GROUND PENETRATING RADAR STUDY OF THE CHEKO LAKE AREA (SIBERIA)

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SUMMARY

We performed an integrated acoustic and GPR study of the Cheko Lake area (101° E, 62° N) during summer 1999. The GPR study aimed at imaging lake bottom and shallow sedimentary layers to plan coring of sediments coeval with the catastrophic 1908 explosion. The water of the Cheko Lake strongly attenuates radar waves. Therefore, the central and northern sectors of the lake (30 m average depth) were surveyed by means of acoustic techniques only. Integrated acoustic and GPR techniques were used in the shallow southern sector. More than 5 km of radar profiles were obtained in the lake, using 50 MHz and 100 MHz antennas. 150 metres of 200 MHz multi-fold profiles were obtained across the only accessible sectors on land. The GPR profiles processed to date successfully image discontinuities at depths greater than 700 cm. Comparison with acoustic results shows that GPR provides high resolution images of the depth range of interest (0-500 cm) which complement the information obtained from sub-bottom profilers and can be calibrated by the gravity cores. A deep (700 cm) flat sub-horizontal reflector, shallow (0-200 cm) dipping layers, sigmoidal structures and local chaotic lenses are the primary features imaged by GPR in the lake.

Key words: GPR, Freshwater, Imaging, Lake, Sediments, Siberia

INTRODUCTION

A GPR survey was carried out in the Cheko Lake area at the Tunguska Meteorite Site (Russia, 60°57'N - 101°51'E, Fig.1) in July 1999 by a research unit of the Exploration Geophysics Group of the University of Trieste (Italy) in the framework of a scientific cooperation programme with the *Institute of Marine Geology* (Italy), the *University of Bologna* (Italy) and the *Russian Academy of Sciences* (Russia). In summer 1908 a giant explosion, which released an estimated energy greater than 30 million tons of TNT, razed to the ground more than 1200 sqkm of forest and burned down an equivalent area at the Tunguska Meteorite Site. Recent estimates (Fesenkov, 1978), based on observations of the atmospheric turbidity from Mt. Wilson Observatory (California) at the time of the explosion, indicate that an approximate mass of 1 million tons of cosmic material was dispersed in the atmosphere as a consequence of the explosion. A large meterorite or a small comet core, exploded at an approximate altitude of 5,000 m, are the hypotheses which best fit the available data (Chyba et al., 1993; Kolesnikov et al., 1998; Pasechnik, 1976). Evidences in confirmation of such hypotheses are still lacking because material of the presumed Tunguska Cosmic Body (TCB) has not been found to date (Kolesnikov et al., 1999).

Primary objective of the expedition was the study of the sediments of the Cheko Lake, a bean shaped freshwater basin with a long axis of approximately 500 m located some 9 km from the estimated epicentre of the explosion along the Kimchu river (Fig.1), to answer the following questions:

- Is the Cheko Lake an impact structure related to the Tunguska event?
- Evidences of the causes of the event can be found in the structure of the basin and in its sedimentary layers?
- Which chemical or physical anomalies characterize the Catastrophic Sedimentary layer (CSL)?

The GPR survey aimed in particular at the following objectives:

- High resolution imaging of the shallow sedimentary layers.
- Joint interpretation of EM and acoustic data to reconstruct the recent sedimentary history of the lake and identify possible anomalies related to the catastrophic event.

We obtained a GPR dataset consisting of approximately 10 km of *single-fold* (off-shore) and *multi-fold* (land) profiles. The deepest target imaged by the off-shore radar profiles is an unconformity at an average 700 cm depth. Dipping layers and sigmoidal features show up in the shallow 300 cm from the lake bottom and are apparently related to the beginning of fluvial deposition in the area. The same stratigraphic patterns are imaged by the acoustic survey (400 Hz Bubble Pulser, 2kHz FM Chirp pulse sub-bottom profiler). Localized sectors exhibit strong attenuation of the radar waves which are associated with the chaotic patterns imaged by acoustic data. Radar waves velocities to be used in migration and depth conversion are calculated from multi-fold records obtained on land. Based on the preliminary results of the integrated geophysical study, a number of cores of the lake bottom were taken at selected locations and are currenty being analyzed to identify chemical or physical anomalies related to the catastrophic event.

METHOD

Equipment

A RAMAC digital GPR equipped with 50 MHz, 100 MHz and 200 MHz antennas was used. We performed 100 MHz and 50 Mhz off-shore data acquisitions while 200 MHz antennas were selected for the land profiles as an optimum compromise between depth of penetration and resolution. A high amplitude pulse (1000 V) was fed to the antenna element. The raw GPR data were stored in 16 bit binary format on a portable PC.

Data acquisition

The water of the Cheko Lake is rich in oxides and sediment particles which produce a net loss in excess of 8 dB/m at 100 MHz. Therefore, the central and northern parts of the lake, characterized by maximum depths around 54 metres, were surveyed by means of acoustic techniques only [400 Hz (central frequency) Bubble Pulser, 2 kHz FM Chirp sub-bottom profiler). Integrated acoustic and GPR techniques were used in the southern sector, where the average depth is less than 3 metres. More than 10 km of radar profiles were obtained in the lake, using 50 MHz and 100 MHz antennas and DGPS positioning. 150 metres of multi-fold profiles were obtained across the only accessible sectors on land. We performed off-shore single-fold data acquisition using 50 MHz and 100 MHz bistatic antennas located in two inflatable rubber boats at constant 180 cm offset. The bottom of both antennas was 2 to 4 cm below the water surface and was isolated from water by a 2 mm thick rubber sheet. The antennas were towed at regular 1 kn speed and a 3 sec shooting rate provided a spatial sampling of 1 trace per 1.5 m. A DGPS system was used to position the profiles.

The following land data acquisition sequence was performed:

- *Single fold profiles* (200 MHz - 80 cm offset) aiming at a preliminary identification of the targets, calibration of the instrument, selection of the optimum frequency (antenna), analysis of the subsurface response as a function of the orientation of the profile.
- *Multi-fold profiles (multiple common offset, common mid point gathers)* to obtain enhanced subsurface images and information about radar velocities and physical properties of the imaged discontinuities.

The average maximum offset of the land profiles was 200 cm.

Data processing and interpretation

Back-ground subtraction, removal of coherent noise from shallow scatterers (mainly trunks and branches brought by the stream), deconvolution and migration form the basic processing sequence for the off-shore data. Velocity analysis, pre-stack coherent noise filtering, stack and multi-offset reflectivity analysis are additionally applied to the land data. An approximate 25% of the whole off-shore and

land dataset has been processed to date. The following processing sequence was applied to the data:
DC component removal
Time-zero drift correction
Amplitude analysis
Spectral analysis
Spherical divergence correction
Design and application of Band Pass filter
Shape detection based suppression of coherent noise (proprietary algorithm)
Migration
Velocity analysis, stack and correlation of land and offshore data is in progress. The main noise component observed in the data is a short period high-energy reverberation which was removed by means of proprietary Hough Transform based algorithms (Pipan et al., 1998).

SOIL CHARACTERISTICS

The area of study is characterized by sparse extrusive and intrusive outcrops and by a sedimentary layer which may be locally thicker than 3 km. Shallow sedimentary layers in the Cheko lake area range from clays to fine gravels with interspersed plant remains. Layers of peat are found on land.

RESULTS

Several unconformities of interest to reconstruct the main stratigraphic features and the recent evolution of the Cheko Lake were imaged by the GPR profiles obtained in the Cheko Lake. We can group the imaged feature in four classes, characterized by different radar response, average depth and stratigraphic relationships (Fig.2,3):

1. *Deep sub-horizontal reflectors (Fig.2, D)*: such discontinuities are observed in most profiles and are located at an average depth of 700 cm (depth estimates based on the velocity analysis performed on the multi-offset land GPR records).
2. *Zones of chaotic deposition (Fig.2, A)*: they may interrupt the primary reflectors (Fig.2, A_2) or be located within lenses in prograding clinoforms or paleo-channels (Fig.2, A_1).
3. *Dipping reflectors (Fig.2, B)*: they show up in most of the profiles from the SW sector of the lake at depths not greater than 300 cm. They bound features (clinoforms, channels) characteristic of fluvial deposition and mark the beginning of basin sedimentation in the area. Sedimentation rates obtained from the available cores will assess the time relationships between such features and the catastrophic event.
4. *Shallow parallel reflectors [SPR] (Fig.2, C)*: such events were interpreted in a first phase as reverberations from the shallow layers. Tha analysis performed on different profiles indicates that they are primary events which are normally parallel to a shallow discontinuity. In Fig.2, the SPR simulates the above dipping reflector at the NW margin of the profile and assumes a bottom parallel trend to the SE of the toplap termination.

A comparison between a 400 Hz bubble pulser profile and a corresponding segment of the GPR profiles show the resolution attainable and the complementary information which can be obtained from integrated acoustic and GPR surveys.

CONCLUSIONS

The results of this research show that:

a. GPR was used to image sub-bottom discontinuities of a freshwater basin in the 0-1000 cm depth range (including the water layer).
b. The resolution attainable by means of GPR in the conditions of the present work (i.e. low acoustic and radar velocities) is greater than that provided by the low-frequency acoustic system employed in the survey (400Hz central frequency) and can complement the acoustic data in the shallow depth range.
c. A proper selection of acoustic and radar frequency ranges may open up the route to same wavelength acoustic-radar (SWAR) studies. This is of particular interest in the present case, because the main features imaged by GPR match those obtained from acoustic data in the profiles analyzed to date. The good agreement between the seismic and radar stratigraphic patterns reconstructed in the shallow south-east sector of the Cheko Lake indicate that the major unconformities are related with net changes in the electric and elastic properties of the sediments.
d. The similarity of the GPR and acoustic patterns allows the application of seismic stratigraphy techniques to reconstruct the evolution of basin and strandlines.

e. Calibration of radar and acoustic data by means of the available cores and evaluation of the sedimentation rate are in progress.

ACKNOWLEDGMENTS

This research was supported by the sponsors of the Tunguska'99 expedition (see http://www-th.bo.infn.it/tunguska/tu99sponsor-en.htm for a complete list) and by CNR grant n. 98.00556.PF37. Prof. E.M. Kolesnikov is gratefully acknowledged for useful comments and stimulating participation in field work.

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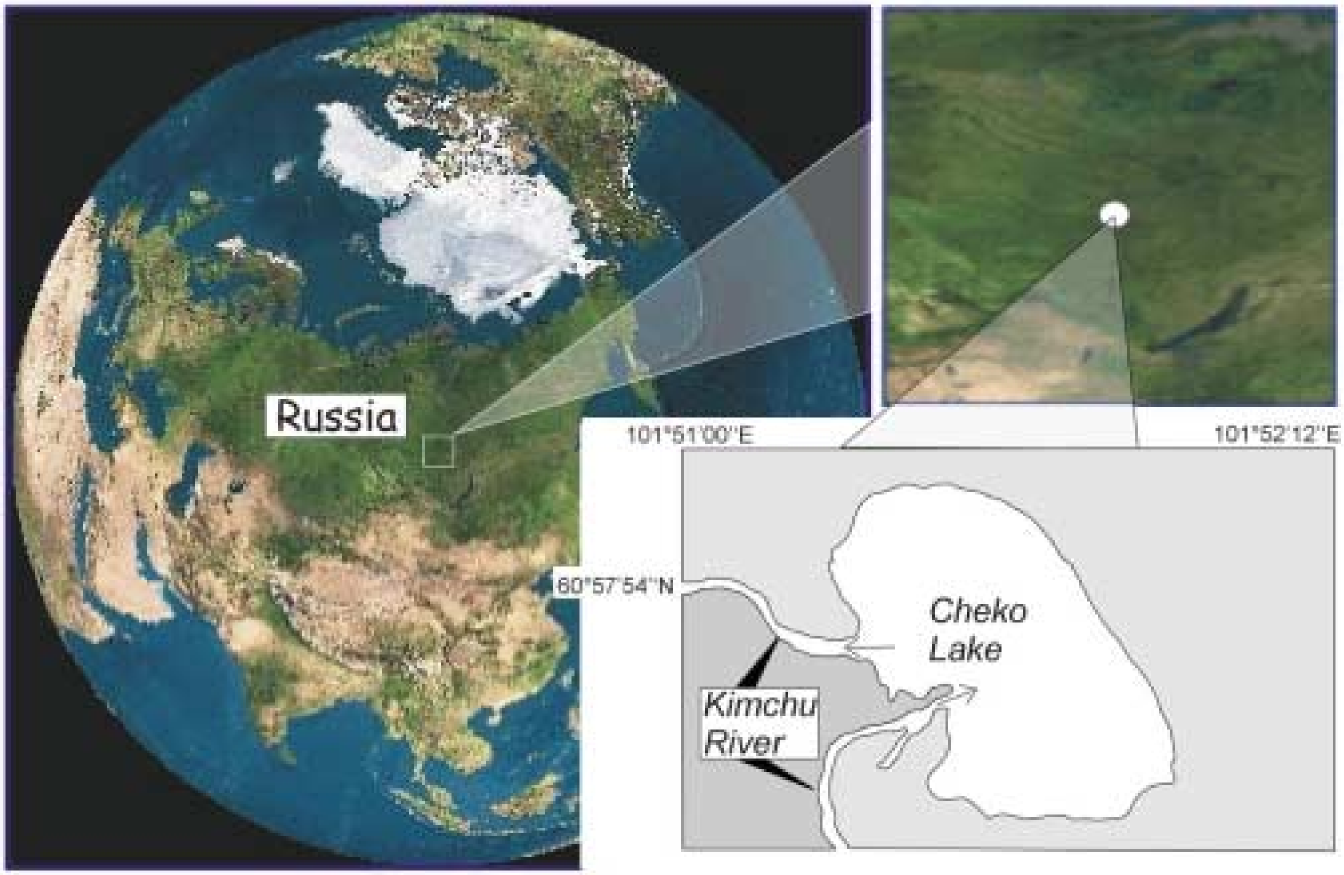

Figure 1: Location map of the area of study

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