj

BLEJSKO JEZERO - 1B

cm	Li	Na	K	Mg	Ca	Sr	Fe	Mn	Zn	Cr	Ni	Cu	Pb	Cd
0.5 - 1.5	16	0.24	0.52	0.49	9.2	160	0.74	140	480	30	14	40	135	2.08
1.5 - 3	16	0.22	0.52	0.56	7.8	160	0.74	90	510	36	14	40	117	2.80
3 - 5	16	0.26	0.42	0.62	10.6	160	0.60	120	504	20	14	40	151	3.24
5 - 7	32	0.44	0.98	1.14	16.6	160	1.08	190	280	38	24	40	60	1.18
7 - 10	24	0.42	0.66	0.88	18.8	160	0.74	190	238	36	14	30	58	1.09
10 - 15	32	0.30	0.98	0.84	9.6	160	0.90	158	160	36	20	30	24	1.09
15 - 20	32	0.26	0.94	0.69	6.2	100	0.90	100	180	58	22	30	14	0.85
20 - 25	32	0.24	0.86	0.65	5.9	100	0.90	100	192	40	22	30	20	0.85

BLEJSKO JEZERO - 15B

cm	Li	Na	K	Mg	Ca	Sr	Fe	Mn	Zn	Cr	Ni	Cu	Pb	Cd
0. - 0.5	20	0.76	0.40	0.71	18.0	200	0.60	250	230	20	16	20	41	0.73
0.5 - 1	13	0.43	1,44	1,68	16.8	132	0.53	158	216	21	16	21	37	1.05
1 - 2	20	0.51	0.65	0.86	16.4	125	0.63	150	248	25	19	20	37	1.18
2 - 3	16	0,44	0,50	0.89	16.6	160	0.56	158	240	22	14	30	43	1.38
3 - 4	13	0.46	0.32	0.74	18.9	250	0.38	163	330	20	8	38	45	1.14
4 - 5	13	0.40	0.30	0.77	20.5	132	0.39	171	242	11	12	39	36	0.79
5 - 6	20	0.48	0.61	1.02	18.2	160	0.67	216	350	22	20	40	32	0.93
6 - 7	16	0.46	0.44	0.84	19.4	160	0.48	200	198	36	14	30	26	1.00
7 - 8	16	0.46	0.46	0.84	19.4	160	0.43	224	322	30	26	30	28	1.05
8 - 9	20	0.48	0.66	0.92	19.1	200	0.60	240	336	30	16	40	30	1.10
9 - 10	32	0.54	1.01	1.08	18.0	160	0.90	240	380	36	20	40	30	1.01
10 - 15	20	0.46	0.67	0.88	17.4	160	0.80	200	220	30	20	30	23	1.38
15 - 20	24	0.42	0.82	0.93	14.6	160	0.88	216	140	36	20	16	19	1.00
20 - 25	40	0.41	1.38	1.02	8.0	160	1.40	200	164	40	26	30	21	0.91
25 - 30	36	0.41	1.36	1.02	8.8	160	1.27	190	160	40	22	30	13	0.73
30 - 35	44	0.46	1.67	1.18	8.2	160	1.58	200	140	40	32	30	17	0.73
35 - 40	44	0.46	1.76	1.20	8.2	200	1.58	190	144	22	35	40	15	0.71
40 - 45	36	0.42	1.18	0.96	9.2	160	1.05	140	262	22	22	30	13	0.63

BOHINJSKO JEZERO - 5B

cm	Li	Na	K	Mg	Ca	Sr	Fe	Mn	Zn	Cr	Ni	Cu	Pb	Cd
0 - 1	42	0.63	0.88	2.17	18.5	208	2.24	750	383	92	57	67	112	1.71
1 - 2	50	0.50	0.80	2.10	20.0	250	2.40	700	420	100	30	80	103	2.30
2 - 3.5	50	0.46	1.20	2.32	16.0	125	2.45	540	345	90	70	100	112	1.90
3,5 - 5	40	0.55	1.26	2.48	17.3	166	2.15	606	260	87	88	50	90	1.47
5 - 7	32	0.52	1.00	2.04	21.8	160	1.92	496	160	76	62	30	61	1.27
7 - 8	32	0.58	1.00	1.91	21.8	160	1.67	476	208	76	59	40	52	1.34
8 - 10	36	0.66	0.95	2.38	20.1	89	2.11	589	321	71	68	54	75	1.58
10 - 15	42	0.53	1.23	2.20	15.7	132	2.84	573	263	105	80	21	78	2.03
15 - 20	43	0.48	1.32	1.99	14.5	174	3.06	584	228	119	99	33	55	2.22
20 - 25	40	0.54	1.32	2.12	14.6	100	2.94	564	180	104	94	40	56	1.94
25 - 30	44	0.56	1.47	2.20	12.2	100	3.18	564	340	120	110	40	66	2.27
30 - 35	52	0.50	1.44	2.38	12.8	160	3.12	552	224	104	120	30	54	2.16
35 - 40	44	0.54	1.41	2.18	14.8	160	2.72	390	220	100	110	40	58	2.05
40 - 45	40	0.59	1.38	2.12	15.6	160	2.32	390	164	104	98	30	30	1.41

Na, K, Mg, Ca and Fe in percent dry weight; Li, Sr, Mn, Zn, Cr, Ni, Cu, Pb, Cd in ppm

Table 17. **Metal data of surface (a: 0—3 cms) and subsurface (b: 5—10 cms). Sediment samples of pelitic fractions from Lake Bled**

BLEJSKO JEZERO

Nr.	Li ppm	Na %	K %	Mg %	Ca %	Sr ppm	Fe %	Mn ppm	Zn ppm	Cr ppm	Ni ppm	Cu ppm	Pb ppm	Cd ppm
1a	25	0.23	0.36	0.60	8.5	125	0.85	160	520	40	19	40	99	2.50
1b	20	0.41	0.76	1.04	16.4	160	0.88	224	408	36	25	40	62	1.34
2a	20	0.20	0.53	0.65	7.1	50	0.80	158	560	30	25	40	104	3.53
2b	20	0.41	0.76	1.07	16.8	100	0.76	224	220	36	22	40	64	1.16
3a	20	0.28	0.36	0.87	10.5	125	0.62	175	600	20	17	50	86	3.04
3b	20	0.42	0.76	1.07	17.4	160	0.76	240	348	36	22	40	66	1.30
4a	17	0.30	0.43	0.93	11.8	266	0.72	200	516	27	13	50	82	2.13
4b	24	0.46	0.76	1.14	18.5	200	0.80	200	230	30	22	30	57	1.00
5a	27	0.37	0.63	1.27	12.5	266	1.27	200	646	37	27	67	93	2.48
5b	40	0.46	1.50	1.56	13.4	160	1.96	264	472	38	51	60	56	1.00
6a	20	0.30	0.69	1.20	10.8	160	1.31	140	664	30	22	40	120	2.64
6b	64	0.56	2.20	1.68	11.0	160	3.06	660	238	90	108	60	64	0.86
7a	35	0.56	0.58	1.85	15.8	250	1.21	200	860	79	32	57	127	2.28
7b	25	0.46	0.58	1.55	22.5	400	0.68	190	310	60	10	40	65	1.28
8	40	0.60	1.05	1.20	16.0	400	1.68	225	970	75	36	75	160	2.03
9a	16	0.29	0.48	0.65	9.6	160	0.74	158	592	36	22	40	92	2.82
9b	20	0.29	0.59	0.88	13.6	160	0.76	224	416	36	20	40	81	1.77
10a	20	0.30	0.32	0.82	16.7	200	0.50	225	425	28	13	38	65	2.30
10b	20	0.41	0.67	0.99	17.4	160	0.70	224	376	36	22	40	58	1.49
11a	13	0.34	0.35	0.95	13.7	200	0.56	163	388	25	13	38	53	2.70
11b	20	0.43	0.69	1.10	16.6	160	0.76	180	416	36	21	60	54	1.85
12a	40	0.55	1.20	1.68	15.0	400	1.25	250	450	55	26	75	58	1.15
13a	24	0.33	0.76	1.04	9.6	200	1.40	158	400	36	26	40	86	2.80
13b	24	0.34	0.78	1.09	13.4	160	1.31	240	540	36	26	60	77	1.85
14a	20	0.27	0.76	0.88	9.0	160	1.08	158	464	38	24	40	80	2.32
14b	32	0.38	0.87	1.12	15.1	160	0.90	224	388	40	28	40	50	1.77
15a	24	0.30	0.86	1.07	8.4	160	1.14	140	430	36	21	40	71	2.43
15b	24	0.38	0.83	1.08	15.1	160	0.94	200	320	39	24	40	53	1.63

components. In the case of manganese concentrations, it was found that most of the investigated samples revealed an enrichment by carbonate. An exception was the sample from Lake Bled, where the relative low values of manganese might be explained in terms of diagenetic effects. The zinc values associated with carbonate seem to be relatively independent of the total carbonate percentage. Low values in lakes of high salinities can possibly be accounted for by the formation of soluble zinc-chloro-complexes, which influence the distribution coefficients of zinc during co-precipitation with calcite (K. H. Wedepohl, 1972). In the samples from Lake Bled and Lake Ohrid (U. Förstner,

Table 18. **Metal data of surface (a: 0—3 cms) and subsurface (b: 5—10 cms) samples of pelitic fractions from Lake Bohinj**

BOHINJSKO JEZERO

Nr.	Li ppm	Na %	K %	Mg %	Ca %	Sr ppm	Fe %	Mn ppm	Zn ppm	Cr ppm	Ni ppm	Cu ppm	Pb ppm	Cd ppm
1	32	0.48	0.91	1.76	16.8	100	1.18	158	140	76	64	30	51	2.21
2a	40	0.55	1.15	2.12	16.9	167	2.56	1665	233	67	85	50	73	2.81
2b	24	0.37	0.78	1.08	16.8	200	0.84	180	242	36	30	40	57	1.54
3a	50	0.50	1.10	2.09	17.4	400	2.50	1090	340	90	83	40	94	1.70
3b	20	0.33	0.66	1.07	18.0	160	0.74	224	208	22	24	80	49	1.08
4a	60	0.42	1.64	1.61	9.0	160	6.10	2100	238	110	112	40	108	2.25
4b	70	0.44	2.16	1.56	5.7	100	4.52	630	292	136	178	60	47	2.48
5a	40	0.50	0.72	2.37	19.2	125	2.25	950	450	55	61	75	100	2.45
5b	32	0.52	1.10	1.84	22.8	160	1.68	476	156	68	68	30	38	1.30
6a	31	0.63	0.78	2.40	21.2	193	1.93	1694	347	58	49	58	87	1.66
6b	40	0.49	1.07	2.09	20.3	167	2.18	633	186	67	65	50	65	1.80
7	40	0.55	0.73	1.90	21.0	250	1.58	166	280	55	66	40	49	2.15
8	25	0.53	0.74	1.46	23.5	200	1.00	125	275	45	36	20	33	1.63

1977 b) concentrations of zinc correspond to the percentages of carbonate, i. e. neither dilution nor enrichment by carbonates takes place; in Lake Constance, the zinc contents are characteristically enriched through the carbonate sediment fraction, and partly by authigenic co-precipitation processes. The copper values reveal no systematic trend; the carbonate-associated copper percentages lie between 2 % (Lake Bled) and 10 % (Lake Constance), indicating that a dilution of copper is brought about, in all studied cases, by the presence of carbonate. Since chromium reveals no association with carbonate, it could be expected that the dilution effect should be even more pronounced that in the case of copper.

The chemical associations of heavy metals in sediments of Lake Bled have been listed in table 23 (from data of G. Schmoll, Heidelberg). It is evident that a large portion of the contents of nickel and chromium, and to a lesser degree of copper and iron are fixed in relatively inert positions to organic and inorganic detritus. The latter fractions are assumed to consist mainly of resistant heavy minerals, such as silicates and oxides. A considerable amount of nickel, chromium, copper and manganese is associated with hydrous oxides, although the major carrier, the hydrous oxides of iron, contributes only 0.02 % to the total sediment composition. As it has been shown from other examples of lake sediments (G. Schmoll, 1977), the oxyhydrate phases — either as direct precipitates or as co-precipitates with hydrous Fe/Mn oxides — effectively accumulate certain trace elements from the aquatic environment. Enrichment of metals in humic substances seems to be particularly important for iron and zinc; for the latter metal example the contribution from sewage effluents must be taken into account.

Table 19. Mean values, standard deviation and variation coefficients of the metal data from pelitic fractions of the samples from Lakes Bled and Bohinj

BLEJSKO JEZERO (n=64)

	Mean values	Standard deviation		Variation coefficient
Li	25,1	± 10	ppm	40
Na	0,40	± 0,11	%	28
K	0,77	± 0,39	%	51
Mg	0,99	± 0,29	%	29
Ca	13,75	± 4,34	%	32
Sr	177	± 67	ppm	37
Fe	0,94	± 0,61	%	48
Mn	196	± 76	ppm	39
Zn	371	± 178	ppm	48
Cr	35,9	± 14,1	ppm	39
Ni	22,9	± 13,9	ppm	60
Cu	40,6	± 13,7	ppm	34
Pb	60,5	± 36,2	ppm	60
Cd	1,57	± 0,81	ppm	51

BOHINJSKO JEZERO (n=28)

	Mean values	Standard deviation		Variation coefficient
Li	40,4	± 10,5	ppm	26
Na	0,51	± 0,07	%	14
K	1,12	± 0,33	%	30
Mg	2,01	± 0,37	%	18
Ca	17,22	± 4,07	%	24
Sr	168	± 61	ppm	37
Fe	2,38	± 1,08	%	45
Mn	635	± 486	ppm	77
Zn	265	± 81	ppm	31
Cr	83,2	± 26,9	ppm	32
Ni	77,1	± 32,6	ppm	42
Cu	47,1	± 19,2	ppm	41
Pb	68,5	± 24,1	ppm	35
Cd	1,88	± 0,42	ppm	23

Table 20. **Correlation matrix for the metal contents in the pelitic fraction of sediments from Lake Bohinj**

BOHINJSKO JEZERO (n = 28)

	Li	Na	K	Mg	Ca	Sr	Fe	Mn	Zn	Cr	Ni	Cu	Pb	Cd
Li	x	-0.045	0.771	0.293	-0.729	0.008	0.859	0.365	0.288	0.803	0.775	0.167	0.368	0.612
Na	-0.045	x	-0.098	0.649	0.354	-0.016	-0.070	0.153	0.152	0.120	-0.001	-0.174	0.091	-0.062
K	0.771	-0.098	x	0.114	-0.846	-0.322	0.806	0.174	-0.198	0.830	0.946	-0.179	-0.088	0.367
Mg	0.293	0.649	0.114	x	0.079	-0.075	0.191	0.249	0.336	0.392	0.235	0.110	0.419	0.218
Ca	-0.729	0.354	-0.846	0.079	x	0.302	-0.776	-0.198	0.028	-0.697	-0.807	-0.010	-0.068	-0.515
Sr	0.008	-0.016	-0.322	-0.075	0.302	x	-0.167	0.132	0.248	-0.179	-0.289	-0.031	0.207	-0.138
Fe	0.859	-0.070	0.806	0.191	-0.776	-0.167	x	0.550	0.110	0.768	0.766	-0.015	0.328	0.537
Mn	0.365	0.153	0.174	0.249	-0.198	0.132	0.550	x	0.281	0.108	0.158	0.191	0.590	0.318
Zn	0.288	0.152	-0.198	0.336	0.028	0.248	0.110	0.281	x	0.054	-0.123	0.602	0.687	0.324
Cr	0.803	0.120	0.830	0.392	-0.697	-0.179	0.768	0.108	0.054	x	0.802	-0.132	0.140	0.441
Ni	0.775	-0.001	0.946	0.235	-0.807	-0.289	0.766	0.158	-0.123	0.802	x	-0.211	-0.120	0.470
Cu	0.167	-0.174	-0.179	0.110	-0.010	-0.031	-0.015	0.191	0.602	-0.132	-0.211	x	0.595	0.092
Pb	0.368	0.091	-0.088	0.419	-0.068	0.207	0.328	0.590	0.687	0.140	-0.120	0.595	x	0.251
Cd	0.612	-0.062	0.367	0.218	-0.515	-0.138	0.537	0.318	0.324	0.441	0.470	0.092		x

Once underlined > 95 % probability; doubly underlined > 99 % probabilitiy

Table 21. **Correlation matrix for the metal contents in the pelitic fraction of sediments from Lake Bled**

BLEJSKO JEZERO (n = 54)

	Li	Na	K	Mg	Ca	Sr	Fe	Mn	Zn	Cr	Ni	Cu	Pb	Cd
Li	x	0.331	0.916	0.627	-0.327	0.194	0.868	0.547	-0.094	0.667	0.768	0.251	-0.167	-0.358
Na	0.331	x	0.290	0.511	0.604	0.426	0.209	0.495	-0.151	0.218	0.276	-0.019	-0.294	-0.502
K	0.916	0.290	x	0.548	-0.345	0.049	0.859	0.519	-0.277	0.488	0.751	0.147	-0.298	-0.402
Mg	0.627	0.511	0.548	x	0.212	0.526	0.632	0.541	0.190	0.593	0.560	0.439	0.023	-0.124
Ca	-0.327	0.604	-0.345	0.212	x	0.324	-0.392	0.229	-0.085	-0.131	-0.208	-0.091	-0.158	-0.248
Sr	0.154	0.426	0.049	0.526	0.324	x	0.148	0.142	0.359	0.354	-0.004	0.462	0.248	0.039
Fe	0.868	0.209	0.859	0.632	-0.392	0.148	x	0.617	0.110	0.659	0.887	0.404	0.093	-0.114
Mn	0.547	0.495	0.519	0.541	0.229	0.142	0.617	x	-0.068	0.505	0.818	0.235	-0.075	-0.239
Zn	-0.094	-0.159	-0.277	0.190	-0.085	0.359	0.110	-0.068	x	0.304	0.035	0.680	0.849	0.654
Cr	0.667	0.218	0.488	0.593	-0.131	0.354	0.659	0.505	0.304	x	0.654	0.457	0.280	-0.032
Ni	0.768	0.276	0.751	0.560	-0.208	-0.004	0.887	0.818	0.035	0.654	x	0.331	0.030	-0.151
Cu	0.251	-0.019	0.147	0.439	-0.091	0.462	0.404	0.239	0.680	0.547	0.331	x	0.571	0.367
Pb	-0.167	-0.294	-0.298	0.023	-0.158	0.248	0.093	-0.075	0.849	0.280	0.030	0.571	x	0.695
Cd	-0.358	-0.502	-0.402	-0.124	-0.248	0.039	-0.114	-0.235	0.654	-0.032	-0.151	0.367	0.695	x

Once underlined > 95 % probability; doubly underlined > 99 % probability

Table 22. **Carbonate-associated heavy metals in Lake Bled and other lakes: examples from Europe (Cc: calcite; MgC: high-magnesium calcite; Dol: dolomite). From R. Deurer et al. (1978)**

	carbonate (%)	carbonate species (%) Cc	MgC	Dol	Fe	Mn	Zn	Cu	Cr
					in carbonate association percent of total metal phases				
Lake Constance	28	20	-	8	7	62	43	10	0
Neusiedler See	37	-	12	25	10	34	15	4	0
Lake Ohrid	44	44	-	-	10	55	43	8	<1
Lake Balaton	55	-	41	14	20	68	13	5	0
Lake Bled	72	70	-	2	26	46	67	12	0

Table 23. **Metal concentrations (Fe in %, other metals in ppm) and percentages of metal associations (*organic and inorganic residues + sulfides) in a sediment sample from the central part of the eastern basin of Lake Bled (data from G. Schmoll, 1977)**

Metal	Total metal conc.	Sorption + H_2O-soluble conc.	%	Humic Substances conc.	%	Hydrous oxides conc.	%	Carbonate fraction conc.	%	Residual* fraction conc.	%
Fe	2.54 %	0.4 %	16	0.5 %	20	0.13 %	5	0.67 %	26	0.84 %	33
Mn	176 ppm	22 ppm	12	6.5 ppm	4	40 ppm	23	80 ppm	46	27 ppm	15
Zn	162	6.0	4	17.8	11	2	1	108	67	30	18
Cu	17.4	4.0	23	0.4	2	4.0	23	2.0	12	7.0	40
Cr	11.0	0.8	7	0.4	3	2.3	21	0	0	6.6	69
Ni	6.0	0.2	3	0.2	3	2.0	33	0.2	3	4.0	67
Composition of the sample:				4.7 % org.subst.		0.02 % FeOOH		72 % carbonate		23 % residues	

8. Summary and conclusions

The sedimentological and environmental conditions of the Alpine border lakes of Bled and Bohinj presented here are part of a general program on Recent fluviatile and lacustrine sediments of Slovenia. This program was started in 1975, and problems of the Sava-river pollution and the Moste-dam have been studied since.

This time a working group was engaged to sample the lake sediments and to examine them from the mineralogical and geochemical points of view. 15 grab samples and two core profiles (25—45 cm in depth) were taken from Lake Bled, and 8 grab samples and one core from Lake Bohinj. A brief geological and palynological survey of the surroundings of the lakes was carried out to delineate the origin of the sedimentary material and its pollen contents. The Bled sediment abounds in sewage and the lake water is characterized by dissolved plant nutrients and by the seasonal deficiency of oxygen in its hypolimnion. Thereby it becomes eutrophic. To overcome this disturbance of the natural conditions a pipeline has been constructed to convey water of the Radovna river into Lake Bled. Lake Bohinj, however, owes its biological equilibrium to a natural through-flowing stream. The results of the Lake Bohinj sediments are therefore particularly helpful as natural background data for pollution problems in Slovenia. Lake Bohinj should be noted, namely, for its rather high iron, manganese, chromium and nickel contents. Their origin has not been explained as yet.

In the Lake Bled sediment calcareous silt and clay prevail associated with dolomite and organic admixture. The upper most 10 cms shows a laminated structure due to the alternation of inorganic and organic matter. Total carbonate contents of 56 samples are in the range of 55—79 %, and are essentially the same in grab samples and core samples. Calcite prevails but dolomite may occasionally amount up to 38 % of the carbonate fraction. The noncarbonates appear to be mostly diatoms, besides some quartz and traces of feldspar and clay minerals. Near surface sediments from all parts of Lake Bled exhibit an apparent odor from the decay of abundant waste matter from sewers.

In the Lake Bohinj sediment total carbonate content ranges from 53 to 91 percent. Calcareous silt is indeed the prevalent constituent but dolomite content is higher compared to Lake Bled; it amounts locally to 69 %. Dolomite is clearly detrital and is transported to the lake by its affluents whereas a small amount of the low magnesium calcite may also be autochthonous, particularly in the very shallow southern part. The non-carbonate sediments are essentially similar to the Lake Bled sediment, including also very well preserved diatoms. The content of organic substances within Lake Bohinj is much lower than within Lake Bled.

Since both lakes are shallow (maximum depth about 40 m) and their surroundings consist essentially of Triassic carbonate rocks, most of the Recent carbonate sediments are supposed to be detrital. This is apparent for dolomite, but some calcite may also be autochthonous due to activity of plants.

In general the Lake Bled sediment is more fine grained in comparison to that of Lake Bohinj. Clayey matter tends to prevail in it, while silt is more widespread in Lake Bohinj. Sedimentation rates appear to be higher in Lake

Bohinj than in Lake Bled. The present study has revealed distinct human effects on the metal composition of the sediments from Lake Bled. A typical increase of lead, zinc and cadmium towards the youngermost layers strongly point to the influence of major inputs of sewage materials, which are most probably derived from the community of Bled. These effluents are considered to be responsible for the increased eutrophication during the last decades. Eutrophication seems to be delayed since fresh water is conveyed from Radovna river to the lake, although it is still continuing at a lower rate. With respect to these problems, further evidence should be gained from additional studies on the contents of nutrient elements, such as phosphorus, nitrogen, and organic carbon, as well as from the distribution patterns of contaminants other than heavy metals, e. g. synthetic organic substances.

Further studies of the mineralogical and geochemical aspects of the lake sediments should be based on a more closely-knit net of grab samples and on sediment cores. The latter would be particularly useful to elucidate the geological history of both lakes, e. g. by pollen chronology.

9. Acknowledgements

We are particularly indebted to the Research Council of Slovenia, Jesenice Iron and Steel Works, and Geological Survey Ljubljana for supporting this research project. The financial aid for metal analyses in the program "Geochemistry of Trace Substances in the Environment" was provided by the Deutsche Forschungsgemeinschaft.

We are obliged to the Boris Kidrič Chemical Institute Ljubljana for the aid given during the field work and the providing of presented limnological data, and to J. Podobnik for technical help and for the analyses of the lake waters. Thanks must be extended to A. Brezigar and to S. Zakrajšek for the assistance during the sediment sampling. The sieving analyses were carried out by Z. Germovšek, and the sedimentation analyses by V. Kogovšek.

Grateful thanks are to Professor Dr. G. Müller from Heidelberg University for kindly provided laboratory facilities.

The chemical analyses in chapter 7 of the lake sediments were conducted by I. Krüll from Heidelberg University. Data for the section on metal associations have been provided by R. Deurer and G. Schmoll. Chemical analyses of interstitial water were carried out by D. Reinhard. M. Gastner and H. Weiss (Heidelberg), helped with the scanning electron miroscopy.

Our thanks for translation and improving the English version of the manuscript go to N. Klupsch (Swansea, presently Mannheim). For the translation of the Chapter 7 we are obliged to D. Godfrey. The writers are very grateful to N. Sosič (Ljubljana) for translating from Slovene into English.

10. References

Allan, R. J., 1974, Metal contents of lake sediment cores from established mining areas: an interface of exploration and environmental geochemistry. Geol. Surv. Canada Paper 74-1-B, 43—59.

Anderson, T. W. 1973, Historical evidence of land use in a pollen profile from Osoyoos Lake, British Columbia. Geol. Surv. Canada Paper 73-1-A, 178—180.

Bonatti, E., Fisher, D. E., Joensuu, O. & Rydell, H. S. 1971, Post-depositional mobility of some transition elements, phosphorous, uranium and thorium in deep sea sediments. Geochim. Cosmochin. Acta, 35, 189—201.

Deurer, R., Förstner, U. & Schmoll, G. 1978, Selective chemical extraction of carbonate-associated metals from recent lacustrine sediments. Geochim. Cosmochim. Acta. 42, 425—427.

Duthie, H. C. & Sreenivasa, M. R. 1971, Evidence for the eutrophication of Lake Ontario from the sedimentary diatom succession. Proc. 14 th Conf. Great Lakes Res., 1—13.

Engler, R. M., Brannon, J. M. & Rose, 1974, A practical selective extraction procedure for sediment characterization. Techn. Paper 168th Meeting ACS, Atlantic City. 15 pp.

Erlenkeuser, H., Suess, E. & Willkomm, H. 1974, Industrialization affects heavy metal and carbon isotope concentrations in recent Baltic Sea sediment. Geochim. Cosmochim. Acta, *38*, 823—842.

Fabiani, R., Leonardi, P., Kossmat, F., Winkler, A. 1937, Carta geologica delle tre Venezie—Tolmino, 1 : 100 000; Firenze.

Förstner, U. 1976, Lake sediments as indicators of heavy metal pollution. Naturwiss. *36*, 465—470, Berlin.

Förstner, U., 1977 a (in print), Metallgehalte in rezenten lakustren Sedimenten — natürliche background Werte und zivilisatorische Effekte. IHP-Publikation No. 2, Koblenz.

Förstner, U. 1977 b, Metal concentrations in recent lacustrine sediment. Arch. Hydrobiol. *80*, 172—191.

Förstner, U. & Müller, G. 1973, Heavy metal accumulation in river sediments: a response to environmental pollution. Geoforum *14*, 53—61.

Förstner, U. & Müller, G. 1974, Schwermetalle in Flüssen und Seen. Springer Verlag, Berlin.

Gradnik, R. 1946, Toplinski odnošaji v Blejskem in Bohinjskem jezeru. Geograf. vestnik *18*, 94—125, Ljubljana.

Grimšičar, A. 1955, Zapiski o geologiji Bleda (Notes on the geology of Bled). Geologija *3*, 220—225, Ljubljana.

Håkanson, L., 1977, Sediments as indicators of contamination — investigations on the four largest Swedish lakes. Naturvardsverkets Limnologiska Undersökning Rapport *92*, 159 pp.

Hellmann, H. 1972, Herkunft der Sinkstoffablagerungen in Gewässern. Deutsche Gewässerkundl. Mitt. *16*, 137—141.

Hutchinson, G. E. & Wollack, A. C. 1940, Studies on Connecticut lake sediments. II. Chemical analyses of a core from Linsley Pond. Amer. J. Sci. *238*, 493—517, New Haven.

Kemp, A. L. W., Anderson, T. W., Thomas, R. L. & Mudrochova, A. 1974, Sedimentation rates and recent sediment history of Lake Ontario, Erie and Huron. J. Sediment Petrol. *44*, 207—218.

Kemp, A. L. W., Thomas, R. L., Dell, C. I. & Jaquet, J. M. 1976, Cultural impact on the geochemistry of sediments in Lake Erie. J. Fish. Res. Bd. Canada, *33*, 440—462.

Kindle, E. M. 1932, Lacustrine concentrations of manganese. Amer. J. Sci. *24*, 496—504, New Haven.

Kuščer, D. 1955, Prispevek h glacialni geologiji radovljiške kotline (Beitrag zur Pleistozängeologie des Beckens von Radovljica). Geologija *3*, 136—150, Ljubljana.

Leshniowsky, W. O., Dugan, P. R., Pfister, R. M., Frea, J. I. & Randles, C. I. 1970, Adsorption of chlorinated hydrocarbon pesticides by microbial floc and lake sediment and its ecological implications. Proc. 13 th Conf. Great Lakes Res., 611—618.

Livingstone, A. & Boykin, J. C. 1962, Vertical distribution of phosphorous in Linsely Pond mud. Limnol. Oceanogr. *7*, 57—66.

Lloyd, R. M. 1954, A technique for separating clay minerals from limestones. J. Sedim. Petrol., *24/3*, 218, Menasha (Wisc).

Mackenzie, F. T., Garrels, R. M., Bricker, O. P., and Bickley, F. 1967, Silica in sea water: Control by silica minerals: Science, *155*, 1404—1405, Washington.

Mortimer, C. H. 1941, The exchange of dissolved substances between mud and water in lakes. J. Ecol. *29*, 280—329.

Müller, G. 1966, Die Sedimentbildung im Bodensee. Naturwiss. *53*, 237—247, Berlin.

Müller, G. & Gastner, M. 1971. The "Karbonat-Bombe", a simple device for the determination of the carbonate content in sediments, soils, and other materials. N. Jb. Miner., Mh., J. *1971*/H.10, 466—469, Stuttgart.

Müller, G., Irion, G. & Förstner, U. 1972, Formation and Diagenesis of Inorganic Ca-Mg Carbonates in the Lacustrine Environment. Naturwiss. *59*, 158—164, Berlin.

Murray, R. C. 1956, Recent sediments of three Wisconsin Lakes. Bull. Geol. Soc. Amer. *67*, 833, Burlington (Vermont).

Nipkow, H. F. 1920, Vorläufige Mitteilungen über Untersuchungen des Schlammabsatzes im Zürichsee. Ztschr. Hydrol. (Aarau), 1—23.

Ohle, W. 1956, Die Seen als Opfer der Abwasserkalamität. Ber. Abwassertechn. Ver. 1956, 268—276.

Rejic, M. 1973, Radovi i efekti na sanaciji Bledskog jezera (A brief survey of reconditioning and sanating the Lake of Bled). Vodoprivreda, *5*, 25, 1973, Beograd, 363—370.

Rossman, R. & Callender, E. 1968, Manganese nodules in Lake Michigan. Science *162*, 1123—1124, Washington.

Schöttle, M. 1969, Die Sedimente des Gnadensees. Ein Beitrag zur Sedimentbildung im Bodensee. Arch. Hydrobiol. Suppl. *35/3*, 255—308, Stuttgart.

Schmoll, G., 1977, Untersuchungen über die Bindungsarten der Schwermetalle Eisen, Mangan, Zink, Kupfer, Chrom, Nickel und Kobalt in rezenten karbonatreichen Seesedimenten. Diplom-Arbeit am Institut für Sedimentforschung der Universität Heidelberg.

Solomon, A. M. & Kroener, D. F. 1971, Suburban replacement of rural land uses reflected in the pollen rain of northeastern New Jersey. Bull. New Jersey Acad. Sci. *16*, 30—44.

Stockner, J. G. & Benson, W. W. 1967, The succession of diatom assemblages in the recent sediment of Lake Washington. Limnol. Oceanogr. *12*, 513—532, Lawrence (Kans.).

Stoffers, P. 1975, Recent carbonate sedimentation in the lakes of Plitvice (Yug.). N. Jb. Miner. Mh., J. *1975*, H. 9, 412—418, Stuttgart.

Suess, E. 1977, How can we distinguish between natural and anthropogenic materials in sediments and can we predict the effects of man's additions? — SCOR/UNESCO Workshop on the Biogeochemistry of Estuarine Sediment, Melreux, Nov. 29.-Dec. 3, 1976 (in press).

Šercelj, A. 1970, Würmska vegetacija in klima v Sloveniji, Razprave SAZU, *13*/7, Ljubljana, 211—249.

Šercelj, A. 1971, Postglacialni razvoj gorskih gozdov v severozahodni Jugoslaviji (Die postglaziale Entwicklung der Gebirgswälder im nordwestlichen Jugoslawien). Razpr. 4. r. SAZU, *14*/9. Ljubljana.

Šercelj, A. 1975, Razvoj in zgodovina gozdov v škofjeloškem hribovju (Die Entwicklungsgeschichte der Wälder im Bergland von Škofja Loka). Loški razgledi *22*, Ljubljana.

Štern, J. & Förstner, U. 1976, Heavy metals distribution in the sediment of the Sava Basin in Slovenia. Geologija *19*, 259—274, Ljubljana.

Thomas, R. L. 1972, The distribution of mercury in the sediment of Lake Ontario. Can. J. Earth Sci. *9*, 636—651.

Vetters, H. 1935, Manuskriptna geološka karta Radovljice (Radmansdorf) 1 : 75 000, (po podatkih F. Tellerja, F. F. Kossmata, F. Härtla in O. Ampfererja).

Vrhovšek, D. & Brezigar, A. 1976, Ocena naplavin, ki zasipavajo Blejsko jezero. Naše okolje *1*, 5, 209—213, Ljubljana.

Vuorela, I. 1970, The indication of farming in pollen diagrams from southern Finland. Acta Bot. Fennica, *87*, 1—140, Helsinki.

Wagner, G. 1972, Stratifikation der Sedimente und Sedimentationsrate im Bodensee. Verh. Internat. Verein Limnol. *18*, 475—481.

Wedepohl, K. H. 1972, Solubilities of compound which control concentrations of zinc in natural water (I); adsorption processes (II). In: Handbook of Geochemistry (Ed. By K. H. Wedepohl), *33-H*, 1—14, Springer Verlag, New York.

Whiteside, M. C. 1965, Paleoecological studies of Potato Lake and its environment. Ecology *46*, 807—821.

Zingg, Th. 1935, Beitrag zur Schotteranalyse, Schweiz. Min. u Petr. Mitt., Bd. *15*, 39—140.

Züllig, H. 1956, Sedimente als Ausdruck des Zustandes eines Gewässers. Schweiz. Ztschr. Hydrol. *18*, 7—143.