Exploring the site of the Tunguska impact

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The Tunguska event is the largest cosmic calamity caused by the impact of an interplanetary body with the Earth atmosphere that happened during historical times. A two-week scientific expedition (Tunguska99, http://www-th.bo.infn.it/tunguska/) to the impact site has been carried out starting from 14 July 1999 by the Department of Physics of the University of Bologna, in collaboration with researchers of the Turin Astronomical Observatory and of the Institute of Marine Geology (CNR Bologna). A camp was built in the taiga, at some hundred kilometers from the nearest roads. Personnel and researchers, mainly from Tomsk (Russia), provided local support. The participants and the equipment were transported from Italy to Krasnoyarsk by a Russian *Iljushin IL-20M* aircraft of the GosNIIAS Institute and from Krasnoyarsk to Tunguska by a Russian *MI-26* helicopter. The main goal of the expedition was to carry out a systematic exploration of the impact site, in order to assess the nature of the body that caused the devastation, felling more than 80 million trees. The explosion occurred at a height of 5-10 km, releasing energy between 10 and 20 million Megatons. Neither macroscopic fragments of the cosmic body, nor a typical signature of an impact, like a crater, have been found. In spite of the vast amount of theoretical and experimental work done up to now (Vasilyev 1998 and references therein), the nature and composition of the cosmic body and the dynamics of the event have not yet been clarified. Some, but no conclusive, data were acquired by the first Italian 1991 expedition (Longo et al. 1994, Serra et al. 1994). The "Tunguska99" expedition (Amaroli et al. 2000) was organized in order to give an answer about the origin of the Tunguska event, and a contribution to the international research programs aiming at the study of cosmic impacts with the Earth. The main tasks of the "Tunguska99" expedition were: 1) to study the structure and sediments of the lake Cheko; 2) to carry out a multispectral (from visible to medium infrared) aerial photosurvey of the explosion site; 3) to collect peat, rock and wood samples; 4) to monitor gamma rays during the flights Italy–Siberia–Italy and in Tunguska. The samples and data collected during the expedition are now under examination in different Italian laboratories. The aim of these analyses is to deduce important characteristics of the Tunguska event and to refine, verifying their accuracy, the mathematical models concerning the impacts with atmosphere of cosmic bodies having different composition and dimensions.

The results of the geophysical/sedimentological study of the Lake Cheko will make it possible to understand its origin and to find whether the lake stores information on the Tunguska body. What obtained up to now is summarized in a second contribution to the present Workshop (Gasperini et al. 2001) and is here omitted.

The expedition Tunguska99 differed from all the previous ones by the fact that the investigations were performed simultaneously by water means on the Lake Cheko, by ground means and by aerial remote sensing, in collaboration with GosNIIAS. Many aspects of the Tunguska event can be studied by comparing the aerophotosurvey of the explosion site made in 1938, with the new one performed during the Tunguska99 expedition. The possibility to analyse the 1938 aerophotosurvey is of fundamental importance because it was carried out only 30 years after the event, when the tree trunks overthrown by the shock wave were still easily recognizable on the ground. This will allow us to locate the fallen trees and to determine accurately their directions. Krinov, referring to the 1938 survey, states: "It is a unique scientific document authenticating the only radial forest devastation of its kind in existence and caused by the explosion of a meteorite" (Krinov 1966). The 1938 photographic material, never completely analysed, could release important information on the fallen tree distribution and on the location of possible secondary "epicentres" produced by the explosion of some large fragments coming from the principal cosmic body, as reported by several witnesses of the event and subsequently deduced by some researchers. A more accurate determination of the forest area destroyed by the explosion will allow us to estimate with higher precision the energy released and could shed light on the impact dynamics. The 1999 aerophotographic survey

Figure 1. Photograph (from 26 July 1999) from the point usually called the "epicentre" of the explosion

covered a surface of more than 250 km^2 between the latitudes 60° 50' 00" N and 60° 58' 30" N and between the longitudes 101° 45' 00" E and 102° 05' 00" E. The photos have been taken in the scale 1:8000 and 1:14000 with coverage of 60% (long.) and 30% (lat.). In parallel, a line scanner made simultaneously a survey in 6 spectral bands, from optical to thermal infrared: 0.43-0.51 μm, 0.50-0.59 μm, 0.61-0.69 μm, 0.76-0.90 μm, 1.5-2.5 μm and 8.0-12.5 μm. Fig. 1 shows the western part of the Southern swamp photographed on 26 July 1999. Kulik's analysis (Kulik 1939, 1940) has indicated in this area the possible presence of two secondary centers of wave propagation (see Serra et al. 1994).

During the flight, the aircraft position was continuously monitored with a GPS system and the geographic coordinates were linked to the photographs. Contemporarily, we measured on ground the coordinates of different reference points in the same area. These data will allow us to recognise ground elements on the aerial pictures and to connect them to the regional topographic net.

Peat, wood and rock samples from the impact site have been collected. A piece of peat (50 x 20 x 80 cm) has been taken at about 500 m from the SE border of the Lake Cheko. Isotopic analysis and pollen examination have been carried out to find indications on the composition of the cosmic body and on vegetation changes due to the 1908 impact. In the layer corresponding to the year 1908 a variation of the ^{13}C and ^{15}N content is clearly observed (see Fig. 2 reproduced from Kolesnikov et al. 2001). Wood samples from trees surviving the 1908 explosion have been collected at different distances from the epicenter, in order to further the investigation carried out by the first Italian expedition in 1991. Pieces of the so-called "John rock" have been collected. SEM observation of these samples has confirmed the rock sedimentary origin.

Gamma rays have been continuously monitored both during the flights Italy-Siberia-Italy and during the two-week stay in the Tunguska Natural Reserve (Longo et al. 2000) by using a detector of the VRC group of the University of Bologna. In the past similar detectors have been used to study gamma ray variation in dependence of solar activity, of the geomagnetic field, and of the environmental conditions in Italy, Antarctica, Svalbard islands, Himalayas, and during the sea trips voyages Italy-Antarctica-Italy. The new in-flight measurements indicate significant cosmic ray flux variation due to the solar activity. At the base camp, gamma rays from cosmic and environmental radiation have been continuously monitored (at 60° 57' 49" N and 101° 51' 22" E) on time scale of 15 minutes, in the 0.05-3 MeV and in the 3-10 MeV energy bands. Daughter radionuclides from the ^{238}U and ^{232}Th chains have been recorded close to the lake Cheko. The data are being processed to find other natural or man-made radionuclides. As previously observed in other places, the measurements in Tunguska confirm the existence of sporadic radonic storms in connection with rain washout.

Our field research can be strengthened by theoretical studies and modelling. A first step in this direction has been achieved and an 83% probability for an asteroidal origin of the Tunguska cosmic body has been obtained (Jopek et al. 2001).

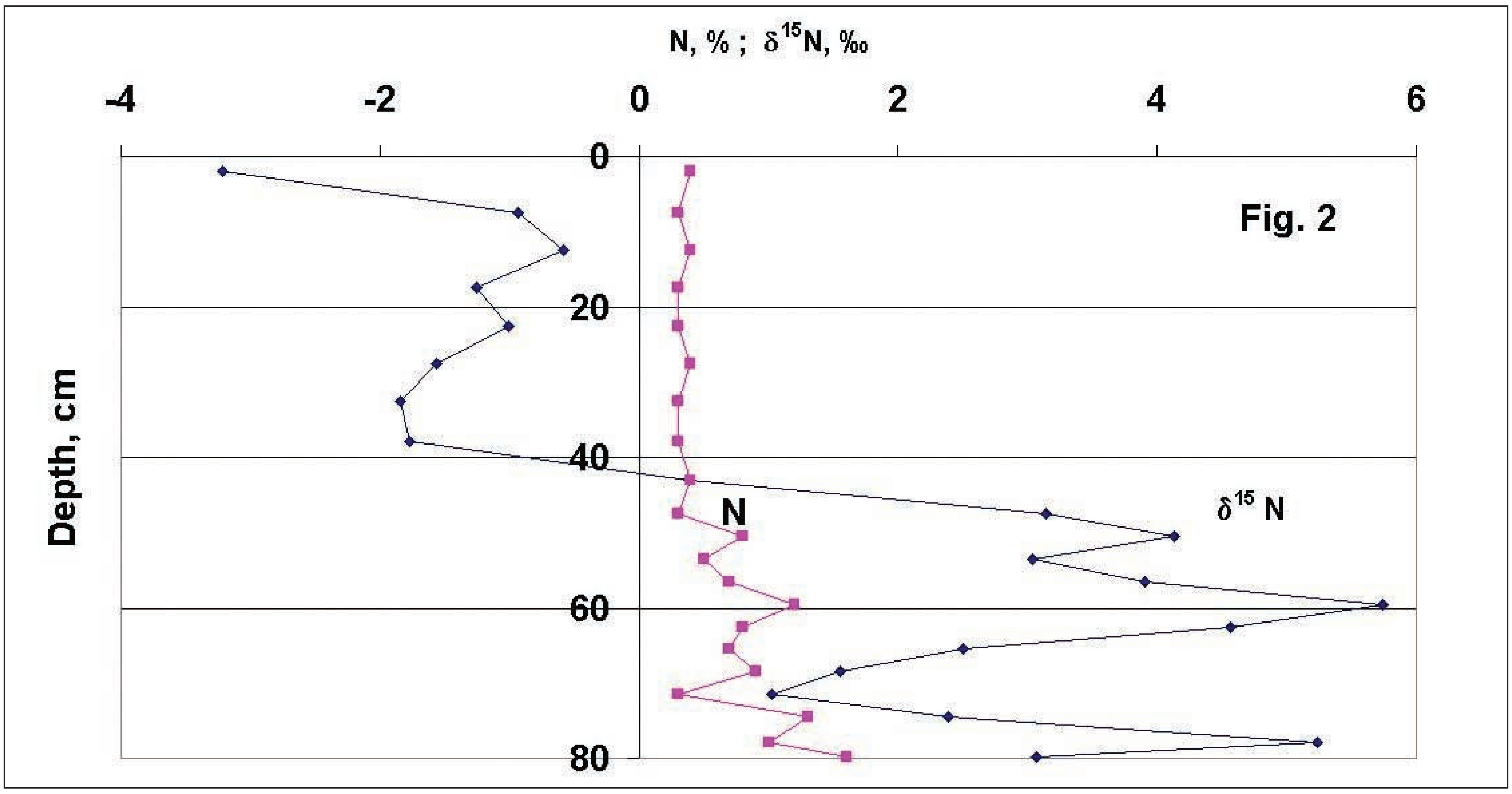

Fig. 2. Content and isotopic composition of nitrogen in peat column taken near Lake Cheko during the Tunguska99 Expedition.

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Geophysical/sedimentological study of a lake close to the epicenter of the great 1908 Siberian (Tunguska) Explosion

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A scientific expedition took place in July 1999 in the region of Tunguska (Siberia). The objective (Longo et al. this volume) was to gather data that could help understand the so-called "Tunguska event", namely, an explosion that on June 30 1908 devastated over 2000 square km of Siberian Taiga. Several hypotheses have been put forward to explain the Tunguska event. Most assume the explosion in the atmosphere of a small asteroid or comet. However, fragments of the cosmic body have not been found to date, although several data (including iridium anomalies in peat deposits) support a cosmic impact hypothesis (Longo et al. 1994, Kolesnikov et al. 1999). One of the main tasks of the 1999 expedition was a geophysical/sedimentological study of Lake Cheko, a small (~ 500m diameter) lake located 8 km from the inferred epicenter of the Tunguska event (Florenskij 1963, Fast 1967). An inflatable catamaran was used both for the geophysical survey, and for the coring operations. Our work had two main objectives: 1) to check whether or not the lake fills an impact crater related to the event; 2) if the lake is not an impact crater related to the 1908 event, to detect in the lake sediments mineralogical, chemical and biological evidence on the nature of the cosmic body. The field study lasted 12 days, and included acquisition of: a) morphobathymetry; b) bottom acoustic reflectivity; c) side scan sonar; d) high resolution reflection seismic and Ground Penetrating Radar (GPR) profiles; and e) sediment coring. The bottom topography of the lake was obtained using a digital single-beam echosounder. Reflectivity data from each ping have been collected, together with the depth sounding, by sampling and on-line analyzing the bottom echoes. This, together with accurate DGPS postioning, allowed the creation of a detailed bathymetric map of the lake. The sedimentary infill of the lake has been studied collecting a tight grid of high resolution seismic reflection profiles with two different systems that allowed a vertical resolution of about 1 and and 0.05 m respectively, and by a GPR that has been employed on the shallowest portion of the lake and on shore.

Gravity cores were collected from the lake bottom at different locations chosen after a preliminary analysis of the geophysical data. Sedimentological, geochemical, mineralogical as well as radiometric and magnetic analyses were subsequently carried out on selected samples. The large body of data collected during our fieldwork is still being processed. However, some preliminary results can be discussed.

Aerial images collected during the 1999 expedition (Fig.1) show that the lake stands within an alluvial plain (lighter, flat areas), covered by the sedimentary deposits of a river (the Kimchu River) that flows into the lake on its SW side, and outflows ~200m away on the same side. The western shore of the lake is partially bounded by a about 200m high relief made of igneous rocks (mainly dolerites), part of the pre-Mesozoic regional basement (Sapronov 1986). The river, like other rivers in this region, displays wide meanders, due to the low topographic gradient. The lake, if we exclude a shallow (< 2m) flat area on its SW side, has a nearly circular shape, slightly elongated in the SE-NW direction, and a funnel-like morphology, with a maximum depth of about 50 m close to its center (Figure 1). The slopes are slightly asymmetrical, the northern being a little steeper that the southern, but do not show important morphological breaks. The major irregularities are related to recent sedimentary processes, observed mostly in two areas: the northern slope where slump deposits are shown both in side-scan and bathymetry imagery, and the southwestern sector, where the inflowing river's deposits prograde into the lake, off the river's mouth, forming a ~100m-long, 50 m-wide sedimentary wedge (Fig.1).

From the high resolution seismic reflection profiles we can divide the sedimentary sequence in two units: a finely layered upper unit, roughly from 20 to 100 cm thick, and a lower chaotic unit, the base of which was not imaged by our profiles (Fig.2).

The lake's sediments show a general dark brown-blackish colour, a high content of organic matter, a fine grain

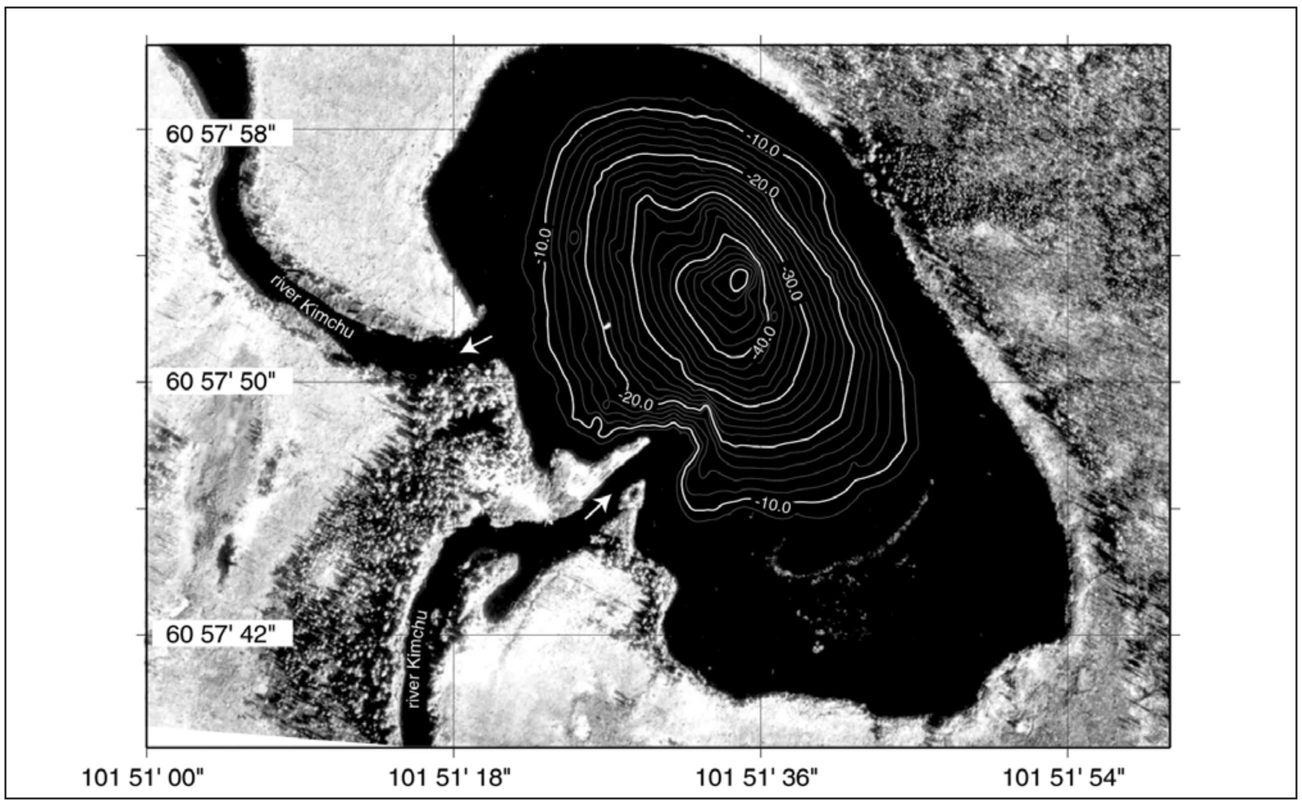

Figure 1. Aerial image and superimposed bathymetric map (isolines each 2 m) of the Lake Cheko obtained during the 1999.

size and alternating laminated and massive intervals. Water content is high in all cores. Cores collected from shallow-water areas show laminations throughout their length. The sediment is mainly sandy mud (pelite ranges from 60 to 80% d.w.) with organic matter ranging from 5 to 16 % d.w. The mineralogical composition is rather constant in different cores, showing predominant quartz, plagioclases, K-feldspar and clay minerals, mostly a smectite. Cores collected form the lake center display a more complex stratigraphy, i.e., two different facies: an upper, laminated and a lower massive units, in agreement with the seismo-stratigraphic observations. Within the upper unit the sandy component is larger (up to 60%). Analyses of several biological proxies (e.g. diatoms, pollen, algal pigment) are being carried out in order to understand the environmental significance of the two facies.

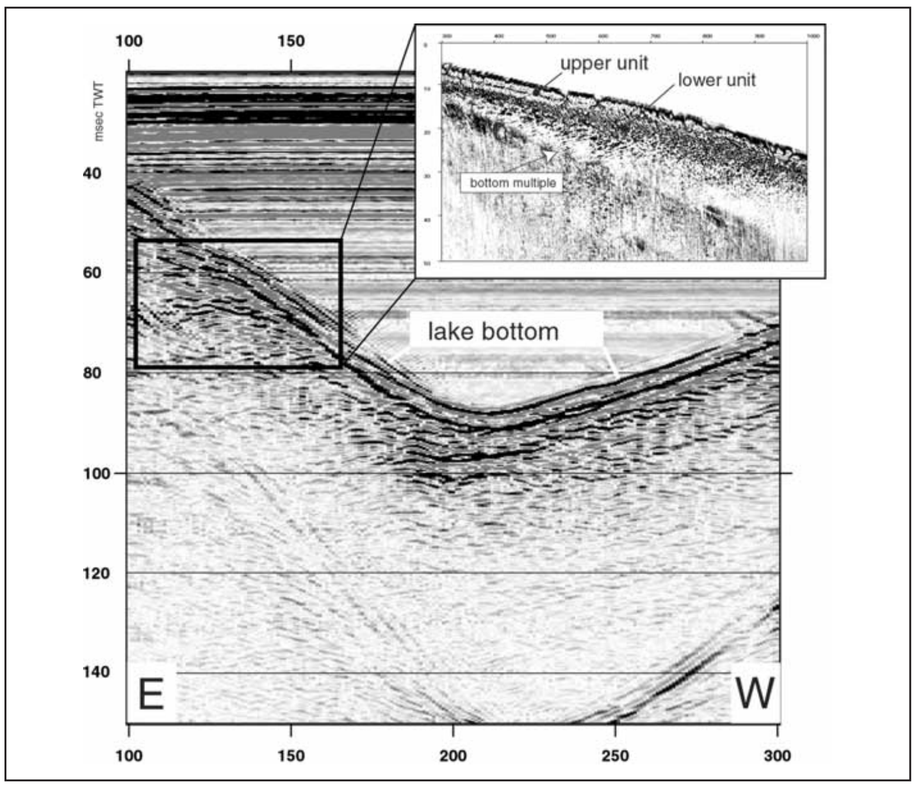

Figure 2. Example of E-W seismic reflection profiles across the lake center. The higher resolution profile (close-up) clearly shows the contact between the two main seismic units: the upper, finely laminated and the lower, chaotic.

The time frame, derived from ^{137}Cs and ^{210}Pb activity-depth profiles, identifies the interval corresponding to the 1908 event at different depths in cores. The average depth of this level is from 20 to 40 cm in the shallow-water cores, and between 60 and 80 cm in the cores collected near the lake's center. Preliminary biological investigations suggest that the lake pre-existed the 1908 event, because similar assemblages of lacustrine organisms were found above and below the 1908 event layer. The shallow-water cores do not show important facies changes close to the 1908 event, although an increase in the grain size occurs. Deep-water cores record intstead important sedimentological changes below the event: larger organic remains (larch cones, leaves, herbs or moss, wood fragments), massive or oblique laminated layers and higher C/N ratios. All these occurences can be interpreted as an increase in the energy of the sedimentary processes within the lake, as well as disturbances in the drainage basin, around the level corresponding to the 1908.

A preliminary analysis of the geophysical data and of some sediment cores indicate that the Lake Cheko is a young feature and its sedimentary infill record a major change in the environmental conditions, from 0.2 to about 1 m below the lake floor. Although the morphology of the lake is compatible with an impact origin, several sedimentological and biological proxies indicate that its formation pre-dates the 1908 event. The isotopic composition of the organic matter and the sediment geochemistry (major and trace elements), will help define the nature of the cosmic body that caused the 1908 Tunguska event.

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