Geophysical Benchmarking of Cave Cavities and Underground Water Horizons

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Summary

Seismic-electric effect method was applied in field to forecast subsurface cave dome cavities and to benchmark underground water horizons. A source of seismic waves were repeated blows of a heavy hammer or powerful signals of magnetostrictive installation. Main frequency used was 500 Hz. Passing layers the seismic wave caused electromagnetic fields on the boundary interfaces. Electric responses of these electromagnetic fields were measured on a surface by pair of grounded dipole antennas or by one pivot and a long wire antenna acting as a capacitive pickup. The arrival times of responses from a cave cavity and from a water horizon correspond to the time of seismic wave propagation from a source to the cavity or to the water interface correspondently. The method depths successfully investigated were between 2,5-25m. An advantage of our method in comparing with usual seismic ones is in a fact that signals registered from boundary interfaces are distinctly traced on a receiver to be available for a proper treatment.

Introduction

A seismic wave propagating in a fluid saturated medium can induce an electromagnetic field (PRIDE, 1994). Generally in a porous rock, adsorption of electrical charge to the surface of solid grains creates an excess of mobile ions of the opposite charge in the pore fluid. A seismic wave propagating in such rock displaces the ion-carrying fluid with respect to the solid matrix generating a streaming electrical current that results in a macroscopic charge separation inducing an electrical field. The value of the induced electrical field depends on the type of a saturation, porosity, permeability, chemical properties of the solid matrix and so on (BOULYTCHOV, 1997), (BOULYTCHOV & KOKSHAROV, 1999).

Field experiment

When a spherical incident P-wave crosses an interface between two mediums it creates a dipole charge separation due to imbalance of the streaming currents induced by the seismic wave on the opposite sides of the interface. The electrical dipole radiates an electromagnetic wave that can be detected by remote antennas on a surface. The SE conversion is numerically showed to occur at permeability or fluid chemistry contrasts (HAARTSEN & PRIDE, 1994). A source of seismic waves were blows of a heavy sledgehammer or repeated powerful impulses of magnetostrictive installation. The vertical ground motions were measured using an array of geophones. Main frequency used was 500 Hz. As a base the nonmetallic lucite plate was used for the source impact with the plate to avoid a high frequency electromagnetic pulse generated while the impact moment. To eliminate an undesirable current in the ground induced by an electric current flowing through the trigger cable at the moment of the source impact, the trigger cable was isolated from the ground and cut as short as possible. The horizontal electrical fields were measured on a surface by low noise preamplifiers connected to a pair of grounded dipole antennas represented by two stainless steel electrodes-stakes or by one pivot and a long insulated wire acting as a capacitive pickup. Exit signals were recorded by a data acquisition installation elaborated in our institute geoacoustics laboratory. In different experiments antenna lengths used were to be 2,4m or 4,8m, a spacing between the antennas was chosen to be 0,6m or 1,2m. The offset between the source and antennas measured to the electrode closest to the source ranged from 1,2m to 14,4m. The antennas measured the potential of the electrode closer to the source with respect to the electrode further away from the source. Two mutually perpendicular remote antennas were used for the coherent noise recording and were located at about 35m away from the seismic source. The first reason of the coherent noise may be an electrical current induced in the ground by remote power lines. Another one may be a telluric current induced by a time variation of the Earth's magnetic field. Both noises usually dominate in recorded signal (trace A on fig. 1: signal/noise rate is about 0,01). But the noises are observed to be the same either close or far away from the seismic source. Thus to get a pure SE signal, the noises are possible to be subtracted from the electrical records. Two mutually perpendicular antennas are used because the telluric and the power line induced currents can change direction and amplitude (but not phase) with location due to ground resistivity variations. Traces B and C are the remote noise records. The coherent noise in each individual electrical trace was matched with a linear combination of traces B and C. The coefficients of the linear combination were estimated to obtain the best (least-squares) match. So, trace D was got as result of a linear combination of traces B and C subtracting from the trace A. The cutoff frequency of the low pass filter in the Fourier domain was set to be 1500 Hz. It was made to avoid a smearing in the first breaks in the electrical traces what was due to an influence of high frequencies of power line harmonics. To evaluate an influence of remaining coherent harmonics of power line induced noise, the phases, frequencies, amplitudes of these harmonics were estimated by a least-squares fit in the time domain (BUTLER & RUSSEL, 1993). The corresponding sinusoids got wasn't too significant in our experiments. Thus the trace E is a result of the trace D magnified by 100 and of consequent use of the low pass filtering. The signal-noise ratio in trace E is 100. Such procedure was applied to deduce pure SE traces suitable for a further treatment. Experiments were carried out on Seminsky range plateaus of Altai mountains. Vertical cross-sections of the subsurface at the experimental site (fig.2) were derived from SE measurements and seismic refraction observations and verified by hydrogeological data.

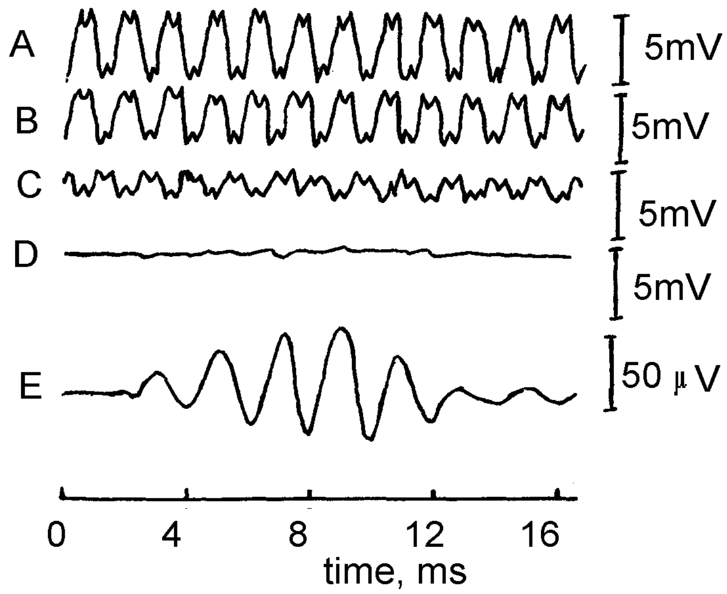


Fig.1 Noise reduction in the electric data.
Trace A - electric signal recorded by antennas; traces B and C - remote noise records; trace D - result of linear combination of traces B and C subtracting from the trace A; trace E - result of trace D magnified by 100 and of the use of low pass filtering.

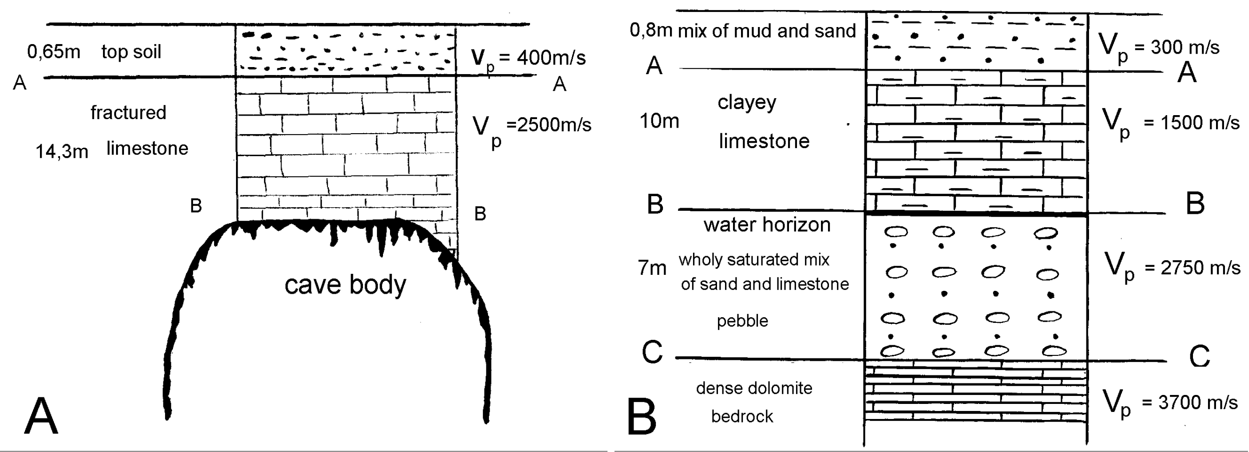
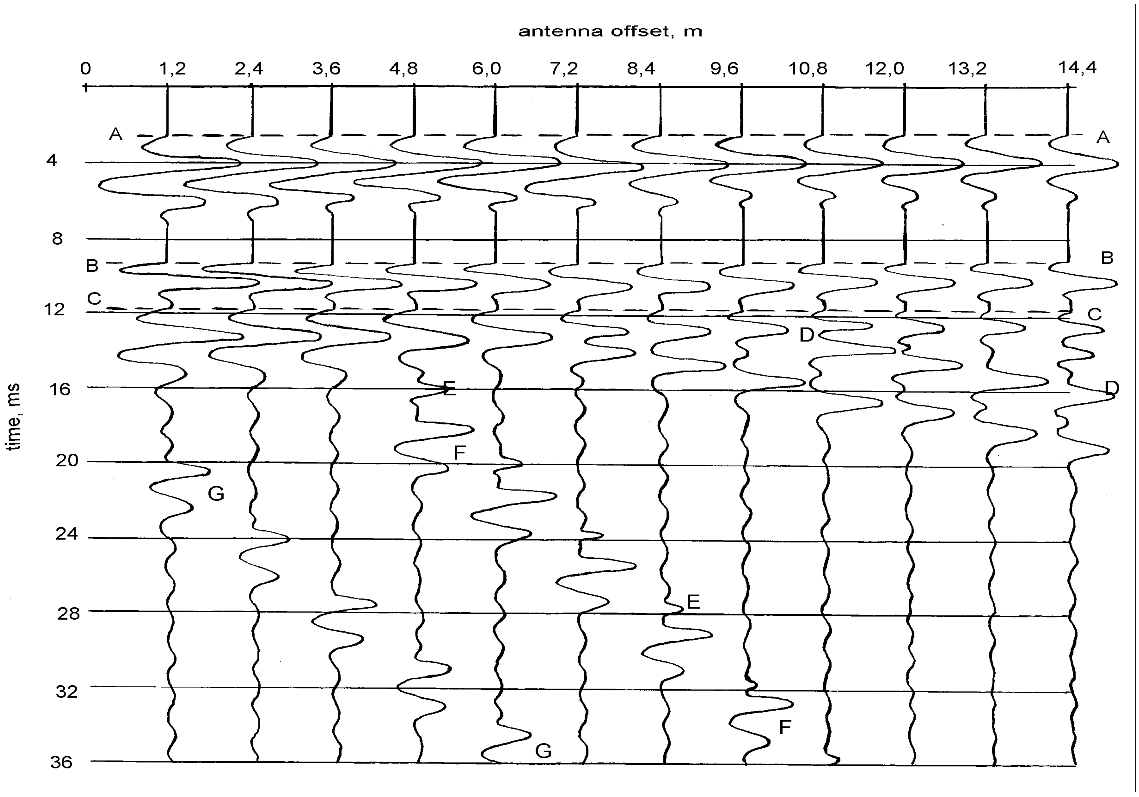


Fig.2 Samples of investigated vertical cross-sections (not to scale) of the subsurface at the experimental site: A - with a cave dome, B - with a water horizon.

A



B

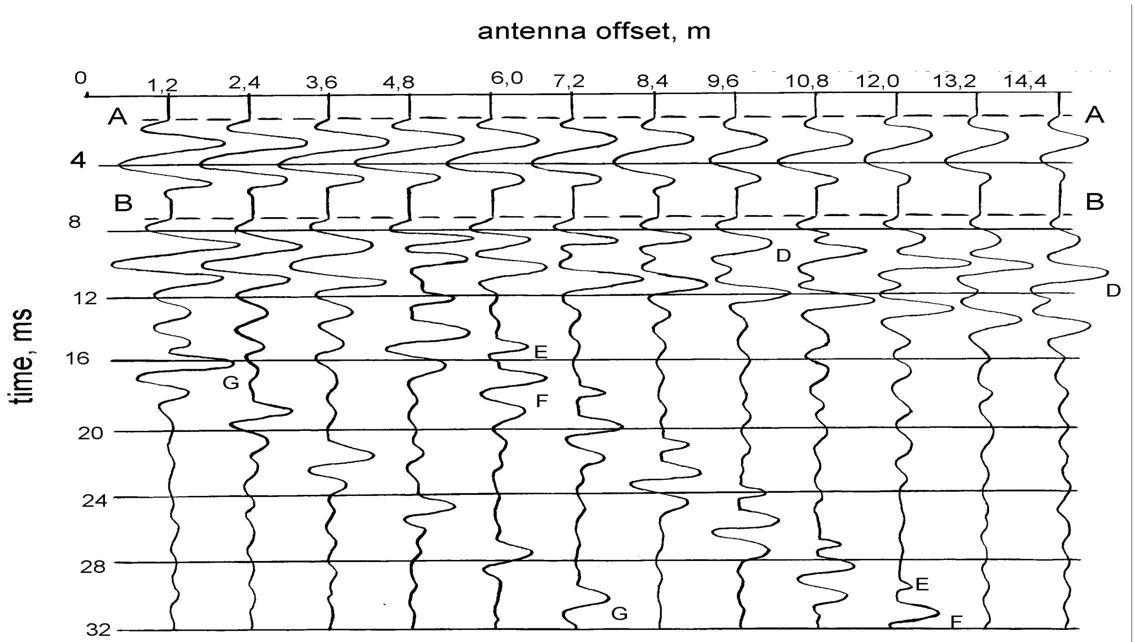


Fig.3 SE data observed in the field: A - with a cave dome, B - with a water horizon. Event A-A - SE response from the first boundary between layers, event B-B - SE response from the cave dome in case A and from the water horizon in case B, event C-C - SE response from a bedrock in case B, event D-D – SE response of head wave travelling along A-A interface, event EE – SE response of guided wave propagating along a day surface, event F-F – SE response of reflected wave from A-A interface, event G-G – SE response of reflected wave from B-B interface

Results of the Field Measurements

The negative electrical pulses arriving simultaneously at all antennas can be seen on samples of SE data (fig.3) observed in the field with 2,4m antennas and 0,6m spacing between the antennas. The amplitudes of the pulses are strongest at the antenna closest to the source and decrease further away from the source, thus the pulses originated directly below the source. Since the arrival times of these pulses occur to be the same at all antennas, the pulses traveled with electromagnetic wave velocity. At last the arrival times of the pulses-responses from any boundary interface are exactly equal to the times of seismic wave propagation from a source to correspondent boundary interface. Therefore these pulses are concluded to be caused by electromagnetic waves radiated from the interfaces at the time when the incident P-waves cross its. Particularly the event A-A (fig.3, A) is identified to be the SE response from the top soil and limestone boundary. The event B-B appears to be the SE response from the cave dome. The event A-A (fig.3, B) is found to be the SE response from the first boundary between top layer and clayey limestone. The event B-B occurs to be the SE response from a water horizon of a water bearing layer, and finally the event C-C is revealed to be the SE response from the interface between the water bearing layer and dense dolomite bedrock. Several regular waves were registered accurately as well. Waves D-D are estimated to be the SE response of head wave travelling along A-A interface. Its velocity can be easy evaluated from the field records (fig.3). It's equal to P-wave velocity beneath A-A interface. E-E wave may correspond upon its arrival time to the SE response of guided surface wave. F-F wave is calculated to be SE response of reflected wave from A-A interface. Its evaluation may give P-wave velocity above A-A interface. G-G wave is estimated to be SE response of reflected wave from B-B interface. It may give P-wave velocity value above B-B horizon. All evaluations of mentioned above waves may represent a thorough information about subsurface cross-section in order to calculate the depth locations of stratigraphic horizons. Thus for described samples of cross-sections the properly registered SE responses can allow to benchmark the dome cave emptiness and underground water horizons.

Conclusion

In comparing with observations made by other researchers (MIKHAILOV et al., 1997), (WOLFE & GERSHNZON, 1996) where the signals registered from the second frontier were too weak and not evident, in our experiments we succeeded to get perfect and clear SE signals from the second and the third boundary interfaces. It was made owe to a stronger source use and by means of fitted higher seismic wave frequencies as well due to a proper registering device used. The results obtained appear to be promissory for shallow subsurface investigations and perspective for a mapping of stratigraphic boundaries in general geology particularly in geomorfology, archaeology, gidrogeology and of course speleology.

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