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A multitracer study of peat profiles from Tunguska, Siberia

L. Tositti [a,*], M. Mingozzi [a], S. Sandrini [a], L. Forlani [b], M.C. Buoso [c], M. De Poli [c], D. Ceccato [c], D. Zafiropoulos [c]

[a] *Environmental Radiochemistry Lab., Department of Chemistry "G. Ciamician", University of Bologna, via Selmi, 2. 40126, Italy*
[b] *Department of Evol. Biology, University of Bologna, Italy*
[c] *Nat. Inst. Nuclear Physics-National Laboratories of Legnaro LNL-INFN, Italy*

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Abstract

Two peat columns from Tunguska (Siberia) were analysed for pollen, spores, charcoal, trace elements and γ-emitters in order to identify the fingerprints of the impact of a still unidentified cosmic body (TCB), which occurred in the summer of 1908, and the level of environmental pollution in a background area of central Siberia. Peat layers were subject to non-destructive γ-ray spectrometry to derive radiochronology by the *excess* ^{210}Pb method. The age-to-depth relationship was crosschecked by using both 1963 horizon of ^{137}Cs associated to maximum global fallout deposition and palynological data profiles. Vertical distributions of trace elements in the peat columns were obtained by PIXE multielemental analysis allowing determination of the levels of environmental contamination in a background region of the Siberian taiga.

The association of heavy metals such as Ni, Co and Cu in the profiles suggests the connection of the area with mining and metal smelting activity in the north of the region through atmospheric circulation. As concerns global scale contamination, the inventory of the artificial radionuclide ^{137}Cs (4.6 kBq m^{-2}) shows a value typical of remote slightly contaminated areas resulting from global scale redistribution of radioactive fallout from Cold War nuclear weapon testing. The atmospheric inventory of the natural radionuclide ^{210}Pb, for which a mean annual flux of 200 Bq m^{-2} yr^{-1} has been calculated, is typical of continental regions.

The influence of Tunguska Cosmic Body in the peat is recognizable by a large discontinuity in the palynological profile of the peat monolith at a depth coinciding with the 1908 layer as determined by the ^{210}Pb technique, showing a large peak of total pollen counting attributed to the impact of the shockwave on the area in which huge tree stands were destroyed. Following the event, tree pollen concentration decreases abruptly showing the temporary inception of a mire environment with an increase of *Sphagnum* spore concentrations. Results of elemental analysis so far available do not show anomalies in the concentration profiles at depths coinciding with the Tunguska event layer indicating the need for pre-concentration technique enabling the detection of element associations typical of extraterrestrial materials.

Keywords: peat bogs; Tunguska; elemental analysis; PIXE; ^{210}Pb dating; ^{137}Cs; palynological analysis

1. Introduction

Ombrotrophic peat bogs are efficient receptors of atmospherically cycled matter of both terrestrial and extraterrestrial origin (Shotyk, 1996). In this paper we present preliminary data from *Sphagnum* peat profiles

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* Corresponding author. Tel.: +39 051 2099488; fax: +39 051 2099593.
E-mail address: laura.tositti@unibo.it (L. Tositti).

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collected in central Siberia in the area affected by the catastrophic effects of the so-called Tunguska Cosmic Body (TCB), which fell and exploded in the terrestrial troposphere above central Siberia in the summer of 1908 (Vasilyev, 1998; Bronshten, 2000). Though the event occurred relatively recently, hence representing one of the rare cases of direct observation of cosmic bodies falling on the Earth, the complete understanding of the facts is still far from being conclusive. The principal reasons for the difficulties encountered are the lack of reliable direct observations at the time of the event due to the limited accessibility of the region, and the lack of apparent signals such as the presence of an impact crater and/or the finding of macroscopic remnants of the fallen cosmic body. As widely described in the literature the event caused the destruction of a wide forest area together with a limited forest fire, while the shockwave produced signals in seismic recording. Seismograph recording stations were already active at the time in Irkutsk and elsewhere. Though in the months following the Tunguska event intense optical effects, possibly related to the dust produced by TCB explosion, were observed and reported in the Northern hemisphere, no macroscopic chemical or geological signal has been so far identified.

For this reason in 1999 the University of Bologna started an interdisciplinary research project with the aim of collecting information about the nature of the event itself and of the consequences it brought to the Tunguska region. Details on the expeditions and on the work so far carried out are available in Farinella et al. (2001) and on the web page http://www-th.bo.infn.it/tunguska/.

In an extensive review devoted to the Tunguska research Vasilyev (1998) pointed out how peat bogs might play a key role in the event reconstruction. Since then a certain number of papers reporting results arising from the application of several analytical and isotopic techniques applied to Tunguska peat have been published. All of them indicate the occurrence of some chemical (Iridium and Platinum group elements) and/or of isotopic anomalies possibly connected to TCB (Kolesnikov et al., 1998a,b; Hou et al., 1998; Kolesnikov et al., 1999; Rasmussen et al., 1999; Hou et al., 2000; Kolesnikov et al., 2003; Hou et al., 2004).

In this paper we report the results of a study concerning the analysis of two peat profiles from the Tunguska area by means of a multitracer approach in order to detect not only the microchemical traces of TCB fragments, but also to associate the latter to an ecological and chronological framework. Furthermore, the availability of peat samples from Central Siberia also provides the opportunity of collecting information about the level of contamination in a region scarcely investigated, but of high environmental relevance such as the eastern part of the Eurasian continent.

1.1. Area description

The investigated area is located in the central part of Krasnoyarsk Krai, Central Siberia. It lies in the Middle Siberian Plateau with altitudes of 250–500 m. Vegetation is characterized by coniferous stands (larch and pine forests) with a significant cover of hummock peat (http://www.fao.org/forestry/fo/fra/general.jsp?geo_id=4309).

The climate is typically continental with average annual temperatures of −10 °C to −6 °C (minimum −55 °C in January and maximum 19 °C in July). Annual precipitation is 500–600 mm. The territory is snow covered for long periods during the year, and has continuous permafrost. The main wind pattern is characterized by northerly winds from the Arctic in summer and by southerly winds in winter (Schulze et al., 2002).

The studied area is still sufficiently pristine, owing to the absence of road connections. Since 1996 it has been under the management of local administration as a natural reserve of Krasnoyarsk Krai.

2. Materials and methods

2.1. Sampling

Two *Sphagnum* peat monoliths were sampled in the Raketka bog, located at about 500 m SE of Lake Cheko and about 8 km N–NW from the impact location (Fig. 1). Permafrost was found at about 40 cm below the soil surface, so that a monolith could be extracted only above this depth, while deeper layers had to be cut manually down to an overall depth of an extra 40 cm using a steel axe. The first peat (KEM21; 80 cm deep) was collected during the TUNGUSKA99 expedition in 1999, while the second one (CORE2002; 52 cm deep) was collected in the summer 2002 at about 20 m from the first trench. *Sphagnum* peat samples were obtained by sectioning the peat profile every 3–5 cm (KEM21) or every 2 cm (CORE2002). The samples were dried at 30 °C in a ventilated oven to constant weight.

2.2. γ-spectrometry

Dried samples were subject to direct γ-ray spectrometry with an intrinsic n-type Germanium detector (PGT, relative efficiency: 40% and FWHM 1.8 keV at 1.33 MeV) for the determination, respectively, of

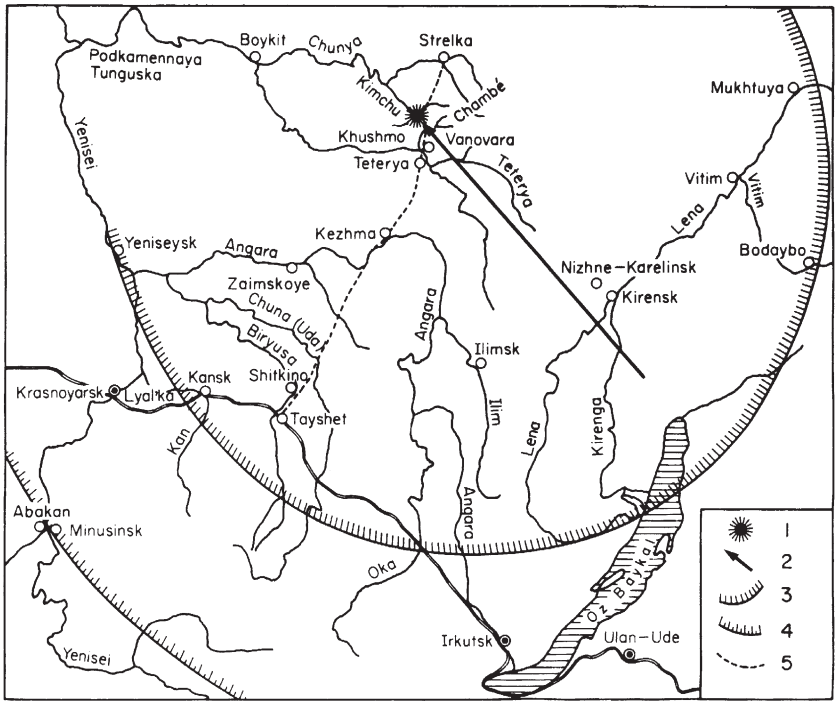

Fig. 1. Map of the region interested by the TCB catastrophe kindly provided by Prof. G. Longo responsible of Tunguska project.

^{210}Pb at 47 keV and ^{137}Cs at 662 keV. Each sample (30 g dry weight) was counted in a polystyrene container (disk geometry) for 250,000 s. Efficiency calibration of the detector was carried out by means of a mixed standard solution of γ-emitters (QCY48 and ^{210}Pb standard solution by Amersham) in the same counting geometry as the samples. ^{241}Am was determined at 60 keV using a planar detector under the same counting conditions as for the n-type counts. This detector was used to achieve a better signal-to-noise ratio at low energy, useful to detect the extremely low activity of this radionuclide in the environment.

γ-spectra have been acquired and analysed by means of Gamma2000 software package (Silena International, Milan). Uncertainty on activity measurements at 1σ level is obtained by propagating the uncertainties on both counting statistics and the efficiency vs. energy curve fit determined for the detectors under the geometrical conditions chosen. Average uncertainty for the radionuclides measured was 12% for ^{210}Pb, 8% for ^{137}Cs, and 28% for ^{241}Am.

2.3. Palynological analysis

Subsamples of peat were processed for pollen and spores by acetolysis using hot NaOH 10%, cold HCl 37%, and cold HF 40% (Erdtman, 1960). According to this method pollen and spores can be recovered and deposited onto slides after debris elimination (cellulose degradation by acid hydrolysis) and darkening of the bioparticles, therefore enabling their counting and morphological examination. Tablets of *Lycopodium clavatum* spores were added to calculate pollen, spores and charcoal particles concentration expressed as the number of pollen/spores grains and charcoal particles per cm^3. Pollen slides were mounted with glycerol jelly. About 500–2000 pollen grains per sample were identified. Charcoal analysis and charcoal classes were determined according to Sarmaja-Korjonen (1991). The particles exceeding 5 μm in diameter were counted, measured and divided into two classes: small/medium charcoals (5–125 μm) and large charcoals (>125 μm).

2.4. PIXE

Aliquots of about 200 mg of material have been weighted to form 13 mm pellets under a pressure of 5 tons. For each peat sample, 3 pellets were prepared for analysis. The pellets were coated with an evaporated carbon layer of 5 μg cm^{-2} to ensure electrical conductivity during bombardment. Certified standard reference materials (Citrus Leaves — NIST 1572, Apple Leaves — NIST 1515 and Peach Leaves — NIST 1547) were prepared and analysed in the same way as the peat samples.

The PIXE analysis was performed at the Analytical Experimental Facility of the AN2000 Van de Graaff accelerator of INFN-National Laboratories of Legnaro (Italy). Samples were irradiated using a 1.8 MeV proton beam with a diameter of 6 mm after collimation. A 200 μg cm^{-2} gold diffuser was used to homogenize the beam on the samples. X-rays were detected using an 80 mm^2 Si(Li) detector with a resolution of 180 eV at 5.9 keV. A standard electronic chain and a PC controlled MCA were used for data acquisition and energy spectra storage.

To enhance the sensitivity for heavy elements a “thick” aluminium absorber (80 μm thickness) was placed in front of the detector to eliminate X-rays from light elements with energies lower than 5 keV. No deterioration of the sample was visible after irradiation. Low energy parts of spectra were obtained separately using a Mylar funny filter with 3.3% hole and 170 μm thickness as an absorber (Gama et al., 2001). The accuracy of the results was verified by analysing pellets of standard reference materials (listed above) prepared in the same way as the peat samples. The PIXE spectra were analysed by means of the GUPIX (Maxwell et al., 1995) code to obtain the dry weight (dw) elemental concentrations.

2.5. Statistical analysis

Principal Component Analysis (PCA) was performed using Statistica software package (StatSoft). Only elements presenting a sufficiently high number of observations were considered in the analysis, in order to maximize the reliability of results. Elements discarded were Na, Cr, Sr, and V whose concentration data were rejected in some sections due to the high associated uncertainties or because not detected. PCA was carried out both on concentrations and on Ti-normalized data.

3. Results and discussion

3.1. Radiometry and palinology of KEM21

Specific activity profiles of *excess* ^{210}Pb and ^{137}Cs in KEM21 obtained by γ-spectrometry are reported in Fig. 2. Spectra were checked for the ^{226}Ra-supported fraction of ^{210}Pb, which was analysed using the γ-emissions of the ^{214}Pb and ^{214}Bi in the collected spectra; the latter radionuclides were found only in the deepest layers in which several mineral components were found at higher levels than in the upper strata and where they are in radioactive equilibrium with ^{210}Pb.

^{214}Pb and ^{214}Bi, as well as ^{210}Pb, belong to the radioactive decay series of ^{238}U that is ubiquitous in all crustal materials as the most abundant isotope of elemental U. In depositional environments, such as mires, however, an extra fraction of ^{210}Pb is provided by atmospheric deposition. Airborne ^{210}Pb, usually named *excess* or *unsupported* ^{210}Pb, is formed in the atmosphere by the decay of ^{222}Rn emitted by soil and rocks by diffusion. Owing to the efficient removal

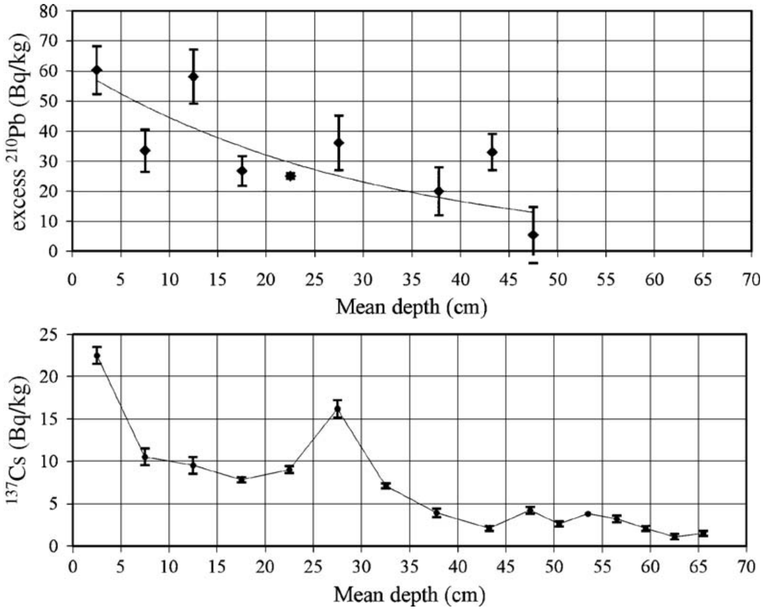

Fig. 2. ^{210}Pb and ^{137}Cs (Bq/kg) profiles as obtained from γ-spectrometry analysis of peat samples.

processes of atmospheric submicronic aerosols to which it is associated, *excess* ^{210}Pb can be used for radiodating, as in this work. In particular, geochronology based on *excess* ^{210}Pb ($t_{1/2}=22.3$ yr) is useful for dating recent deposits spanning back the past 100–150 years with a time resolution of the order of years. It is therefore an ideal tool for the identification of the 1908 event studied in this work.

In the upper part of the peat column analysed ^{210}Pb precursors are below the detection limit, therefore all the ^{210}Pb detected was assumed to coincide with the *excess* fraction which is thus determined without subtracting the supported one. This circumstance may also be taken as a likely indication that the peat is ombrotrophic. At depth below 50–55 cm the presence of ^{214}Pb and ^{214}Bi in the profile indicates the presence of mineral matter in agreement with other results from elemental analysis, suggesting a variation in the nature of the deposit from a given depth downward (see below further comments on PIXE data).

KEM21 was dated applying the Constant Rate of Supply (CRS) model to *excess* ^{210}Pb determined (Appleby and Oldfield, 1992; Appleby et al., 1997). This model accounts for the occurrence of variations of mass accumulation rate of *Sphagnum* as a result of interannual weather variability. In addition the ^{210}Pb chronology was augmented by an independent age value provided by a charcoal horizon detected at −55 cm; that is, at a depth in which ^{210}Pb dating was very critical due to the time limits of this geochronological approach, in connection with its half-life and to the poor resolution of peat subsampling. The concentration peak of charcoal particles >125 μm at this level corresponds to a huge local forest fire that occurred in 1870, as documented in Sokolev (1975). Based on the resulting age-to-depth relationship, the layer corresponding to 1908 (year of the Tunguska catastrophe) was located by extrapolation at a depth of about 42 cm. A mean accumulation rate of 0.69 cm y^{-1} was estimated for the 20th century portion of the peat, in agreement with the average age-to-depth curve determined by Doroshin (Tomsk University, personal comm.) who applied a dating method based on pine root hypocothyl penetration depth to a statistically significant population of peat columns from Tunguska. At the depth of 42 cm, palynological analysis shows peaks of total pollen and *Sphagnum* spore concentrations as shown in Fig. 3. The coincidence of this large discontinuity in bioparticle profiles with the 1908 level suggests a possible effect of the shockwave of the TCB, whose impact might have caused a huge resuspension in the area. The diagram shows also another abrupt decrease in tree pollen concentration at −55 cm, probably in connection with the forest fire in 1870. The detailed results of palynological analysis are reported in Gambetti (2002).

It is interesting to note that in the −55 cm layer, not only charcoal grains show a concentration maximum, but also ^{40}K, another naturally occurring γ-emitter detected in the peat spectra. Since it is known that K can be associated to ash from biomass burning (Andreae, 1983) and owing to the constant isotopic fraction of ^{40}K in the element, we think that this finding may further support the identification of the local 1870 fire. Though not shown in this paper, KEM21 presents other levels in which charcoal and ^{40}K show coincident peaks, though associated to less important forest fire events than in the 1870 layer. Therefore ^{40}K has some potential in adding environmental information to peat studies. This parameter should be considered with caution though, owing to the great mobility of K in the peat chemical environment. In fact ^{40}K, in analogy with ^{137}Cs and K, as discussed further on in this paper, presents a concentration maximum in the top of the core possibly resulting from relocation mechanisms induced by physico-chemical processes in the soil as well as by living *Sphagnum* (Gerdol et al., 1994; Rafferty et al., 1997; MacKenzie et al., 1997). All the elements, and in particular the γ-emitting radioisotopes mentioned, have long been studied for their complex behaviour in the soil environment where they not only interact with the soil itself but they may enter the food chain through metabolic incorporation by plants (Papastefanou et al., 1999; Ciuffo et al., 2002).

As reported in the literature (Vile et al., 1999), ^{210}Pb does not seem to be subject to post-depositional mobility in mires; however it is advisable to test the dating accuracy by independent means, in particular using the ^{137}Cs horizon associated to 1963 fallout maximum due to weapon testing.

Radiometric data (Fig. 2) show a ^{137}Cs specific activity peak in the 25–30 cm layer, to which a mean date of 1964 was attributed by ^{210}Pb geochronology. Therefore there is a good agreement between dates within the experimental uncertainty associated to sampling and measurement conditions as well as to dating accuracy. Since ^{137}Cs is apparently mobile along the peat profile (Fig. 2 and discussion below), its reliability in testing ^{210}Pb dates could be dubious. However the detection of a small peak of ^{241}Am (1.5 ± 0.5 Bq $\mathrm{kg}^{-1}{}_{\mathrm{dry\ weight}}$) in the same section — another artificial radionuclide characteristic of radioactive fallout from nuclear weapon tests, less mobile than ^{137}Cs — seems to support the convergence of dates previously indicated (Testa et al., 1999).

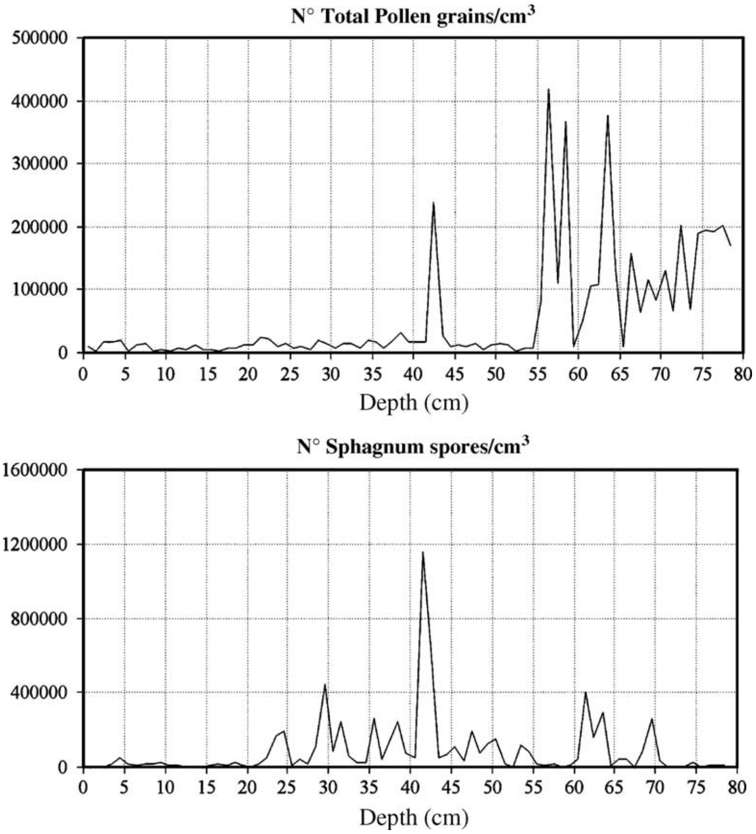

Fig. 3. Palynological data in the peat profile.

As for the mobility of ^{137}Cs along the peat column, this artificial radionuclide was found in almost all the samples of the peat profile analysed (Fig. 2). In particular the maximum for ^{137}Cs specific activity is found at the surface of the peat column as already observed by other authors in ombrotrophic peats (Gerdol et al., 1994; MacKenzie et al., 1997). This is believed to result from its upward relocation by active and passive mechanisms. ^{137}Cs shows a penetration depth corresponding to 19th century dates (well before its first environmental release at the end of World War II, and mostly during the Cold War) due to downward migration of the radionuclide (MacKenzie et al., 1997). We speculate that the behaviour of hindered migration of ^{137}Cs along the peat column is due to the presence of continuos permafrost. The presence of permafrost and low temperature throughout the year within the peat may be responsible for the limited and slow down-column migration, thus contributing to the preservation of the ^{137}Cs peak of 1963.

No ^{137}Cs peak was found in the 1986 section corresponding to the Chernobyl accident release, but this could not be checked by the ratio ^{134}Cs/^{137}Cs owing to the total decay of the lighter radioisotope ($t_{1/2}$= 2 years) since the time of the release. However, its influence in this scarcely investigated region, which was upwind the emitted plume, is thought to be rather low compared to Europe as found in the Altay, a region east of Chernobyl and several hundreds km W–SW from Tunguska (Sukhorukov et al., 2000). There, Chernobyl contribution to surface ^{137}Cs in virgin soil amounted to 18–28% based on the ^{137}Cs/^{134}Cs activity ratio, while ^{137}Cs inventories are of the order of 2 kBq m^{-2}; that is, typical of background conditions. The difference between Tunguska and Altay inventories, both rather low, is thought to be mainly due to spatial inhomogeneity in fallout deposition (Battiston et al., 1988). ^{210}Pb annual flux in the area is 200 Bq m^{-2} yr^{-1} as a result of the continental nature of the location and supports the values projected by atmospheric models developed at the Laboratoire de Glaciologie et Géophysique de l'Environnement, in Grenoble (http://www-lgge.obs.ujf-grenoble.fr/~christo/gcm/resultats_rn222pb210.html).

3.2. Elemental analysis by PIXE

To date, elemental analyses are available only for CORE2002, still undated, while *PIXE* analysis of the dated core KEM21 is in progress. In order to establish a rough chronological framework useful for chemical profile interpretation of CORE2002, sampled at a short distance from KEM21, we compared the profile of Si concentration available in both cores at a very good level of reliability. Silicon has been chosen for comparison for its conservative behaviour and for the geochemical information it provides on the accumulation pattern of peat.

The Si pattern is very similar in both peat columns (Fig. 4) but a large difference is found in the depth along which the pattern is developed; that is, within 80 cm in the older core and within 52 cm in the CORE2002, possibly due to compaction. On this basis, we expect to find the 1908 layer of CORE2002 between 25 and 30 cm. This estimate is based on an approximate proportionality ratio of 5:8 in the Si profile length and a correction for peat growth between the dates of the two samplings applied to the 1908 depth estimated for KEM21. Results of PIXE analysis are reported in Fig. 5, in which the concentration of Si, Al and Ti is expressed as % dry weight. The scatter plots of these elements are reported in Fig. 6. While Si and Ti are linearly correlated ($R^2 = 0.85$, $p < 0.06$), this is not the case for Si and Al ($R^2 = 0.15$, $p < 0.06$). This may be partly due to the higher solubility of Al in the acidic peat environment as suggested by Shotyk (1996). However Al and Si solubility are not so different to explain such a highly scattered behaviour that is probably affected by other factors as suggested by the depth variation of the Al/Si ratio ranging between 2.1 in the top section and 0.2 in the bottom section (mean = 0.6 ± 0.4). For all the other elements Ti-normalized ratios (E/Ti) were used in order to compensate for the effects due to variations in peat density as well as in mineral inputs (Shotyk, 1996). The

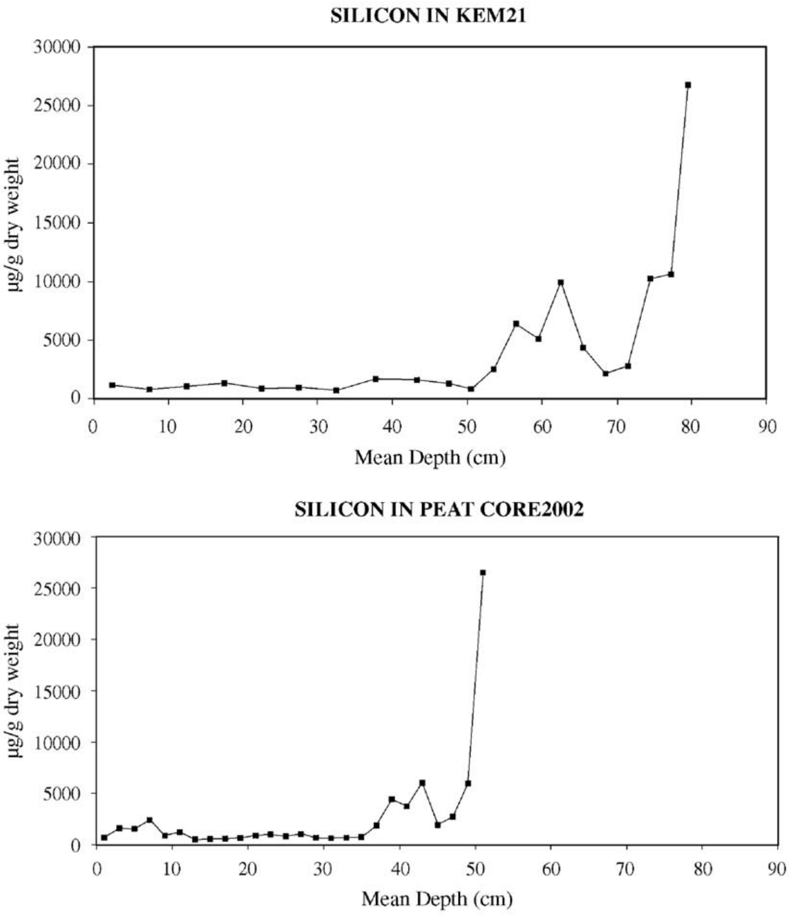

Fig. 4. Depth profile of silicon in the two peat cores KEM21 and CORE2002.

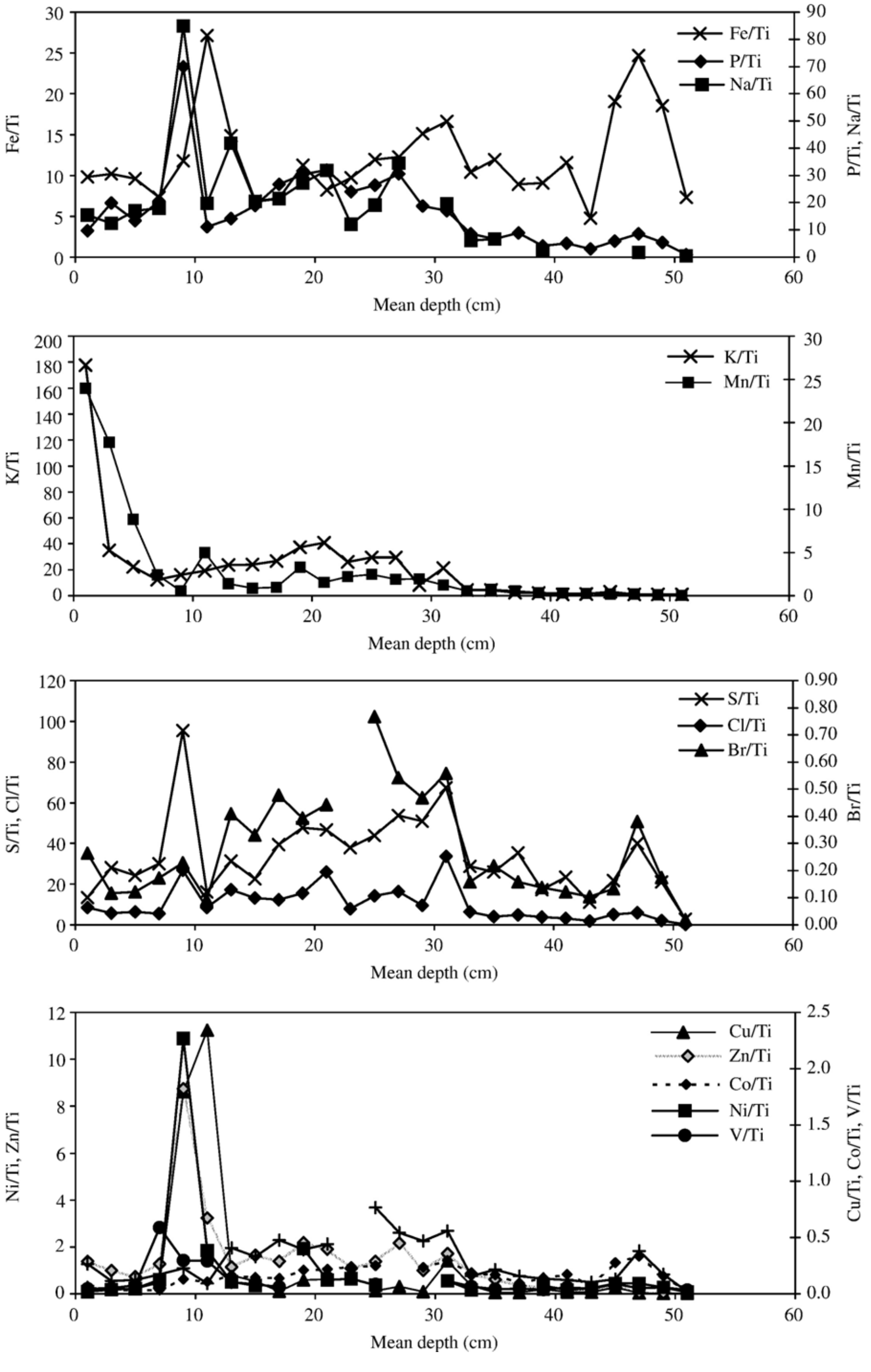

Fig. 5. Concentration profile of elements in CORE2002. Si, Al and Ti concentrations are expressed as % dry weight, while for the other elements Ti-normalized concentration is used.

E/Ti ratios obtained in this way show different patterns according to sources, chemical properties and biological implications. The latter aspect is especially evident for K, a typical nutrient element, and for Mn, both showing a maximum in the top section (Fig. 5), similarly to radionuclides ^{137}Cs (nutrient like behaviour) and ^{40}K as discussed in the previous section. However, differently from K and ^{137}Cs, Mn pattern is mainly ascribed to its tendency to get reduced and therefore to be more soluble in the peat pore water (Sugden, 1993).

The calcium profile (Fig. 7), with lower concentrations in the upper 30 cm and higher values below this

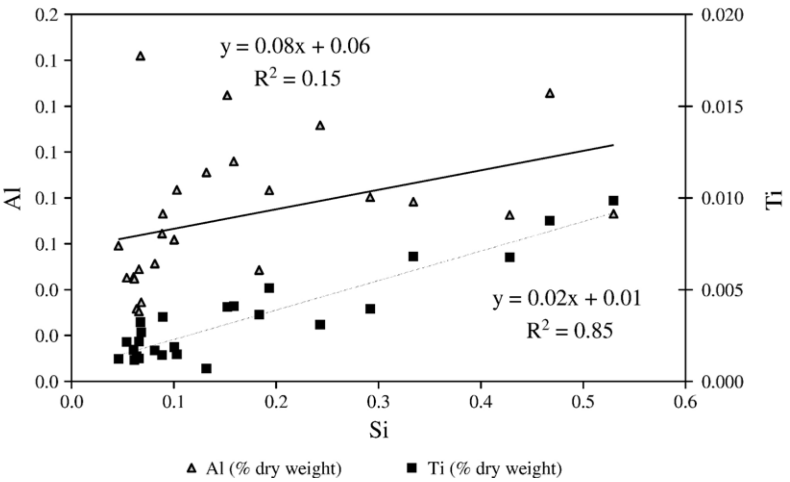

Fig. 6. Scatterplots of Al and Ti respectively vs. Si. linear relationships and correlation coefficients are also reported.

level suggests that the bog is presently ombrotrophic, in agreement with the characteristic presence of *Sphagnum* indicated by Kolesnikov et al. (2003). The same trend is observed also for Sr that is linearly correlated with Ca in the peat profile ($R^2 = 0.87$, $p < 0.06$) as a result of their similar ionic radii leading to a great geochemical affinity. Mg, the third alkaline-earth element detected in the peat, has an opposite behaviour with a maximum at the top and a minimum at the bottom suggesting a nutrient-like behaviour.

Many of the E/Ti ratios present a strong peak in the section −8 to −10 (S, P, Cl, Br, Cu, Ni, Zn) and a peak of a more limited number of elements just below this level (Fe, Cu). On a first approximation, no particular enrichment in elemental profiles suggesting an extraterrestrial source was found at a depth −25–30 cm where the Tunguska layer is expected, indicating the need for pre-concentration techniques and/or the use of microscopic techniques (micro-beam PIXE allowing for single particle elemental analysis) for a better analytical

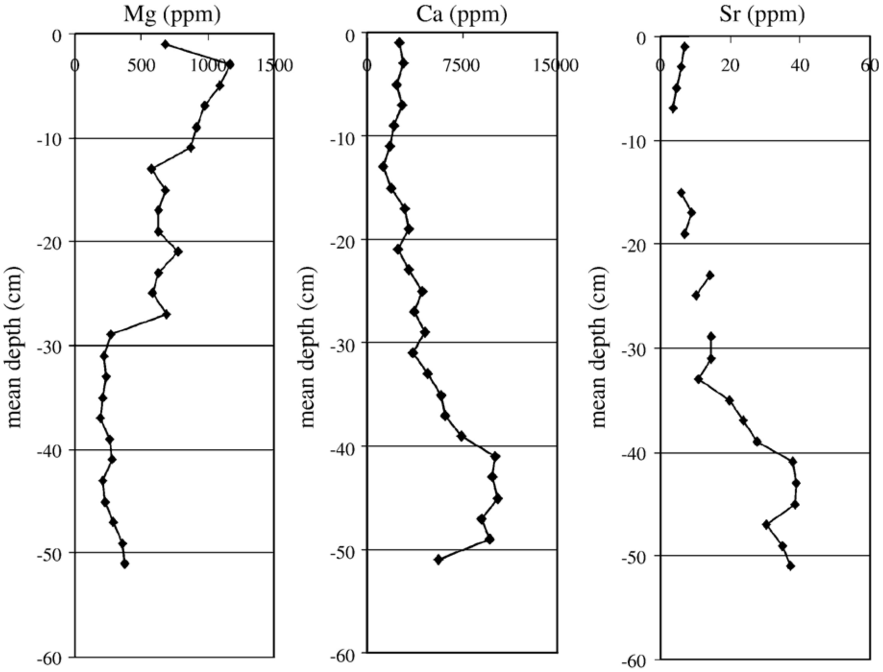

Fig. 7. Depth profiles of Mg, Ca and Sr in CORE2002.

Table 1
Results of the principal component analysis

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Si	**0.966251**	−0.094255	0.045705	0.013229	0.189632
Ti	**0.977702**	−0.038179	0.028331	−0.003082	0.150892
Al	**0.972411**	0.114431	0.005806	0.142721	0.072952
Mg	−0.131087	0.230248	−0.243338	**0.746341**	−0.51149
P	0.19592	0.102087	−0.060038	**0.937869**	0.002152
S	0.371779	−0.159793	0.137101	0.243579	**0.838885**
Cl	−0.358331	0.446803	−0.272177	−0.318151	−0.022209
K	0.071949	**0.904665**	0.028143	0.021247	−0.216318
Ca	0.067439	−0.21002	0.172907	−0.191276	**0.883811**
Mn	−0.044953	**0.828957**	−0.002528	0.42156	−0.162849
Fe	**0.912462**	−0.032142	−0.100126	−0.003698	0.358157
Co	0.337106	−0.193747	0.037998	−0.241598	**0.85744**
Ni	0.311893	−0.367225	**−0.757936**	0.152116	−0.016275
Cu	−0.022528	0.024014	**−0.950432**	−0.037462	−0.100514
Zn	−0.142343	0.18328	**−0.83969**	0.210718	−0.415621
Br	0.228142	0.133615	0.301642	−0.116601	**0.756981**
Expl. var	4.285381	2.08718	2.474639	1.973402	3.503943
Prp. totl	0.267836	0.130449	0.154665	0.123338	0.218996

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Eigenvalue	6.12	3.49	2.20	1.33	1.18
% Total variance	38.25	21.84	13.76	8.30	7.39
% Cumulative var.	38.25	60.08	73.84	82.14	89.53

approach. As for the large peaks in the upper layers, no explanation is presently available and this would require focussing on the mineralogic and chemical characterization of peat ash.

Principal Component Analysis (PCA) was carried out to determine the associations among the elements. The results of the analysis are reported in Table 1; coefficients in bold indicate elements with the highest degree of association in each group. The analysis yielded five significant factors explaining 90% of the variance of the system. Factor 1 includes the elements characteristic of the mineral fraction; that is, Si, Al, Ti and Fe (geochemical source). Factor 2 contains K and Mn showing a similar pattern as explained before. Factor 3 represents heavy metals such as Ni, Cu and Zn, suggesting atmospheric transport of pollutants. A possible source of these metals by long-range transport could be a large mining district in the North, including the nickel copper (basically in the form of sulphide minerals) smelter at Norilsk at about 800 km from Tunguska, known for emitting large amounts of pollutants into the atmosphere (Zubareva et al., 2003). This hypothesis seems fairly reasonable since Tunguska region can be considered as a background area owing to its remoteness; it therefore allows the identification of low levels of pollution transported there by large-scale atmospheric circulation, as in the case of radioactive fallout. Factor 4 includes P and Mg, two nutrient elements important for plant biochemistry. Factor 5 is of less clear interpretation and associates S, Ca, Co and Br. It may indicate another pollutant source. In particular S can be supplied to peat by atmospheric deposition following the scavenging of secondary aerosols resulting either from marine sources and/or from pollution as a result of SO_2 oxidation. The connection between factor 5 and a marine source (presence of Br and S) does not seem very likely given the distance from the sea to this continental location.

The application of PCA to Ti-normalized data largely confirms the results obtained from the statistical analysis on concentration data, but produces 4 factors, as it associates Mg and P to the factor including Ni, Zn and Cu. However it is interesting to note that, in addition to the factor connecting Ca, Co, Br and S, in this case S appears also in the heavy metals factor, further supporting a possible connection with a smelter activity.

4. Conclusions

Analysis of peat profiles from Tunguska, Central Siberia, offered the opportunity of investigating two interesting environmental aspects characteristic of this scarcely accessible region, namely: (a) the study of the consequences of the catastrophe associated to the explosion of a cosmic body whose nature is still unexplained and (b) the assessment of the levels of contamination from stable and radioactive pollutants in a background area of major environmental relevance, still largely unexplored.

Results so far collected concerning the integrated use of multiple experimental techniques show the following:

a. Radiometric analysis on KEM21 core allowed the determination of levels of natural and fallout radionuclides at a remote continental location in central Siberia where environmental data are presently very scarce. A ^{137}Cs inventory of 4.6 kBq m^{-2} has been found and a mean annual flux of 200 Bq m^{-2} of ^{210}Pb has been estimated at this site.
b. ^{210}Pb geochronology of KEM21 placed the 1908 horizon at −42 cm. At this level an intense peak of tree total pollens and *Sphagnum* spores was found, suggesting a possible connection between the impact of TCB shockwave and a large effect on pollen resuspension.
c. Elemental analysis by PIXE in CORE2002 has not yet revealed TCB microtraces suggesting the need for further analytical efforts. Chemical composition data was treated by Principal Component Analysis in order to establish associations among sources of the elements. It was possible to detect a geochemical source (Si, Ti, Al, Fe); an association between K and Mn whose similar profiles are caused by different mechanisms; a factor connecting nutrient elements, and two factors suggesting traces of regional pollution, one of which possibly related to a known mining/smelting district in the north of the country.

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