Rexhep KOÇI*, Salvator BUSHATI**, Agim MESONJESI***,
Christian BECK****, Aurélien VAN WELDEN****

SEDIMENTARY ACCUMULATION IN THE LARGE SHALLOW SHKODRA LAKE

Përmbledhje: Liqeni i Shkodrës ndodhet në pjesën veri-perëndimore të Shqipërisë dhe në perëndim të Alpeve Shqiptare. Është një liqen natyral me një sipërfaqe prej 5180 km^2 në basenin ujë-mbajtës dhe me një lartësi mesatare prej 770 m mbi nivelin e detit. Kjo tregon që dhe pse është një liqen në veri të vijës bregdetare dhe një liqen i thjeshtë, ujërat e tij akumulohen nga një territor malor natyor. Sedimentët e Liqenit të Shkodrës shtrihen në një bazament karbonati, ku një fenomen karstik është zhvilluar gjerësisht. Nëpërmjet një miniplatforme, një numër i konsiderueshëm mostrash janë përftuar nga sedimentet e Liqenit të Shkodrës. Këto mostra janë ekzaminuar përsa i takon përmbajtjes së tyre litologjike dhe granulometrike dhe përsa i takon ritmit sedimentar për investigimin e ngjarjeve sizmike. Ekzaminimi i masës së kokrrës me përmbajtje karboni dhe profile të aktivitetit radionuklid ^{210}Pb, ^{137}Cs, ^{241}Am është i dobishëm për gjetjen dhe datimin e ndryshimeve klimaterike në periudha të ndryshme kohore.

Fjalët kyç: *Liqeni i Shkodrës, pleistoceni i mesëm, holocen, karbon (^{14}C), radioaktiviteti ^{210}Pb, ^{137}Cs, ^{241}Am.*

Abstract: Shkodra Lake is situated in the north-western part of the territory of Albania and west of the Albanian Alps. It is a plain lake of 5180 km^2 surface in its water-bearing basin, and with a mean altitude of 770 m. above the sea level. This shows that, although it is a lake north of the coastal littoral and a plain lake as well, its waters are accumulated from a territory mountainous in nature. Sediments of the Shkodra Lake lay on a carbonate basement, where a carst phenomenon is widely developed. By means of a mini platform, a considerable number of samples have been obtained from the sediments of the Shkodra Lake. These samples were examined as to their lithological and granulometric content, and to their sedimentary rhythm, for the investigation of old seismic events as well. Examination of

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* Rexhep Koçi, Department of Seismology and Seismic Engineering, Institute of Geosciences

** Salvator Bushati, Academy of Sciences of Albania

*** Agim Mesonjesi, DWM Petroleum A. G., Tiranë, Albania

**** Christian Beck, Aurélien Van Welden, Laboratoire de Géodynamique des Chaînes Alpines, Université de Savoie, France

grain size, of carbon content and of the profiles of the radionuclide activity of ^{210}Pb, ^{137}Cs, ^{241}Am has been helpful for finding and dating the environmental changes in various periods of time.

Key words: *Shkodra Lake, Middle Pleistocene, Holocene, carbon 14 (^{14}C), Radioactivity ^{210}Pb, ^{137}Cs, ^{241}Am*

INTRODUCTION

Shkodra Lake is of the greatest size in the Balkan Peninsula. It is 48 km in length and 15 km in width, up to 26 km. width in some cases. Its depth goes between 5 and 7 meters (Fig. 3). The surface of water-bearing basin is changeable, its stable surface being 368 km^2, of which 149 km^2 are within Albanian territory, and the rest within the Montenegro territory (Fig. 1).

The lake size varies depending on precipitations. With abundant rains, especially during fall, winter and spring months, water level in Drini and Buna rivers ris-

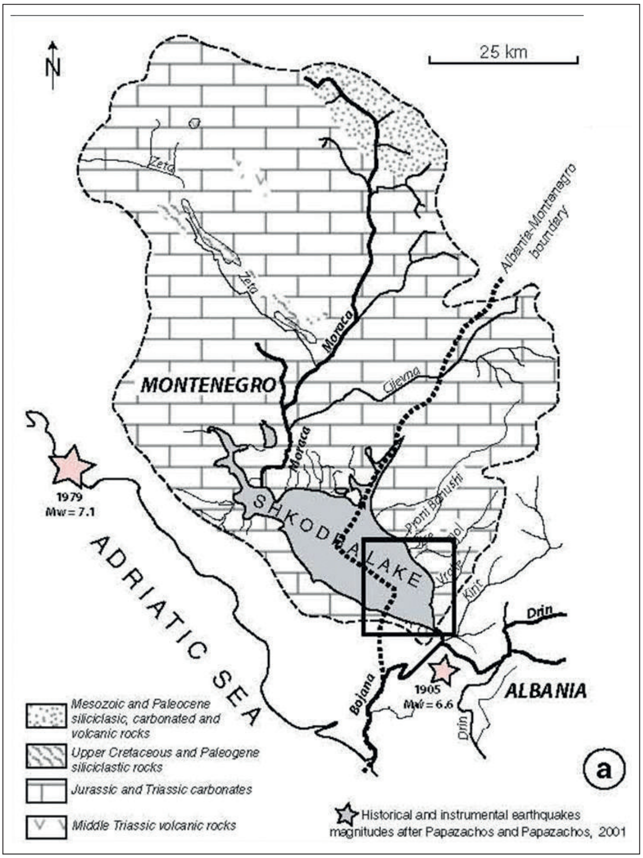

Figure 1. Map of water-bearing basin for the Shkodra Lake

es, which make the lake level rise 2 m. above the normal position. Such a phenomenon was observed in 1962–63 and some other year, and more recently in 2010. Maximum depth of Shkodra Lake is 44 m., and it is outside Albanian territory. When maximum rise of level occurs, its surface comes to 542 km^2, covering part of the Upper Shkodra plain and some of the north-western area of the Shkodra town as well (Koçi, 2004). Area round the Shkodra Lake is confined on all sides by tectonic faults aged Middle Pleistocene-Holocene (Fig. 2a). Tectonics developed in the lake zone shows that Shkodra Lake is of tectonic origin. Those faults are very active, as proved by lots of seismic events occurred in the Shkodra Lake area, in the past and in recent times as well (Fig. 2b).

An Albanian-French NATO Project (*Science for Peace* 977 993) was carried out for the assessment of seismic hazards, combining morphotectonic, seismologic and geodetic research, with a view of finding possible traces of earthquakes verified within lake sediments. To assess impacts of this kind, detailed paleo-environmental examinations were carried out, using well-known classic parameters. As to the period of investigation, it was between 5th and 7th centuries BC, depending on the position of sampling; and the length of samples obtained was from 90 cm to 8 m. Special attention was devoted to the last century (where thickness of sediments varies between 20 to 40 cm) for two reasons:

1. This interval involves well-known historically registered earthquakes.
2. Radioactivity of ^{210}Pb and ^{137}Cs allows an accurate chronological control over the sediment rhythms.

GEOLOGY, HYDROLOGY AND SEISMOLOGY OF SHKODRA LAKE AREA

Water-bearing basin of the lake has been developed by limestone formations of the tectonic zone of Alps and Cukali Mountains. Carbonate deposits of the Alps zone are of a wide age range, starting from Upper Triassic (T_3) and going on with those of Jurassic ($J_{1–2-3}$) and the Lower Cretaceous (Cr_1) (Fig. 1). In the carbonate deposits of the Alps area, an intense karst phenomenon has been developed, and that's why the zone often is called as a zone of high carst. In the lake area, deposits of Cukali zone occur in a more limited way. They are observed in the southern part of the lake and of the Upper Shkodra area, and are mostly flysch deposits aged Upper Cretaceous (Cr–2 m)-Paleocene.

In the north and north-eastern part, where karst phenomenon is most developed, there occur powerful water springs, like those called Syri i Sheganit (Shegan's Eye), Viri, Kozhnja and Rrjolli Springs etc.

Around the lake, where breccia deposits are concentrated, subterraneous drainage of infiltration water is most developed. It is a phenomenon best observed in water wells digged in gravel deposits and in breccia situated on slopes in the vicinity of lakeside, as in the village of Shiroka and the town of Koplik.

Several streams and rivers feed the lake with water. From outside Albanian territory, abundant quantities of water flow into the lake by the Moratsha River and its

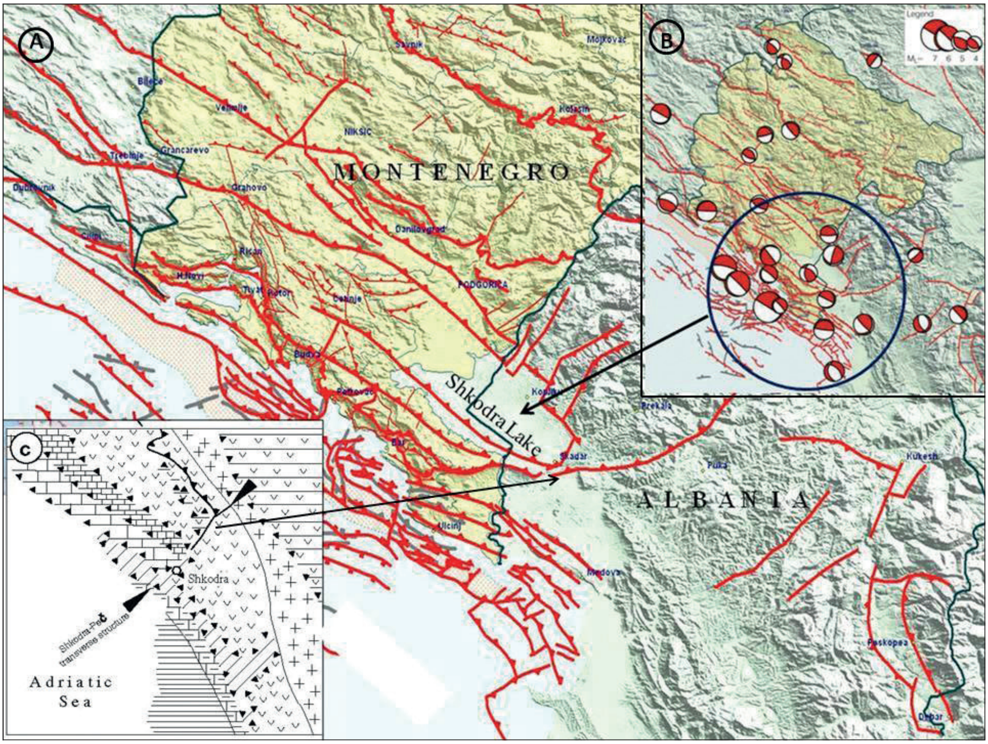

Figure 2. Geodynamics of Shkodra Lake area. a – Map of active tectonic faults, Gllavatovci 2010 and Aliaj 2000. – Map of seismic activity. c – Geological structural after Aubouin 1974.

affluents, Zeta and Tsemi. Moratsha River is the main contributor, with 62 % of all the water that flows into the Shkodra Lake (Weden *et al.,* 2008). On Albanian side, there are several streams of periodic load into the lake, such as Përroi i Thatë, Përroi i Banushit, Përroi i Rrjollit, Përroi i Vrakës (Dry, Banushi, Rjolli, Vraka streams). The last is the only stream to flow water into the lake throughout the year

Water discharge from the lake occurs by way of Buna River. Calculations made show that about 10 km^3 water moves through Buna River within a year time (Geço, 1961).

Tectonically, Shkodra Lake area is situated in the western sector of the great Shkodra-Peja fracture, which separates Dinarides from Albanides. In general, this fracture is not very active, but in certain sections, like that of Shkodra-Buna river mouth, it shows high seismicity (Fig. 2b).

Besides events of low and constant seismicity, caused mainly by changes in the level of subterraneous waters (Muço, 1998, 1999), some rare, yet strong and disastrous earthquakes have occurred in Albania (Muço *et al*., 2002; Duni *et al*., 2003). There were two quakes in 1905 and 1979, magnitude 6.6 (epicentres shown in fig. 2 b), that caused destruction and victims in the town of Shkodra (Duni *et al*., 2003; Sulstarova *et al*., 2003; Koçiaj & Sulstarova, 1980). The June 01 1905 quake was of a high intensity (IX by MSK–64 scale) and with a number of aftershocks (600 within a year). Earth conditions were of a considerable impact on the observed intensity (Koçiaj & Sulstarova, 1980). Magnitude of main events was calculated in Mw = 6.6 (Sulstarova & Koçiaj, 1975); (Mw-moment magnitude); the shock lasted 10–12 sec (Mihajloviç, 1949). The quake destroyed a considerable number of buildings; there were deformations and joints, changes in the level of subterraneous waters, falling of rocks (Koçiaj & Sulstarova, 1980; Mihajloviç, 1949). The 1979 earthquake (known also as „Montenegro Earthquake") was the strongest that has occurred in Albania and one of the most important in the Balkans (Duni *et al.*, 2003). Its epicenter was located in the Adriatic coast, in Montenegro, its magnitude being between Mw=6.6–7.2 (Duni *et al.*, 2003; Karnik, 1996; Papazachos & Papazachos, 2001). Such phenomena as that of year 1905 have occurred in Shkodra region, especially along the lakeside.

METHODS OF SAMPLING FOR THE STUDY OF SHKODRA LAKE SEDIMENTS

Shkodra Lake is surrounded nearly on all sides by carbonate deposits that have a big dip towards the lake. These deposits build high mountains of 1600–1700 m. above the sea level. Such a differentiated relief favors the accumulation of sediments in the lake.

Surface hydric network also plays an important part in the accumulation of sediments in the lake. It brings from the Alps zone thick halfrounded matters in breccia-conglomerate form. In times of rapid and frequent load, during fall-winter-spring period, arteries of hydric network around the water-bearing basin of the Shkodra Lake bring down to the lake basin fine clay deposits, too, besides thick ones.

Among the elements of the ecosystem of Shkodra Lake as a whole, two of them are the most essential, water mass and the sediments. In this connexion, in recent years large scale research has been carried out on sediments, as to their lithology, age, paleoseismicity and as to the rhythm of sedimentation, as well. Interesting data on the sediment accumulation in Shkodra Lake has offered the work made in this lake during the research for the project „Quantitative assessment of present-day tectonics".

The above-mentioned work was carried out by means of a self-moving platform of UWITEC™ type, able for ob-

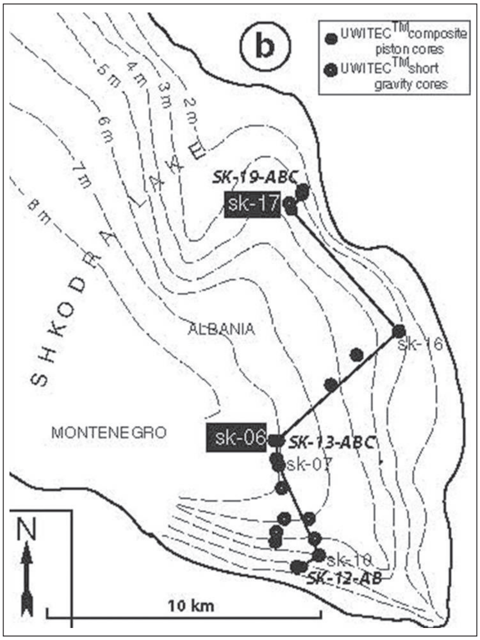

Figure 3. Profile of samples taking in Shkodra Lake

taining, by a hermetical sample of various dimensions for detailed sedimentology studies. In the process of work, there were obtained 17 samples of 70–90 cm. in length and 4 samples up to 8 m. in length. Sampling was carried out in the way of a ruptured profile from Shiroka village to Koplik town (inside the lake) (Fig. 3).

Samples up to 90 cm. length are obtained by free dip, whereas those of greater length by shock drilling. Sampling was carried out in such a way as to preserve the samples in depth conditions, by keeping them hermetically in a special drilling bit obtaining cores to keep the volatile elements and the structure intact. Their examination was accomplished in the Laboratory of Alps Geodynamics in Grenoble, France.

THE METHODIC OF GETTING THE CORES IN SHKODRA LAKE

The Shkodra Lake is almost surrounded on all sides by carbonatic sediments dipping towards the lake with high angle. These deposits represent the high mountains up to 1600–1700 m above see level. This differentiated relief creates favorable conditions for sediment accumulation.

An important role for transporting the sediments into the lake belongs to superficial hydric network. This development network transport the half rounded coarse material from the tectonic zone of Alps. During the drastic and frequent inputs, during the autumn and winter periods, fine clay sediments are also transported into the basin through the hydric network.

In general, from all the elements of the ecosystem in Shkodra lake area, two of them are most important: the water mass and the sediments. As for sediments, some studies of lithologic character, age determinations, paleo seismic and the sedimentation rates of lake sediments are accomplished. Some new interesting data on the accumulation of the sediments were gathered from Shkodra Lake during the study „The quantity evaluation of present-day tectonic".

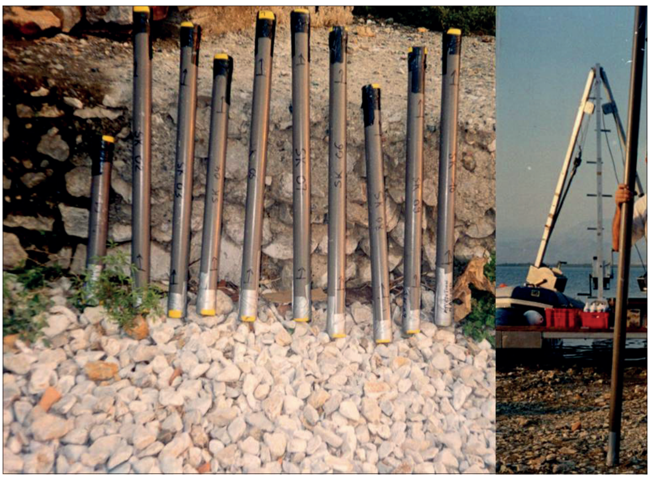

Photo 1. View of samles obtained in Shkodra Lake

The work was performed using a self moving platform of type UWITEC™, able to get cores of different length with hermetic equipment for detailed sedimentological study. Seventeen cores 70–90 cm long and four cores up to 8 m long were taken during the work (Photo–1). The cores were taken drilling on a broken profile base Shiroka to Koplik village (Fig. 3).

The samples up to 90 cm long were taken using the free fall method, while the longer samples were taken using the drill jars.

Taking the cores was realized in such a way to preserve the depth conditions, packing the sample inside a special drilling bit obtaining cores, in order not to let the fluoride elements get away and not to destroy its structure. Their analyses were made in Geodynamic Laboratory of Alps in Grenobel of France.

LATERAL CORRELATIONS AND ^{14}C-DERIVED CHRONOLOGY

Two different records: one along the main axis of the lake where sedimentation was relatively Except for a few dark brownish levels, no clear layering could be visually identified in short cores. Neither laminations nor strata were observed on split cores. Only subtle colour changes could be seen in the core. Sedimentation rates derived from ^{14}C dating of long cores (Van Welden *et al.*, in press, Fig. 3) show various sedimentation rates at sites within the lake: 1.50 mm/year for the central core (SK 13), 0.60 mm/year for the easternmost part (SK 19) and 0.85 mm/year for the western part of the lake (SK 12, Fig. 3). Long cores also show higher MS values with strong fluctuations mostly related to tephra layers (van Welden *et al.*, in press., Sulpizio pers. commun.).

Extrapolating the mean sedimentation rates, cores SK–17 and SK–06 should respectively represent six and three centuries. The cores were chosen to compare constant with higher sedimentation rates, and one in a more coastal situation where sedimentation was slower, but more variable through time.

Depth correlation between short cores is based on MS profiles (Fig. 4). Unit A is defined by a global increase in MS (magnetic susceptibility) whereas unit B exhibits fluctuations in MS that cannot be correlated in all cores, except for proximal cores SK 17 and SK 16 (Fig. 3). Top of unit „C" is characterized in all the cores by strong MS values

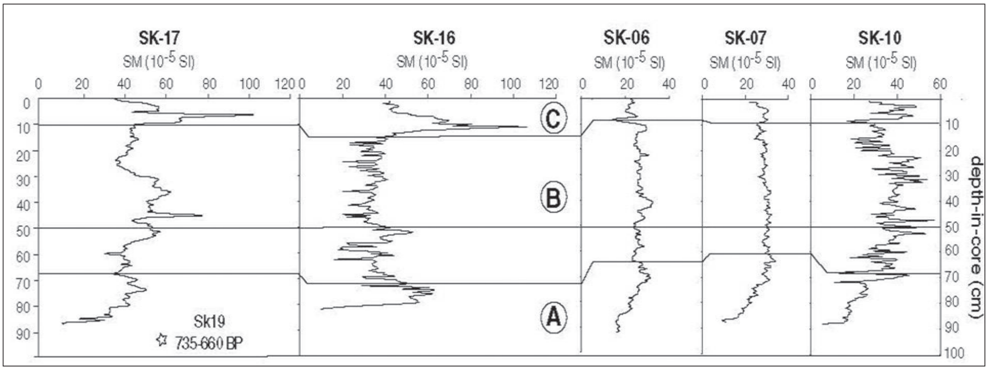

Figure 4. Correlation between short cores magnetic susceptibility profiles, measured on split cores with contact sensor and 5 mm spacing ^{14}C AMS dating comes from SK–19 piston core as the 90 cm of SK–17 core correspond to the 90 first centimetres of SK–19 piston core. ^{14}C age is 775±30 year BP and was calibrated using Oxcal 4.0.1 (Bronk & Ramsey, 2001) and Intcal 04 calibration curve (Reimer et al., 2004)

GRAIN SIZE AND MAGNETIC SUSCEPTIBILITY OF THE SEDIMENTS

Sediments are fine-grained, brownish to reddish, with no visible bioturbation. Karaman & Beeton, 1981 did not mention in their benthic fauna list, any deep dwelling organisms, only some grazing epibenthic fauna (gastropods, bivalves, chironomids). The sediment basically consists of carbonate grains (detrital calcite and dolomite, in situ bio-induced calcite), clay minerals, oxidized (brown) organic matter (OM); quartz, opaque particles and diatom frustules represent a minor component. OM ranges from 5%wg to 11%wg and carbonate content comprises between 30%wg and 55%wg (Fig. 5, 6). X-ray diffractometry (XRD) performed on the upper part of core SK–19 (van Welden *et al.*, in press) indicates domination of illite and chlorite (80%) minerals with a minor contribution of kaolinite (15%).

Some levels contain large (mm-cm) shell fragments mixed in a clayey-silty matrix (Fig. 5, 6). Long-term transport of either aquatic or terrestrial gastropod shells by floating is a common phenomenon in lakes, sometimes powered by wind rather than currents.

SK 17 and SK 06 cores present similar grain size evolution characteristics (Fig. 5, 6): 1–5% of very fine sand 20–40% silt. Greater sand content appears in the upper 8 cm (SK–17) or the upper 10 cm (SK–06). Modes, medians, and mean grain sizes similarly evolve in both cores: they range from 5 to 20 μm. Sorting is generally weak (SO index between 2 and 2,5) except in the upper part of core SK–17, with values between 1,5 and 2,0. Skewness is high (index SK<<1) reflecting a strong asymmetry towards

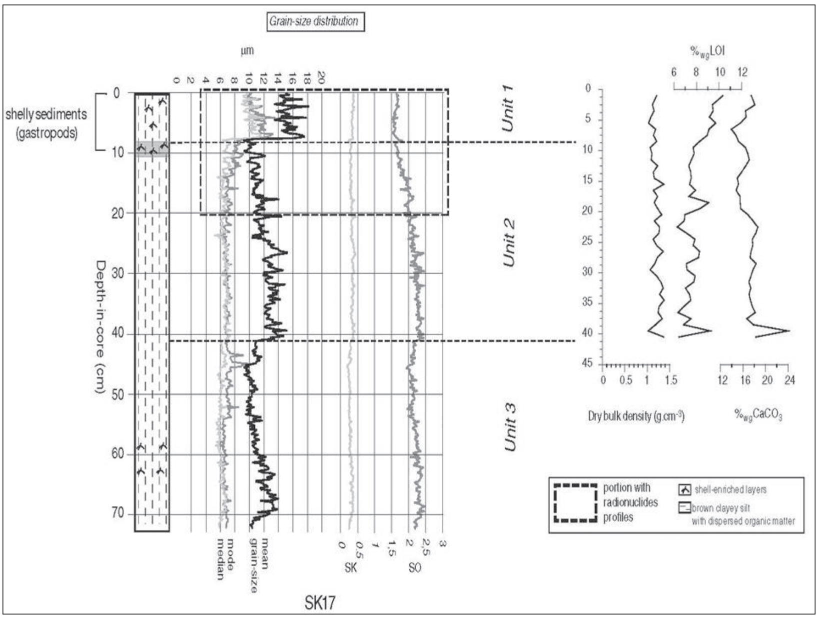

Figure 5. Detailed grain-size distribution and LOI of core SK–17 (after Welden et al, 2008)

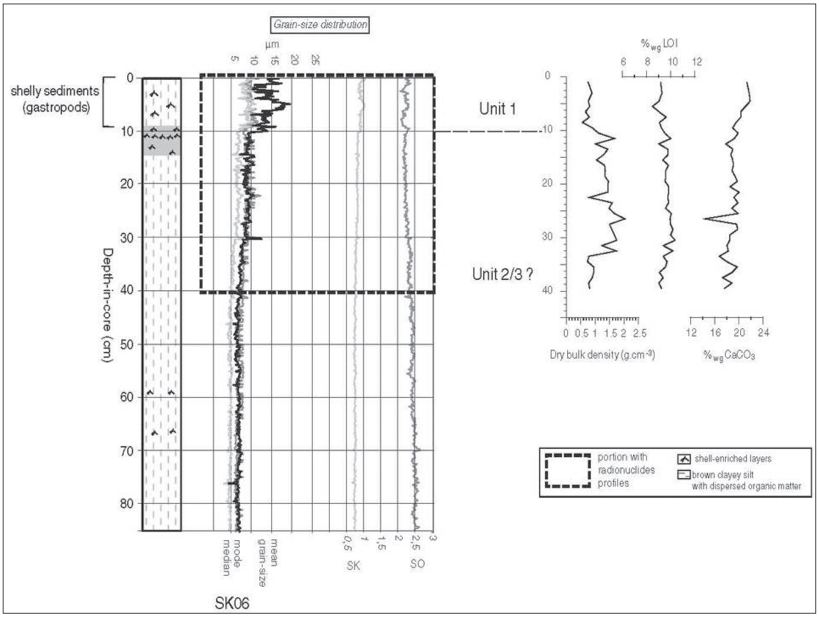

Figure 6. Detailed LOI and grain-size distribution of core SK–06 (after Welden et al, 2008)

fine-grained particles. Organic matter comprises between 7%$_{wg}$ in SK–17 (Fig. 4) and is quite stable around 9%$_{wg\ in}$ Sk–06 core (Fig. 5). Carbonate content varies between 15%$_{wg}$ and 18%$_{wg}$ in SK–17 core with an increase in the last 6 cm. The mean carbonate value is about 18%$_{wg}$ in SK–06 core with an increase of 2%$_{wg}$ within the last 10 cm (van Welden *et al.,* 2008).

Analyzing the depth cores from the lake according to the Shirok-Koplik direction show that the average sedimentation rates in the central part are 4–5 mm/year, while in the sides of the lake it is 1,7 mm/year (see Table–1). Based on the isotope analysis of carbon 14 (^{14}C) the age of the sediments at 4,5–5 m deep, in core 13, result 7500–10000 years (Bekc *et al*., 2007). The age of the sediments at the depth 90 cm in the core SK–19 result 735 ± 30 (van Welden *et al*., 2008).

The radioactivity was not measured in Albania territory during the periode of nuclear tests or during the time of Çermobili accidental eruption. We got the data measured in Greece and from the Europian Atlass for Cesium radioactivity during the time of accidental eruption of Çermobili. Those data were used comparing with the radioactivity of the sediments in Shkodra Lake.

Detailed analysis of the content of the radioactive elements like ^{210}Pb, ^{137}Cs, ^{241}Am, ^{226}Ra show anomaly in two periods: the first is dated on 1963 and the second in 1986 (Fig 7&8). The first is related with any nuclear eruption test and the second is related with the accidental eruption of Çernobili central. The high values of those radioactive elements tell a lot for the sedimentation rates during the last century (Table–1). The dated section covers sedimentation from about 1900 to 2003.

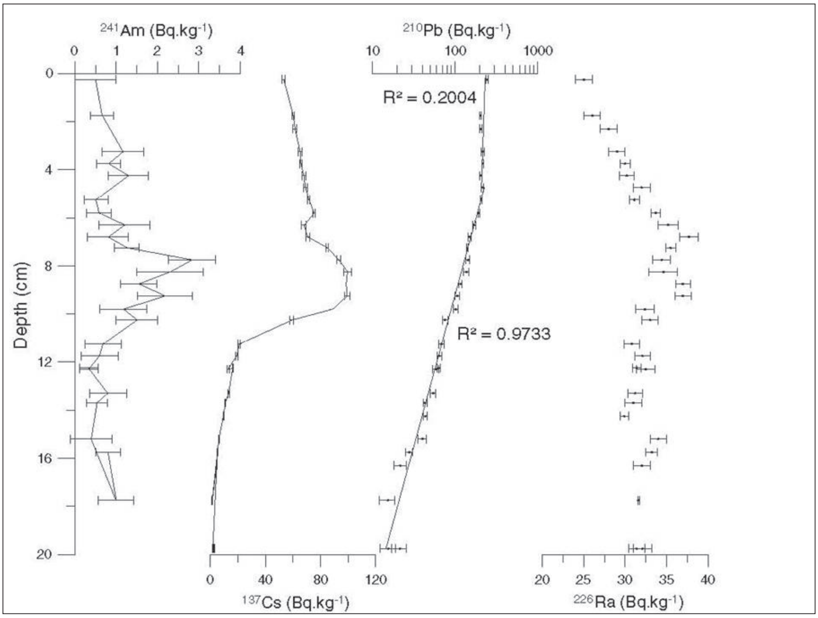

Figure 7. $^{210}Pb_{xs,}$ ^{137}Cs, ^{241}Am and ^{226}Ra radionuclide profiles for core SK–17. core.

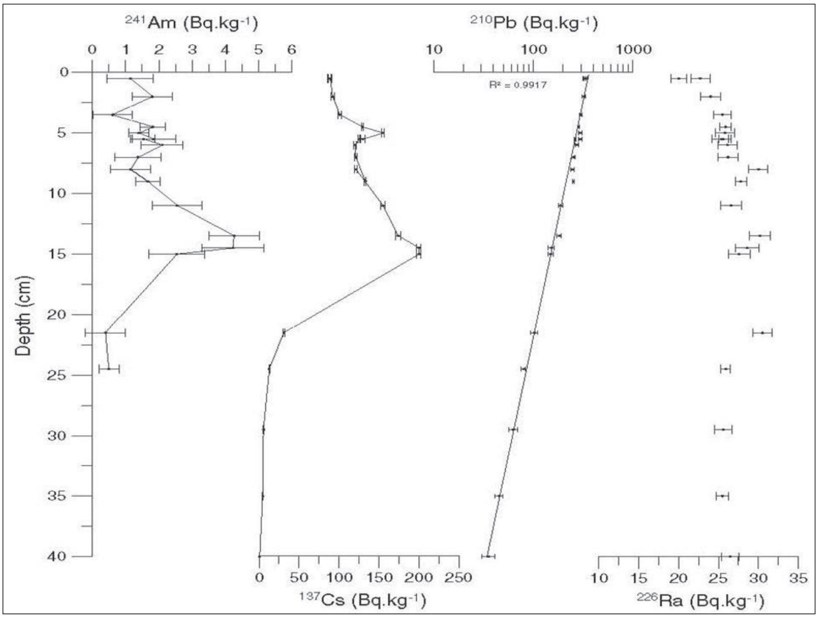

Figure 8. $^{210}Pb_{xs,}$ 137, Cs ^{241}Am and ^{226}Ra radionuclide profiles for core SK–06

Results shown in (Table–1) confirm that below 5 cm, the ^{210}Pbxs-derived dating is in quite good agreement with a 1.7 mm/year.

For the SK 06 core (Fig. 8), accumulation rates derived from the three radionuclides have quite similar values, between 5 and 3 mm/year (Table 1). We chose a mean value of 4 mm/year. As for the SK 17 core, almost one century of sedimentation is datable with radionuclides. These derived accumulation rates may be extrapolated to the bases of cores SK–17 and SK–06.

Regarding the possible record of major seismic events, the 1979 and 1905 earthquakes had noticeable impacts in the town of Shkodra, and a resulting seiche was observed. Thus we would expect some traces in the sediments. Cores do not exhibit any liquefaction or mass movement-related deposit associated with the earthquakes. Furthermore, ^{210}Pb does not exhibit any disturbance that could be related to the 1979 or 1905 earthquakes.

Table 1. SK–06 and SK–17 core data

Radionuclide/event	Depth	Accumulation rates (AR) mm/year
SK–17		
^{210}Pb	Under 5 cm	1,7
1986 Chernobyl	5,8	3,4
1963 Nuclear tests	7,8–12	1–3
1986–1963	2–6,2 cm thickness	0,9-,3
1986–1963 210 Pb	9,7 cm	1,7
SK–06		
^{210}Pb	Full archive	5,1
1986 Chernobyl	5 cm	2,9
1963 Nuclear tests	13,5–16 cm	3,4–4
1986–1963	8,5–11 cm thickness	3,7–4,8
1986–1963 ^{210}Pb	16,7 cm	5,1

Grain size evolution and LOI values do not display any evidence of strong changes of the sedimentation dynamics as a consequence of either event except for the break in sedimentation (and associated shell levels in both cores) around 1979. If this change in sedimentation dynamics is associated with the 1979 earthquake event, we might expect to see evidence of the 1905 earthquake too. We explain this lack of recording of rather strong earthquakes to: the shallow depth, the lack of dipping deltaic forests, and (at least in the analyzed upper meter) the lack of contrasting lithology in successive layers. Similar shallow lakes in coastal situations (unlike the situation discussed here) may record tsunamis when receiving marine allochthonous particles.

REFERENCES

[1] Aliaj, Sh., Sulstarova, E., Muco, B. & Kociu, S., 2000. *Seismotectonic Map of Albania in scale 1: 500.000*. Seismological Institute Tirana.
[2] Aubouin, J. 1974. *Des tectoniques superposées et de leur signification par rapport aux modeles géophysiques: l'exemple des Dinarides; paléotectonique, tectonique, tarditectonique, néotectonique*. Bull Soc Géol Fr, 7: 426–460.
[3] Geço, P. 1961. *Observations on some features in Shkodra Lake (Albanian)*. Buletini U. SH. T. Seria e Shkencave IV.
[4] Duni, L., Kuka, N. & Dushi, E. 2003. *Monitoring of seismicity in Albania*. CSEM/ESMC Newslett., 24.
[5] Karaman, G. S. & Beeton, A. 1981. *The biota and limnology of Lake Shkoder*. Smithonian Institution, Washington DC and Univerzitet Veljko Vlahovic, Titograd: 450.
[6] Kociaj, S. & Sulstarova, E. 1980. *The earthquake of June 1, 1905, Shkodra, Albania; Intensity distribution and macroseismic epicentre*. Tectonophysics. 67: 319–332.
[7] Koçi, R. & Bushati, S. 2004. *Shkodra Lake, the origine and accumulation of sediments (Albanian),* Studime Sizmilogjike, Nr 11. Arkivi i Institutit Gjeoshkencave.
[8] Mihajlovic, J. 1949. *La Sismicité de la Région du Lac de Scutari*. Geofisica Pura e Applicata 14: 3–4.
[9] Muço, B. 1998. *Catalogue of earthquakes in Albania from 1976 to 1995 and distribution of seismic energy released*. Tectonophysics, 292: 311–319.
[10] Muço, B. 1999. *Statistical investigation on possible seasonality of seismic activity and rainfall-induced earthquakes in Balkan area*. Phys. Earth Planet N. 114: 119–127.
[11] Muço, B., Vaccari, F., Panza, G. & Kuka, N. 2002. *Seismic zonation in Albania using a deterministic approach*. Tectonophysics, 344: 277–288.
[12] Papazachos, C. B. & Papazachos, B. C. 2001. *Precursory seismic deformation in the Aegean area*. Ann geofisica 44: 461–474.
[13] Sulstarova, E., Muço, B., Aliaj, S., Kuka, N. & Duni, L. 2003. *Earthquakes, seismic hazard and seismic risk in Albania*. Archive of the Seismological Institute (Internal report): 82.