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RUDJER BOŠKOVIĆ INSTITUTE RADIOCARBON MEASUREMENTS IX

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The following radiocarbon date list contains dates of samples from Plitvice Lakes measured since our previous list dealing with tufa from this region (Srdoč *et al*, 1982). Tufa measurements from the Knin area in S Croatia and some localities in Bosnia are also listed. Age calculations are based on the Libby half-life (5570 ± 30) yr and reported in years before 1950. Reported ages are based on the initial activity of 85% except for lake sediments where calculations of initial activity have been performed. The modern standard is 0.95 of the NBS oxalic acid activity. Sample pretreatment and counting technique are essentially the same as described in R, 1971, v 13, p 135–140, supplemented by new techniques for groundwater processing (R, 1979, v 21, p 131–137). Statistical processing of data has been computerized (Obelić & Planinić, 1977; Obelić, 1980). The errors quoted correspond to 1σ variation of sample net counting rate and do not include the uncertainty in ^{14}C half-life.

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GEOLOGIC SAMPLES

Tufa from Plitvice Lakes area

Tufa samples from outcroppings scattered in the Plitvice Lakes area (44° 50′ N, 15° 35′ E), central Croatia. Sixteen lakes are separated by tufa barriers; 3 major and several minor springs feed lakes and the Korana River. Measurements of ^{14}C activity of dissolved inorganic carbon in water samples as well as that of recent tufa deposited on the surface of polyamide mats and aquatic plants in the Plitvice National Park area performed since 1981 showed a systematic increase of ^{14}C activity from karst springs to the

Korana R mouth. The increase has been attributed to the influx of atmospheric CO_2 and to the contribution of terrestrial plants, through detrital decay and root respiration, and a model based on the described process was developed (Srdoč *et al,* 1986b). Dates help to determine periods of intensive tufa formation in the area. Samples coll 1981–1985 by D Srdoč.

Crna Rijeka series

Crna Rijeka brook feeds Plitvice Lakes joined by Bijela Rijeka brook at Plitvički Ljeskovac, forming rivulet Matica which discharges into the uppermost Lake Prošće. Crna Rijeka brook flows over solid tufa terraces which belong to earlier phase of tufa deposition. Mud covering riverbed contains large fraction of dolomite (Popović, Srdoč & Grgić, 1986), thus, its ^{14}C activity does not reflect its age.

Z-702. Crna Rijeka No. 1 **69.1 ± 0.6% modern**
1630 ± 100

Recent tufa near waterfall, right bank.

Z-703. Crna Rijeka No. 2 **47.6 ± 0.5% modern**
4630 ± 110

Surface layer of tufa upstream from bridge near waterfall.

Z-751. Crna Rijeka No. 3 **53.2 ± 0.5% modern**
3720 ± 100

Tufa, right bank upstream from bridge near waterfall.

Z-810. Crna Rijeka No. 4 **48.3 ± 0.5% modern**
4500 ± 120

Tufa, right bank upstream from waterfall.

Z-1064. Crna Rijeka No. 5 **8.3 ± 0.3% modern**
$\delta^{13}C = +1.9‰$

Sandy deposit covering creek bottom.

Bijela Rijeka series

Large deposits of tufa above right bank of Bijela Rijeka brook. Tufa rocks, 10 to 12m high above ground level belong to preglacial period (Riss/Würm) as determined by $^{230}Th/^{234}U$ (Srdoč *et al,* 1986a), whereas river terrace is much younger.

Z-1050. Bijela Rijeka No. 1 **0.0 ± 0.3% modern**
>37,000

Compact tufa, right bank of Bijela Rijeka, village Plitvički Ljeskovac.

Z-1051. Bijela Rijeka No. 2 **0.4 ± 0.4% modern**
34,700 $^{+3800}_{-3200}$

Same block as Z-1050.

73.6 ± 0.5% modern

Z-1115. Bijela Rijeka No. 3 **1120 ± 140**

Coarse calcareous grains, Bijela Rijeka terrace.

3.9 ± 0.3% modern

Z-1116. Bijela Rijeka No. 4 **24,600 ± 1300**

Compact tufa, Plitvički Ljeskovac.

2.3 ± 0.2% modern

Z-1117. Bijela Rijeka No. 5 **28,800 ± 2200**

Same block as Z-1116.

Kavga brook series

Right tributary of Matica R near Plitvički Ljeskovac.

63.3 ± 0.7% modern

Z-1057. Kavga No. 1 **2320 ± 150**

Tufa block above brook.

60.7 ± 0.6% modern

Z-1058. Kavga No. 2 **2700 ± 150**

Tufa from terrace above brook.

Pećina series

Spring Pećina near Plitvički Ljeskovac, left tributary of Bijela Rijeka brook.

77.5 ± 0.7% modern

Z-1052. Pećina No. 1 **Modern**

Recent tufa deposited around spring Pećina.

69.6 ± 0.5% modern

Z-1055. Pećina No. 2 **1570 ± 140**

Hard, porous tufa above spring Pećina.

Plitvički Ljeskovac series

Confluence of Crna Rijeka and Bijela Rijeka brooks is in tufa-covered valley near Plitvički Ljeskovac. Outcroppings of preglacial tufa and thick deposits of recent tufa are very abundant in valley.

65.3 ± 0.6% modern

Z-705. Ex Bio-station **3200 ± 100**

Outcroppings of tufa in marshy field, presently flooded area (*cf* Z-700; R, 1982, v 24, p 356).

71.5 ± 0.7% modern

Z-1059. Confluence site No. 1 **1350 ± 140**

Recent, porous, coarse-grained tufa covered with moss.

1.3 ± 0.4% modern

Z-1069. Confluence site No. 2 **33,000 $^{+4000}_{-3500}$**

Compact, inner layer of tufa tube.

1.8 ± 0.4% modern

Z-1070. Confluence site No. 3 **31,000 $^{+3300}_{-2700}$**

Porous, outer layer of tufa tube. *Comment:* tubular forms of tufa are frequent, as result of encrustation of wood branches and trunks.

45.8 ± 0.5% modern

Z-1135. Matica **4900 ± 160**

Fine-grained calcareous deposit, mixed with organic detritus, Matica rivulet mouth. Material transported by water and deposited at river mouth. Matica R flows through preglacial and Holocene tufa deposits. *Comment:* no formation of recent tufa concretions has been observed in Matica R.

77.5 ± 0.6% modern

Z-1031. Prošće, Spiljski vrt **Modern**

Recent tufa under moss, Cave garden. Measurement of initial ^{14}C activity of recently deposited tufa.

Lake Ciginovac series

73.3 ± 0.6% modern

Z-1029. Ciginovac No. 1 **Modern**

Recent tufa under growing moss *(Cratoneurum commutatum). Comment:* determination of initial ^{14}C activity of sediment in Upper Lakes (*cf* Z-817: R, 1982, v 24, p 361).

77.9 ± 0.6% modern

Z-1416. Ciginovac No. 2 **Modern**

Freshly deposited tufa on surface of artificial substratum (polyamide mat) immersed in water from May to Sept 1984. Microlocation: waterfall connecting lakes Prošće (upper) and Ciginovac (lower). *Comment:* determination of initial ^{14}C activity.

Veliki Jovinovac series

Lake Veliki Jovinovac is in middle of Upper Lakes, Plitvice Natl Park. Entire area covered with thick tufa deposits.

74.4 ± 0.6% modern

Z-1001. Veliki Jovinovac No. 1 **Modern**

Dry, porous tufa, mossy shape, green algae on surface.

75.4 ± 0.6% modern

Z-1002. Veliki Jovinovac No. 2 **Modern**

Porous tufa from cave in dry tufa barrier.

74.9 ± 0.5% modern

Z-1006. Lake Vir **Modern**

Hard, porous, mossy structured tufa above surface of Lake Vir.

Lake Galovac series

Samples of tufa deposits lying above present level of Lake Galovac.

71.2 ± 0.6% modern

Z-1003. Galovac No. 1 **1390 ± 110**

Hard, dry tufa near pathway, right side.

73.9 ± 0.6% modern

Z-1004. Galovac No. 2 **1080 ± 110**

Porous tufa below pathway.

69.2 ± 0.4% modern

Z-1005. Galovac No. 3 **1610 ± 110**

Hard tufa barrier.

Lake Gradinsko series

Thick deposits of hard and powdered tufa above surface of Lake Gradinsko.

51.8 ± 0.4% modern

3950 ± 90

Z-835. Gradinsko No. 1 $\delta^{13}C = -8.4‰$

Powdered microcrystalline calcareous deposit 2m above present level of lake (*cf* Z-832 to Z-834: R, 1984, v 24, p 366).

47.0 ± 0.4% modern

Z-836. Gradinsko No. 2 **4700 ± 120**

Compact tufa 2m above lake surface, near Z-835.

53.8 ± 0.5% modern

Z-837. Gradinsko No. 3 **3600 ± 120**

Porous tufa, mossy structured (*Cratoneurum commutatum*) ca 2m above lake surface.

50.0 ± 0.4% modern

Z-1056. Gradinsko No. 4 **4220 ± 150**

Tufa 2m above present level of lake.

Gradina series

Isolated hill on peninsula above Lakes Gradinsko and Kozjak, with remnants of prehistoric and medieval ramparts. Hill encircled with deposits of Holocene tufa with outcroppings of preglacial tufa on top. Lake Gradinsko is in Upper Triassic well bedded dolomite containing >90% $MgCa(CO_3)_2$. Stromatolithic fms are very frequent. Systematic measurements of preglacial tufa using fractional dissolution revealed contamination with more recent calcareous material (see Table 1). $^{230}Th/^{234}U$ dating on samples of preglacial tufa gave age of ca 120,000 yr (Riss/Würm interglacial) (Srdoč *et al,* 1986a).

61.2 ± 0.5% modern
Z-830. Gradina No. 1 **2600 ± 110**

Powdered, microcrystalline calcareous tufa.

63.4 ± 0.4% modern
Z-996. Gradina No. 2 **2310 ± 110**

Tufa blocks used for building ramparts.

62.4 ± 0.6% modern
Z-997. Gradina No. 3 **2450 ± 120**

Tufa boulders used to build fortification. *Comment:* only Holocene tufa was used to construct fortifications at Gradina.

2.8 ± 0.3% modern
Z-1208. Gradina, hilltop No. 1 **27,200 ± 1500**

Porous tufa, Block C. Upper surface under atmospheric influence. Samples used for testing contamination with recent carbonate.

1.5 ± 0.3% modern
Z-1210. Gradina, hilltop No. 2 **30,900 $^{+3200}_{-2600}$**

Compact tufa, Block S, covered by porous tufa.

General Comment: ^{14}C measurements show that each subsequent soluble

TABLE 1
Test of fractionation of sample Z-1211 (Porous tufa, Block S)

Sample no.	Grain size (mm)	Fraction no. (%)	% modern	Age BP (yr)
Z-1268	1–5	I (30)	12.1 ± 0.4	15,600 ± 400
-1269	1–5	II (30)	5.8 ± 0.3	21,500 ± 800
-1270	1–5	III (30)	3.8 ± 0.3	24,800 ± 1100
-1271	<1	I (50)	10.8 ± 0.4	16,500 ± 400
-1272	<1	II (50)	3.6 ± 0.2	25,300 ± 1200
-1273	1	I (50)	7.8 ± 0.4	19,100 ± 600
-1274	1	II (50)	1.7 ± 0.3	31,200 ± 2400

fraction obtained from porous tufa gave successively older age indicating that surface of sample was contaminated by younger carbonates. No consistent effect of grain size on ^{14}C age is observed.

Burget series

Freshly deposited tufa on surface of artificial substratum (polyamide mat) immersed in streamwater. Waterfall connecting Lakes Burget (upper) and Kozjak (lower). *Comment:* determination of initial ^{14}C activity.

85.4 ± 0.7% modern
Z-980. Burget No. 1 **Modern**

Substratum immersed in water from June to Oct 1981.

83.8 ± 0.6% modern
Z-1011. Burget No. 2 **Modern**

Substratum immersed in water from Oct 1981 to Apr 1982.

Rječica series

Rječica brook is a major tributary to Plitvice Lakes. Tufa deposition starts at approx half-way between its springs and Lake Kozjak. Upper part of Rječica bed is cut in old tufa.

84.0 ± 0.6% modern
Z-1020. Rječica No. 1 **Modern**

Hard, porous, recent tufa from last barrier before brook discharges into Lake Kozjak.

46.3 ± 0.6% modern
Z-1038. Rječica No. 2 **4830 ± 170**

Hard tufa, riverbed.

56.3 ± 0.4% modern
Z-1060. Rječica No. 3 **3260 ± 150**

Tufa in form of small pebbles covering riverbed.

70.9 ± 0.6% modern
Z-1061. Rječica No. 4 **1420 ± 140**

Tufa from river terrace, coarse grains several mm in diameter.

89.0 ± 0.7% modern
Z-1068. Rječica No. 5 **Modern**

Freshly deposited tufa on surface of artificial substratum (polyamide mat) immersed in stream water from July to Oct 1982.

General Comment: two distinct ^{14}C activities were found in Rječica brook: recent activity of fresh tufa is from 84 to 89% modern, whereas tufa riverbed belongs to older, Holocene deposits (Popović, Srdoč & Grgić, 1986).

Lake Kozjak series

Samples of hard, porous tufa and other calcareous material presently above surface of Lake Kozjak. Tufa outcroppings around lake mark position of dried-up tributaries, and ^{14}C dating helps to reconstruct history of lake.

61.8 ± 0.6% modern
Z-676. Kozjak No. 1 **2500 ± 100**

Hard, porous tufa, resembles petrified moss (*Cratoneurum commutatum*), 7 to 8m above lake surface; sample taken from huge block of tufa emerging from lake.

69.9 ± 0.5% modern
Z-844. Kozjak No. 2 **1530 ± 100**

Hard, porous tufa from NW shore.

53.0 ± 0.4% modern
Z-1037. Kozjak No. 3 **3750 ± 150**

Powdered, microcrystalline calcareous sediment, ca 8 to 10m above lake surface.

75.2 ± 0.6% modern
Z-1082. Kozjak No. 4 **950 ± 130**

Compact tufa overgrown by moss, left approach to waterfalls connecting Lake Kozjak (upper) and Lake Milanovac (lower).

59.8 ± 0.6% modern
Z-1114. Kozjak No. 5 **2800 ± 150**

Dripstone from cave, 4 to 5m above lake surface.

General Comment: all samples belong to warm and humid periods in Holocene.

Kozjak barrier series

Core samples taken by drilling at barrier connecting Lakes Kozjak and Milanovac. Coll 1983 by S Merkt.

64.1 ± 0.5% modern
Z-1463. Kozjak barrier No. 1 **2230 ± 150**

Depth 0.5 to 1.0m.

59.9 ± 0.4% modern
Z-1464. Kozjak barrier No. 2 **2770 ± 140**

Depth 2.2 to 2.6m.

57.2 ± 0.5% modern
Z-1457. Kozjak barrier No. 3 **2840 ± 120**

Depth 3.0 to 3.2m.

Plitvica series

Plitvica brook is major tributary to Korana R, discharging into Korana at "Sastavci" (confluence). Tufa deposition starts at Crkvine, ca 1km downstream from Plitvica karst spring.

83.0 ± 0.7% modern

Z-1066. Plitvica No. 1 **Modern**

Freshly deposited tufa on artificial substratum (polyamide mat) immersed in streamwater from May to Oct 1982.

84.6 ± 0.6% modern

Z-1067. Plitvica No. 2 **Modern**

Same as Z-1066, except microlocation.

69.9 ± 0.6% modern

Z-1118. Plitvica No. 3 **1530 ± 140**

Hard, porous tufa from riverbed near Hajduković Mill.

66.8 ± 0.4% modern

Z-1083. Plitvica waterfall No. 1 **1890 ± 140**

Hard, porous tufa from river terrace above 76m high waterfall. *Comment:* recent tufa activity of Rječica brook (Z-1068, Z-1020, above) and Plitvica brook are similar.

87.9 ± 0.7% modern

Z-1012. Plitvica waterfall No. 2 **Modern**

Freshly deposited tufa on surface of artificial substratum (polyamide mat) immersed in water from Oct 1981 to Apr 1982 under Plitvica brook waterfall. *Comment:* determination of initial ^{14}C activity.

88.2 ± 0.7% modern

Z-1276. Novakovića brod **Modern**

Recent tufa under growing moss *(Cratoneurum commutatum). Comment:* ^{14}C activity increases along river course (Srdoč *et al,* 1986b).

Hajduković pit series

Pit, 2 to 3m deep in flat terrace ("polje") near Hajduković Mill. Layer of charred decayed leaves entrapped between tufa deposits.

66.3 ± 0.6% modern

Z-1119. Hajduković pit No. 1 **3260 ± 130**

Charred wood in Hajduković pit surrounded by tufa layer.

66.2 ± 0.6% modern

Z-1204. Hajduković pit No. 2 **3300 ± 130**

Charred leaves in Hajduković pit surrounded by tufa layer.

51.5 ± 0.5% modern

Z-1205. Hajduković pit No. 3 **4000 ± 130**

Tufa layer above charred leaves.

50.9 ± 0.4% modern

Z-1206. Hajduković pit No. 4 **4100 ± 130**

Tufa layer below charred leaves.

General Comment: ratio of activity of tufa and that of organic material gives initial activity of tufa at this location equal to 77.3% modern.

Smolčić flat series

Outcroppings of tufa in small flat above Smolčića pećina cave. Very hard, porous tufa dated by ^{14}C and $^{230}Th/^{234}U$ method. ^{14}C dating gave inconsistent ages, depending on contamination of samples with more recent carbonates (see Table 2) whereas $^{230}Th/^{234}U$ dating pointed at warm and humid interglacials (Riss/Würm, Mindel/Riss) (Srdoč *et al,* 1986a).

1.5 ± 0.3% modern

Z-1213. Smolčić flat No. 1 **32,000 ± 2900**

Hard, compact tufa, Block N.

11.9 ± 0.4% modern

Z-1214. Smolčić flat No. 2 **15,800 ± 400**

Hard, porous tufa. Humus and rootlets in pores and crevices removed mechanically and by washing.

Smolčić cave series

Dripstones and tufa from Smolčić cave, ca 60m above present level of Korana R. Measurement of tufa and dripstone samples from same site could reveal any difference in degree of contamination with more recent calcareous material. Dripstones are considered less susceptible to contamination, as opposed to porous tufa. *Comment:* no conclusive remarks can be drawn from this series of measurement.

36.4 ± 0.5% modern

6800 ± 160

Z-932. Smolčić cave No. 1 $\delta^{13}C = -7.8‰$

Core of tufa block, entrance to cave.

TABLE 2
Test of fractionation of sample Z-1213 (Compact tufa, Block N)

Sample no.	Grain size (mm)	Fraction no. (%)	% modern	Age BP (yr)
Z-1500	1–5	I (30)	3.9 ± 0.3	24,400 ± 1100
-1501	1–5	II (30)	2.9 ± 0.3	26,900 ± 1600
-1502	1–5	III (30)	1.0 ± 0.3	>37,000

0.2 ± 0.3% modern

Z-1008. Smolčić cave No. 2. **>37,000**

Limestone bedrock.

1.6 ± 0.3% modern

Z-1007. Smolčić cave No. 3. **31,600 ± 2800**

Core of homogeneous tufa block.

3.4 ± 0.3% modern

Z-1144. Smolčić cave No. 4. **25,700 ± 1600**

Inner part of tufa covered by flowstone.

5.0 ± 0.3% modern

Z-1145. Smolčić cave No. 5 **22,600 ± 1100**

Outer part of tufa covered by flowstone.

6.0 ± 0.3% modern

Z-1146. Smolčić cave No. 6 **21,200 ± 900**

Partly crystallized tufa.

Široka Luka series

Korana village is above partly cultivated large river terrace Široka Luka. Terrace consists of calcareous material, mostly tufa, deposited by Korana R and covered with 15 to 20cm layer of soil. Dates help to reconstruct periods of development of terrace.

54.0 ± 0.5% modern

Z-1127. Široka Luka No. 1 **3610 ± 150**

Fine-grained tufa, terrace.

59.2 ± 0.5% modern

Z-1132. Široka Luka No. 2 **2870 ± 150**

Tufa from cultivated field.

72.5 ± 0.6% modern

Z-1133. Široka Luka No. 3 **1230 ± 140**

Dry tufa barrier, village Korana, 1 to 2m above river terrace.

83.9 ± 0.6% modern

Z-1134. Široka Luka No. 4 **Modern**

Recent tufa chips, river terrace Široka Luka under constant influence of Korana R water (DIC activity 90% modern).

Sartuk series

Sartuk brook flows in same area of Plitvice National Park where other streams form tufa barriers. No typical tufa has been found in Sartuk. Calcareous deposits contain much less ^{14}C, consisting of mixtures of weathered

limestone and dolomite rocks which surround Sartuk and some biogenically deposited calcite. No deposit ages can be deduced from ^{14}C measurements.

Z-1026. Sartuk No. 1 **4.4 ± 0.3% modern**

Mixture of soil and calcareous deposit.

Z-1027. Sartuk No. 2. **49.9 ± 0.6% modern**

Calcareous deposit under growing moss.

Z-1028. Sartuk No. 3 **11.2 ± 0.3% modern**

Sandy calcareous deposit. Dolomite with calcite content 5 to 10%, quartz 2 to 5% (Popović, Srdoč & Grgić, 1986).

Z-1339. Sartuk No. 4. **43.3 ± 0.5% modern**

Calcareous deposit, riverbed.

Korana River series

Measurement of ^{14}C activity of calcareous deposits, mostly tufa, along Korana R. For details see Srdoč *et al* (1986b).

93.6 ± 0.5% modern

Z-1019. Korana River No. 1 **Modern**

Recent tufa under growing moss (*Cratoneurum commutatum*).

90.8 ± 0.6% modern

Z-1063. Korana River No. 2 **Modern**

Tufa under moss on waterfall, Tušilović near Karlovac (44° 20′ N, 15° 37′ E).

89.5 ± 0.6% modern

Z-1065. Korana River No. 3 **Modern**

Freshly deposited tufa on artificial substratum (polyamide mat) immersed in water from Apr to Oct 1982, 0.5km downstream from confluence ("Sastavci"). *Comment:* determination of initial ^{14}C activity.

Tufa used for building at Plitvice Lakes region

75.5 ± 0.6% modern

Z-807. Hajduković Mill **900 ± 90**

Hard, porous tufa used for construction of mill.

60.8 ± 0.6% modern

2670 ± 100

Z-808. Crkvina $\delta^{13}C = -8.4‰$

Hard, porous tufa block from foundation of medieval church; origin and denomination of church unknown.

63.8 ± 0.5% modern

Z-916. Old power station **2270 ± 110**

Hard, porous tufa from building housing small power station, now out of operation, Lake Burget above Kozjak.

72.4 ± 0.6% modern

Z-1018. Old power station **1260 ± 100**

Same as Z-916.

General Comment: both preglacial (Z-921: R, 1982, v 24, p 355) and Holocene tufas were hard enough to be used for construction of buildings. However, it should be pointed out that age of tufa used in construction does not indicate date of erection of building, even though it can be used as *terminus post quem non.*

Pevalek collection series

Increased activity of groundwater, tufa, and aquatic plants due to increased activity of atmospheric CO_2 in past decades caused by nuclear weapon tests can be obtained by comparison of activity of recent material with that from pre-bomb era, providing that age of latter is known. Samples coll 1919 by late academician, I Pevalek (*cf* Z-847, -848, -853, -856, -857, -907, -908: R, 1982, v 24, p 365–366).

72.2 ± 0.5% modern

Z-1306. Pevalek colln No. 1 **1280 ± 110**

Tufa around wooden branch.

97.3 ± 0.6% modern

Z-1307. Pevalek colln No. 2 **185 ± 100**

Wooden branch encrusted with tufa.

General Comment: ratio of activity of tufa and wood gives initial activity of tufa at this location equal to 74.2% modern. Present activity of tufa is 80% modern at this location.

Plitvice Lakes Sediments

Lake Kozjak sediment core

In autumn 1983 several sediment cores were retrieved from Lakes Kozjak and Prošće, Plitvice Natl Park area (Srdoč *et al,* 1986c) (Table 3). Lake Kozjak core was retrieved from 24m water depth. First 2m of core gave good stratification with sedimentation rate 0.85mm/a. Next 5m sec gave scattered ^{14}C data in agreement with seismic records. This sec appears to have undergone mass transport and redeposition. Further 5m sec showed good stratification with sedimentation rate 1.1mm/a. Initial ^{14}C activity of 75% modern was determined by measuring activity of top of sediment layer (*cf* Z-840 and -841: R, 1982, v 24, p 367) and pre-bomb test tufa (Z-1082: R, 1982, v 24, p 363). Piece of wood (*Abies* sp) was found in sediment core. Surrounding sediments were carefully collected. Ratio of sediment *vs* wood activity gave initial ^{14}C activity of 74.4% modern.

TABLE 3
Lake Kozjak sediment core

Sample no.	Depth (m)	% modern	Age BP	$\delta^{13}C$ (‰ PDB)
Z-1301	0.15	74.8	Modern	
-1230	0.17	74.9	Modern	
-1372	0.00–0.20	73.3	90 ± 150	−8.7
-1302	0.72	66.3	900 ± 115	−8.6
-1303	1.07	64.0	1190 ± 115	
-1304	1.45	60.0	1710 ± 120	
-1305	1.70	55.6	2310 ± 125	
-1232	2.00	55.3	2350 ± 130	−8.8
-1347	2.40–2.60	52.2	2820 ± 130	−8.6
-1233	3.12	49.8	3210 ± 145	−8.6
-1234	3.45	51.5	2930 ± 130	−8.6
-1235	3.84	52.7	2740 ± 130	−8.6
-1236	4.30	53.7	2590 ± 130	−8.6
-1237	4.68	49.3	3290 ± 130	−8.6
-1373	4.96–5.05	49.8	3200 ± 140	−8.6
-1374	5.05–5.20	50.5	3150 ± 140	−8.5
-1375	5.20–5.35	58.4	1920 ± 120	−8.5
-1376	5.35–5.50	57.4	2070 ± 130	−8.6
-1172	5.60	54.7	2440 ± 130	
-1171	5.70	54.4	2500 ± 150	
-1173	5.80	56.9	2130 ± 140	
-1240	6.13	49.4	3500 ± 140	−8.7
-1241	6.50	46.1	3830 ± 140	−8.6
-1465	6.60–6.80	57.9	1970 ± 120	
-1242	6.86	46.1	1820 ± 120	
-1243	7.24	58.6	1900 ± 140	−8.6
-1246	8.06	53.8	2578 ± 145	−8.6
-1471	8.70–8.90	48.6	3480 ± 140	
-1250	9.20	51.0	3020 ± 150	
-1253	10.20	47.4	3590 ± 160	−8.7
-1472	10.20–10.35	43.3	4380 ± 140	
-1393	10.55–10.75	41.6	4450 ± 150	
-1369	10.90–11.08	38.2	5330 ± 160	
-1370	11.08–11.25	38.6	5240 ± 160	
-1392	11.75–11.95	35.4	5930 ± 160	
-1432	11.95–12.15	39.2	5120 ± 150	
-1348	12.15–12.35	43.4	4300 ± 150	−8.6
Wood (*Abies* sp)				
-1168	5.64	75.0	2280 ± 120	

Lake Kozjak bottom series

Sediment from bottom of Lake Kozjak. Coll 1983 by S Merkt, Niedersächsisches Landesamt f Bodenforschung, Hannover.

Z-1122. Kozjak No. 1 **69.0 ± 0.6% modern**

Bottom of lake. Water depth 43m.

Z-1123. Kozjak No. 2 **73.5 ± 0.6% modern**

Bottom of lake. Water depth 23m.

Lake Prošće sediment core

Lake Prošće core was retrieved from 17.2m water depth and reached clayey residual overlaying bedrock (Table 4). ^{14}C dating of lake sediment revealed uniform sedimentation rate of 1.4mm/a. Pollen analyses of core

sec revealed major settlement phases in Plitvice Natl Park area during last 6000 yr (Müller & Obelić, 1986).

Piece of wood (*Abies* sp) was found in sediment core and dated together with surrounding sediment which enabled determination of ^{14}C initial activity of sediment equal to 72% modern.

Tufa Deposits in Kninsko Polje

Tufa deposits in Kninsko polje (44° 02′ N, 16° 11′ E), S Croatia consist of Holocene and preglacial deposits. Waters of intermittent Krčić creek and perrenial Krka R are rich in carbonates forming thick tufa and lacustrine sediments along their ancient and recent courses in Kninsko polje valley (*cf* Z-1189 to -1194; R, 1984, v 26, p 455). Tufa samples with apparent ^{14}C age > ca 20,000 yr are much older, as shown by $^{230}Th/^{234}U$ analyses (Srdoč *et al,* 1986a).

Krčić series

Samples coll 1984 by D Srdoč and B Obelić.

Z-1323. Krčić No. 1 **88.8 ± 1.1% modern**
Modern

Recent tufa under moss, Krčić brook near village Krčić. *Comment:* activity of recent tufa similar to activities measured in Plitvice Natl Park.

TABLE 4
Lake Prošće sediment core

Sample no.	Depth (m)	% modern	Age BP	$\delta^{13}C$ (‰ PDB)
Z-1441	0.00–0.40	66.2	550 ± 100	
-1398	0.80–1.00	67.6	470 ± 115	
-1658	1.20–1.40	62.6	1100 ± 100	
-1399	1.60–1.80	62.4	1110 ± 120	
-1659	2.00–2.20	60.7	1340 ± 100	
-1661	2.40–2.60	59.0	1560 ± 100	
-1407	2.80–3.00	55.7	2030 ± 120	−9.3
-1662	3.20–3.40	53.8	2300 ± 100	
-1422	3.60–3.80	53.2	2390 ± 125	
-1663	3.80–4.00	53.7	2320 ± 100	−8.9
-1424	4.20–4.40	52.0	2580 ± 130	−8.9
-1664	4.90–5.00	48.8	3090 ± 110	−9.0
-1430	5.20–5.40	47.5	3300 ± 130	−9.0
-1665	5.60–5.80	45.1	3510 ± 120	
-1431	6.20–6.40	43.8	3970 ± 140	−8.9
-1666	6.80–7.00	41.9	4320 ± 140	−8.8
-1438	7.20–7.40	43.8	3960 ± 145	−8.9
-1667	7.60–7.80	38.7	4950 ± 130	
-1436	8.20–8.40	38.4	5020 ± 150	−8.8
-1668	8.90–9.00	36.6	5400 ± 130	−8.3
-1437	9.20–9.40	34.5	5750 ± 160	−9.3
-1669	9.80–10.00	33.7	6050 ± 140	−8.5
-1433	10.20–10.40	34.5	5880 ± 170	−8.8
-1670	10.60–10.75	30.3	6920 ± 150	
-1671	11.00–11.20	29.6	7090 ± 160	
-1435	11.50–11.70	27.8	7450 ± 190	
Wood (*Abies* sp)				
-1395	11.35–11.50	36.4	7850 ± 160	

0.8 ± 0.3% modern

Z-1325. Krčić No. 2 **> 37,000**

Powdered tufa from deposit ca 12m above brook level.

30.7 ± 0.5% modern

Z-1321. Krčić No. 3 **8000 ± 170**

Sample from tufa block lying on brook terrace; first appearance of tufa downstream from Krčić karst spring.

Topoljski buk barrier series

Krka R spring in cave under Topoljski buk barrier. Samples coll and subm 1985 by S Božičević, Geol Inst Zagreb.

47.9 ± 0.5% modern

Z-1562. Topoljski buk No. 1 **4570 ± 110**

Outer layer of tufa tube, bottom of well, passage under Krčić waterfall. *Comment:* age similar to Z-1193 (R, 1984, v 26, p 455).

48.4 ± 0.5% modern

Z-1564. Topoljski buk No. 2 **4480 ± 120**

Outer layer of tufa tube, same as Z-1562.

70.6 ± 0.6% modern

Z-1563. Topoljski buk No. 3 **2770 ± 110**

Mud above tufa tube (Z-1562 and -1564) in passage at Krčić waterfall. *Comment* (SB): expected same age for tufa and mud.

Topolje quarry series

Tufa quarry, edge of Kninsko polje. Coll 1984 by D Srdoč and B Obelić.

1.1 ± 0.3% modern

Z-1311. Topolje No. 1 **$35{,}000^{+4400}_{-3600}$**

Tufa from lowest layer, Topolje quarry.

1.9 ± 0.3% modern

Z-1313. Topolje No. 2 **$31{,}000^{+2400}_{-2000}$**

Tufa from uppermost layer, Topolje quarry.

4.6 ± 0.3% modern

Z-1316. Knin **23,400 ± 900**

Powdered tufa from trench 2.5m deep excavated during building of new hospital in Knin. Coll 1984 by D Srdoč and B Obelić.

Tufa Samples From Bosnia

Systematic ^{14}C dating of tufa in karst regions of Yugoslavia (*cf* Z-1046 to -1049, -1164 to -1167: R, 1984, v 26, p 454–455).

Z-1351. Jajce **56.3 ± 0.5% modern**
3300 ± 130

Tufa from thick deposit above Pliva R, Jajce (44° 20′ N, 17° 17′ E) Central Bosnia. Coll 1984 by D Srdoč and B Obelić.

Z-1354. Janj **0.3 ± 0.3% modern**
> 37,000

Tufa from thick deposits above Janj R, Mujdžići near Jajce (44° 14′ N, 17° 07′ E), Central Bosnia. Coll 1984 by D Srdoč and B Obelić.

Z-1552. Banja, Fojnica **9.9 ± 0.4% modern**

Tufa from thermal spring in Banja near Fojnica (43° 58′ N, 17° 54′ E), alt 670m, Bosnia. Coll and subm 1985 by I Krušić, Geoinženjering Co, Sarajevo.

Kiseljak Slatina series

Tufa deposited from thermal springs Kiseljak Slatina near Banja Luka (44° 49′ N, 17° 18′ E), NW Bosnia. Coll 1983 and subm 1985 by D Hrustanpašić, Geoinženjering Co, Sarajevo.

Z-1459. Kiseljak Slatina No. 1 **13.2 ± 0.4% modern**

Recent porous tufa from hot mineral spring mixed with decayed organic detritus.

Z-1458. Kiseljak Slatina No. 2 **1.9 ± 0.3% modern**
30,600 ± 2500

Porous dry tufa, above water level, partly covered with humus and moss.

Z-1414. Sočkovac **5.8 ± 0.3% modern**

Tufa from borehole OS-2, Sočkovac near Gračanica (44° 39′ N, 18° 18′ E), N Bosnia. Coll and subm 1985 by N Miošić, Geoinženjering Co, Sarajevo.

General Comment: percent of modern carbon in recent samples indicates ratio of biogenic to inorganic carbon in freshly deposited tufa around hot springs. No age of deposits can be deduced from these data because of insufficient knowledge of aquatic chemistry and isotopic composition of hot spring water.

HYDROGEOLOGIC SAMPLES

Plitvice Lakes National Park

Surface water ^{14}C activity was measured in 1983 and 1984 to determine ^{14}C distribution patterns along the river course. For detailed discus-

sion, see Srdoč *et al* (1986b). Samples were coll by Rudjer Bošković Inst staff.

Crna Rijeka series

Cf Z-692: R, 1982, v 26, p 369.

Z-1337. Crna Rijeka No. 1 — **69.2 ± 0.6% modern**, $\delta^{13}C = -12.6‰$

River water, coll May 1984.

Z-1379. Crna Rijeka No. 2 — **90.6 ± 0.6% modern**, $\delta^{13}C = -13.2‰$

Karst spring, coll Sept 1984.

Z-1425. Crna Rijeka No. 3 — **64.9 ± 0.5% modern**, $\delta^{13}C = -13.2‰$

Spring water, coll Dec 1984.

General Comment: Crna Rijeka spring water shows large variations of ^{14}C activity of dissolved inorganic carbon (DIC). Mean residence time is 2 yr, calculated by means of exponential model (Krajcar Bronić *et al*, 1986).

Bijela Rijeka series

Z-1024. Bijela Rijeka No. 1 — **85.9 ± 0.9% modern**

Spring water, coll July 1982.

Z-1159. Bijela Rijeka No. 2 — **83.0 ± 0.9% modern**

Spring water, coll Oct 1983.

Z-1281. Bijela Rijeka No. 3. — **84.7 ± 0.6% modern**, $\delta^{13}C = -12.2‰$

Spring water, coll Apr 1984.

Z-1434. Bijela Rijeka No. 4 — **81.3 ± 0.6% modern**, $\delta^{13}C = -12.6‰$

River water, coll Dec 1984.

General Comment: mean residence time of 4 yr was calculated by using exponential model. ^{14}C activity and $\delta^{13}C$ of DIC in spring water are fairly constant throughout year.

Matica River series

Z-1280. Matica, mouth No. 1 — **85.3 ± 0.6% modern**, $\delta^{13}C = -11.8‰$

River water coll Apr 1984, high waters, snow melting.

Z-1336. Matica, mouth No. 2 — **76.9 ± 0.6% modern**

River water coll May 1984.

Z-1381. Matica, mouth No. 3 **90.1 ± 0.7% modern**
$\delta^{13}C = -12.1‰$

River water coll Sept 1984.

Plitvica spring series

Cf Z-708: R, 1982, v 24, p 369.

Z-1025. Plitvica spring No. 1 **81.9 ± 0.6% modern**

Spring water, coll July 1982.

Z-1160. Plitvica spring No. 2 **83.2 ± 1.1% modern**

Spring water, coll Oct 1983.

General Comment: mean residence time of 3 yr was calculated by means of exponential model.

Korana River series

Z-1279. Korana No. 1 **95.2 ± 0.7% modern**

River water coll Apr 1984, Slunj (45° 07′ N, 15° 36′ E) Croatia.

Z-1278. Korana No. 2 **99.0 ± 0.8% modern**
$\delta^{13}C = -11.2‰$

River water coll Apr 1984, village Tušilović near Karlovac (45° 23′ N, 15° 37′ E) Croatia.

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