Recent sediment of Lake Bled (NW Slovenia)

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Abstract: Sediment cores collected in eutrophic subalpine Lake Bled (NW Slovenia) were analyzed sedimentologically in terms of grain size, mineralogy and sedimentation rates, and geochemically in terms of nutrients and metals. Increasing eutrophication and pollution of the lake started almost 100 years B.P., and especially since 50 years B.P.

Key words: lacustrine sediments, pollution, Lake Bled, Slovenia

Introduction

Lake Bled (Fig. 1) is, according to the thermal classification of lakes, a warm eumictic subalpine lake with anoxic hypolimnion developed most of the year below a depth of 15 m (Molnar et al., 1978). The hypolimnion temperature ranges between 4-8 °C. The input of nutrients causes the eutrophication of the lake evidenced by the sporadic appearance of blooming algae *Oscillatoria rubescens* (Vrhovšek et al., 1984). The inflows are two small streams, Mišca and Solznik, in the west while the water outflow proceeds through the Jezernica stream to the river Sava. Two amelioration projects were undertaken in the past: a fresh water inflow was diverted from the river Radovna and a syphonic pumping of anoxic bottom water. Hence, the mean water residence time dropped to about 1 year. The lake hinterland (Straža hill) is composed of Permian limestone and Anisian dolomite (Buser and Cajhen, 1978) while the surroundings of Zaka bay are composed of Ladinian clastic rocks. The eastern surroundings of the lake comprise morena from the Wurm glacial period. Forty-two sediment cores were used to study the sedimentological and geochemical properties of the lake.

Sedimentology

The surficial (2-3 cm deep) sediment is composed of a dark clayey gyttja type silt with up to 10 % of organic matter. The sediment below is more compact with fine lamination. Below a depth of 5 cm it consists of homogenous silt and clayey silt with a mean grain size of 5-10 μm. The content of the clayey fraction varies between 30 and 40 %. In the mineral composition, carbonate detrital grains prevail (55-90 %) mostly composed of low Mg calcite (up to 5 mol % of $MgCO_3$). Other minerals are quartz (up to 15 %), and feldspars (up to 8 %). Among clay minerals (up to 15 %), muscovite/illite and chlorite prevail. The quartz is mostly of detrital origin though, in part, is also of diatomaceous provenance. Sandy grains (>63 μm) are very rare. Sediments are locally inhabited by

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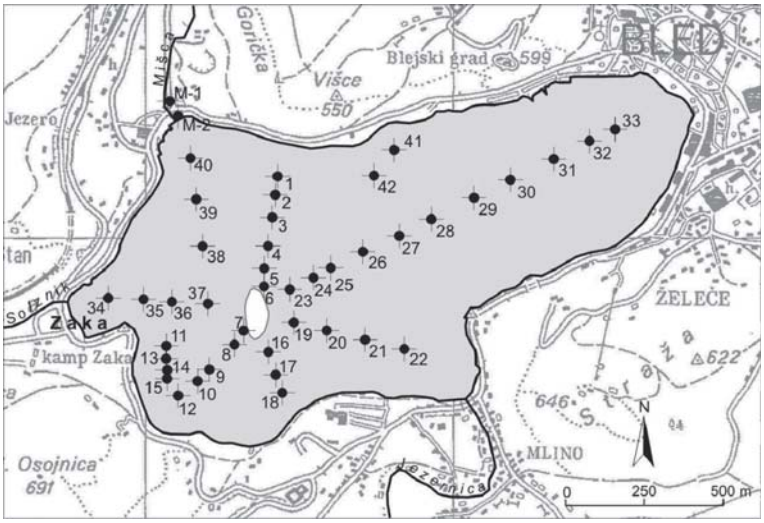

Figure 1. Location of sampling points in lake Bled

clams *Anodonta cygnaea* and pelecypod *Planorbis planorbis*. In the shallow Zaka bay, authigenic lake chalk is formed (DOLENEC ET AL., 1984) containing >98 % of carbonate (low Mg-calcite) with a mean grain size of about 10 μm. The precipitation of calcite is mediated by production of benthic macrophytes and phytoplankton. The mean ^{137}Cs and ^{210}Pb recent sedimentation rates for the western and eastern depressions are 2.4 mm/yr and 1.2 mm/yr, respectively (ČERMELJ ET AL., 1996). Higher sedimentation rate in the western depression is the result of higher particulate matter input from the Mišca and Solznik streams. In comparison, the mean Holocene sedimentation rate of 0.5 mm/yr was estimated in the eastern depression from palynological data (SHULTZE, 1984).

GEOCHEMISTRY

The geochemical properties and contamination (pollution) of recent lake sediment were studied in terms of the occurrence and origin of Al, Ba, Ca, Cd, Co, Cr, Cu, Fe, Na, K, Li, Mg, Mn, Ni, Pb, Sr, V, Zn, Be, La, Mo, organic C, and total N and P. The areal distribution of all studied elements shows higher concentrations in the northwestern and eastern lake sediments due to the input of detrital material by inflows (streams and discharges). The enrichment factors (EF) and, consequently, the degree of pollution of lake sediments were determined on the basis of calculated differences between the normalized element concentrations versus Al, being one of the most abundant elements in the lake sediment, were measured at the surface and in the deepest layers in some longer sediment cores. Pb and Zn are enriched in most sediment cores while Pb (EF=16.7) and Cd (EF=19.1) show the highest surficial enrichment factors. From metal accumulation rates, calculated from ^{210}Pb and ^{137}Cs sedimentation rates, porosity (0.90), density (2.5 g/cm^3) and surficial element contents, it appears that Pb, Zn and P exhibit the highest positve deviations from the mean accumu-

lation rate of each specific element suggesting an anthropogenic origin. Vertical sediment profiles showed increasing contents of Pb, Zn, Cr, V, and total N and P in the upper 10 cm of the core, i.e. in the last approx. 100 years, as well as Cd and Cu in the upper 5 cm of the core, i.e. in the last approx. 50 years. These results reflect increasing pollution and eutrophication over the last 100 years and especially over the last 50 years. Black carbon contents also began to increase about 50 years B.P. (Muri et al., 2002).

The studied elements can in general be divided according to their properties and quantities into carbonate bonded (Ca, Mg), nutrient (organic C, total N and P), mobile (Fe, Mn), lithogenic (Al, Ba, Cr, Li, K, Na, La), enriched (Cd, Co, Cu, Ni, Pb, Zn) and miscellanous (Sr, V, Be). The investigated elements are mostly of lithogenic origin with the exception of enriched elements, except Ni, which are partly of anthropogenic origin, and nutrient elements which are mostly of biogenic and anthropogenic origins. The presence of lithogenic elements is connected to the erosion of the shore rocks and to the input of detrital material into the lake by fresh water discharges and wind. Those of biogenic origin are connected with the primary production and subsequent degradation of sedimented organic matter (Čermelj and Faganeli, 2003). The origin of sedimentary $C_{org.}$ is according to $\delta^{13}C_{org.}$ data, averaging -33 ‰, mostly from deposited phytoplankton debris while the bacterial component seems also quantitatively important (Čermelj et al., 1996; Lojen et al., 1999; Ogrinc et al., 2002). The anthropogenic elements are a consequence of the use of natural (organic C, total N and P) and artificial (total N and P, K and Co) fertilizers, detergents (total P) and fossil fuels (mainly Cd, Pb and Zn) carried into the lake mostly in detrital form.

Lake sediments represent a valuable source of information for reconstructing nutrient and pollutant records. This information could be used to establish the relative levels of contemporary nutrients and pollutants in sediment and to identify long-term trends of eutrophication and pollution.

References

Buser, S., Cajhen, J. (1978): Osnovna geološka karta SFRJ 1:100000, list Celovec (Klagenfurt). Zvezni geološki zavod, Beograd.

Čermelj, B., Faganeli, J. (2003): Anoxic degradation of biogenic debris in sediments of eutrophic subalpine Lake Bled (Slovenia). *Hydrobiologia* 494: 193-199.

Čermelj, B., Faganeli, J., Ogorelec, B., Dolenec, T., Pezdič, J., Smodiš, B. (1996): The origin and recycling of sedimented biogenic debris in a subalpine eutrophic lake (Lake Bled, Slovenia). *Biogeochemistry* 32, 69-92.

Dolenec, T., Pezdič, J., Ogorelec, B., Mišič, M. (1984): The isotopic composition of oxygen and carbon in the recent sediment from the lake Bled and of Pleistocene lacustrine chalk from the Julian Alps. *Geologija* 27, 161-170.

Lojen, S., Ogrinc, N., Dolenec, T. (1999): Decomposition of sedimentary organic matter and methane formation in recent sediment of lake Bled (Slovenia). *Chem. Geol.* 159, 223-240.

Molnar et, F. M., Rothe, P., Forstner, U., Štern, J., Ogorelec, B., Šercelj, A., Culiberg, M. (1978): Lakes Bled and Bohinj; Origin, composition and pollution of recent sediments. *Geologija* 21, 93-164.

MURI, G., ČERMELJ, B., FAGANELI, J., BRANCELJ, A. (2002): Black carbon in Slovenian alpine lacustrine sediments. *Chemosphere* 46, 1225-1234.

OGRINC, N., LOJEN , S., FAGANELI, J. (2002): A mass balance of carbon stable isotopes in an organic-rich methane-producing lacustrine sediments (Lake Bled, Slovenia). *Global & Planet. Change* 33: 57-72.

SHULTZE, E. (1984): Contribution to paleolimnology of the Lake Bled, Slovenia, and to evolution of adjoining vegetation and climate. *Geologija* 27, 97-106.

VRHOVŠEK, D., ZUPAN, M., BLEJEC, A. (1984): The occurrence of *Oscillatoria rubescens* in Lake Bled. *Biol. Vestn.* 32, 45-56.