The joint use of transient electromagnetic and vertical electric sounding in groundwater prospecting

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Summary

TEM and VES were applied to groundwater prospecting at a site near Syktyvkar city (Komi Republic, Russia). We used multisequential TEM and VES inversion scheme, that allowed to improve the recovery of layered earth parameters. A relationship between the resistivity-thickness product (T) and the water conductivity k_m was evaluated, that could be used to estimate k_m based on electric and electromagnetic data in a similar geological situation. As a result of k_m estimation along the profile, an interval was defined, where water wells were most productive.

Introduction

Electric and electromagnetic methods are applied wide to hydrogeological investigations. These methods provide the valuable information, based on the relationships between the electric (resistivity, polarizability, permittivity) and hydrogeological parameters (pore water mineralization, porosity, permeability etc.) [1]. Direct current vertical electric soundings (VES) are used successfully to assist with a range of hydrogeological investigations, but has some disadvantages: they are quite low productive and shallow penetrating, VES results are easily disturbed by shallow local objects, uneven relief and masking highly resistive overburden. Besides there is the thin-layer equivalence problem: resistivity (conductivity) and thickness can not be estimated separately from VES results interpretation.

Unlike VES, transient electromagnetic (TEM) soundings do not need grounding, they are highly productive and deep penetrating. Top resistive layer can not prevent electromagnetic field from penetrating to deeper ground structures, so TEM soundings can be used in winter time and in case of poor conductive overburden. In the other hand, it is difficult to obtain TEM response from shallow depths and TEM has poor sensitivity to resistive layers. Summing up, we can say, that VES and TEM soundings are complementary, so combining advantages of VES and TEM soundings one can substantially improve the recovery of the earth model parameters [4]. TEM-VES complex was successfully used to assist with solving some hydrogeological problems [2, 3].

We present some results of joint use of TEM soundings and VES applied to groundwater prospecting near Syktyvkar city (Komi Republic, Russia).

Geology. TEM and VES field surveys

Sandy and clayey deposits are spread throughout the area of investigation (fig. 4). The top aquitard composed mainly of quaternary tills and sandy clays, its thickness 30 to 70 m. Thickness of the aquifer (commonly Middle Jurassic fine sands and clayey sands) is 15 to 70 m. The bottom aquiclude composed of Early Triassic compacted blue-green clay. Our survey was conducted to map the aquifer, investigate lateral variations of its water conductivity and estimate areas where water wells could be most productive.

The joint TEM-VES survey was carried out along 11 km long profile. We used multifunction STROBE-M instrumentation developed in VIRG-Rudgeofizika [5]. TEM data were collected with coincident loop array of 50 m side length. TEM responses were recorded in time windows from 50 μs to 20 ms. VES were carried out with four-electrode Schlumberger array with current electrode half-spacing (AB/2) from 1 m to 1000 m. Spacing between VES points was 500 m. Soundings data answer commonly the tree-layer K-type model ($\rho_1<\rho_2>\rho_3$), where the first layer corresponds to the top aquiclude, the second (relatively resistive) layer – to the aquifer and the third – to the bottom aquiclude.

TEM and VES data interpretation

DC resistivity and electromagnetic methods demonstrate different sensitivity to resistive and conductive earth structures and its parameters. Numerical modeling shows, that response of a resistive layer in coincident loop TEM depends principally on its thickness and not on its resistivity. So in TEM, unlike VES, the resistive thin–layer equivalence is much less of a problem. Due to this feature of TEM, one can carry out multisequential interpretation of TEM and VES data (using parameters from inversion of one method data set for another data set inversion) and estimate resistivity and thickness of a layer separately.

We used the ZOND VES-IP data interpretation program (by A.Kaminsky) and electromagnetic sounding interpretation program ERA-PLUS [6]. First, using TEM data, we estimated the top and the bottom boundaries of the aquifer (fig. 1-A), and then used them as fixed parameters in VES data interpretation (fig. 1-B). As a result of TEM data interpretation depth and thickness of the aquifer were estimated to an accuracy of better than 5 m, whereas independent VES data inversion leads to errors from 10 to 75 m, because of the equivalence problem. Generally, TEM and VES data inversion results match each other well, but there is a notable discrepancy at the interval 100-200 pc, probably because of the strong lateral discontinuity. In the left part of the profile a thick and long aquifer was detected.

Water conductivity estimation

Both hydraulic conductivity K and resistivity ρ of soils depends strongly on the clay particles content, so these parameters correlate well to each other (in case of constant mineralization of pore water). The results of field application of electric methods to estimation of hydraulic properties demonstrate better correlation between integral parameters: the resistivity-thickness product $T=\rho h$ and the water conductivity $k_m=Kh$ [1]. Matching k_m and T obtained at our site, we evaluated approximate parameters of the $k_m=F(T)$ dependence and also found, that both VES and TEM data could be used for k_m estimation. Based on the found approximate dependence we estimated k_m parameter along the profile (fig. 3) and defined southwest interval (beginning from 500 pc), where water wells could be most productive, that was confirmed by hydrogeological results.

Conclusion

Our study has shown that VES-TEM complex is effective for groundwater prospecting. We found an approximate dependence $k_m=F(T)$, that could be used to estimate k_m based on electric and electromagnetic data in a similar geological situation. Matching advantages and disadvantages of TEM and VES one can conclude, that TEM sounding (as being more productive) could be used first to find areas with thick and wide aquifers with relatively high water conductivity. VES could be carried out to verify TEM results and to investigate shallower depths, where VES is more effective than TEM. Joint using and inversion of TEM and VES can noticeably improve the recovery of the layered earth parameters.

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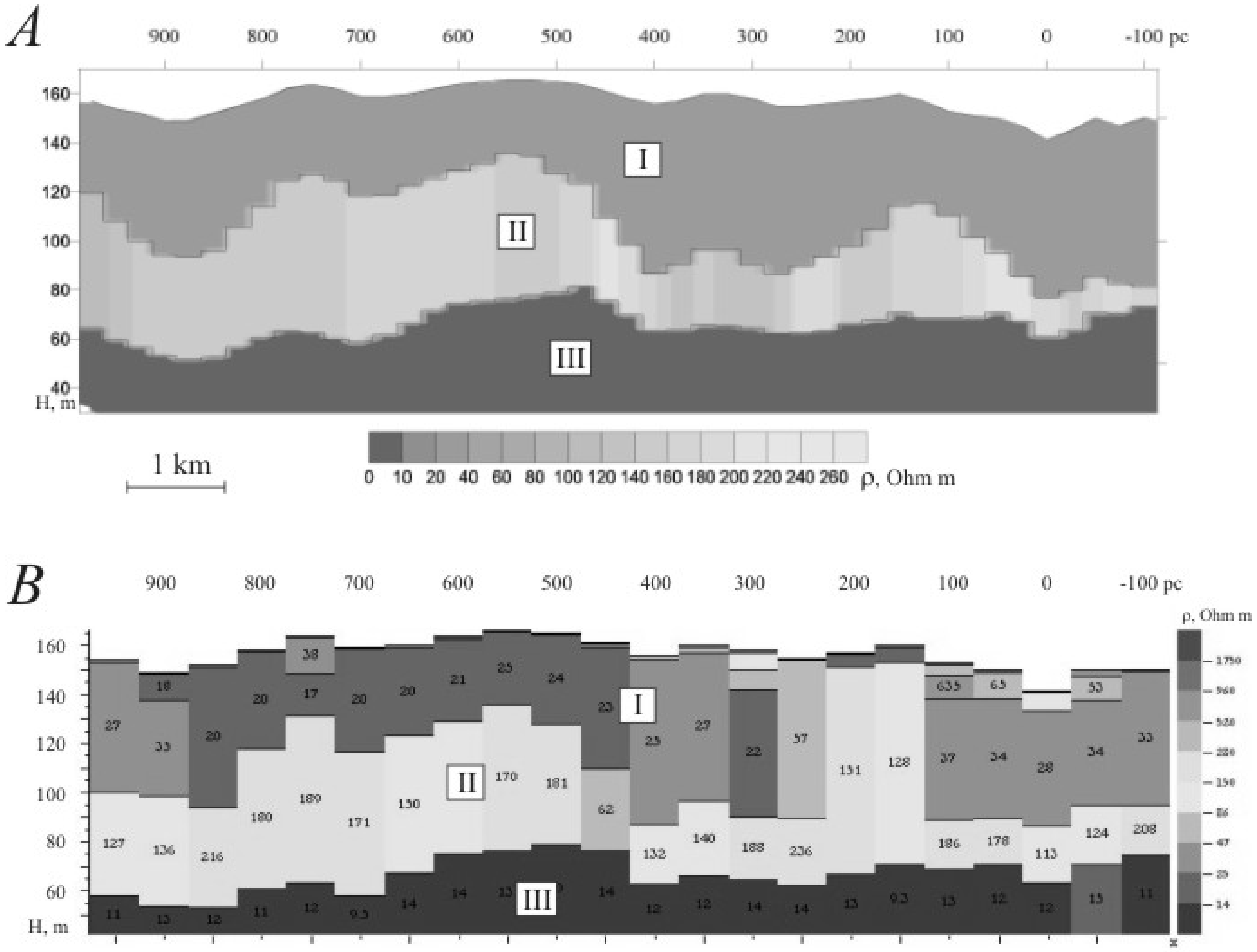

Fig. 1. Groundwater prospecting near Syctyvkar city
Resistivity sections: A - as a result of TEM data inversion,
B - as a result of VES data inversion. I - top aqiutard, II - aquifer,
III - bottom aquiclude.

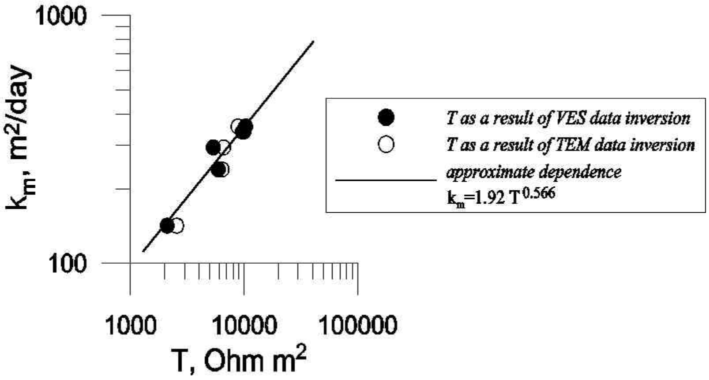

Fig 2. Relationship between the resistivity-thickness product (T) and the water conductivity (k_m)

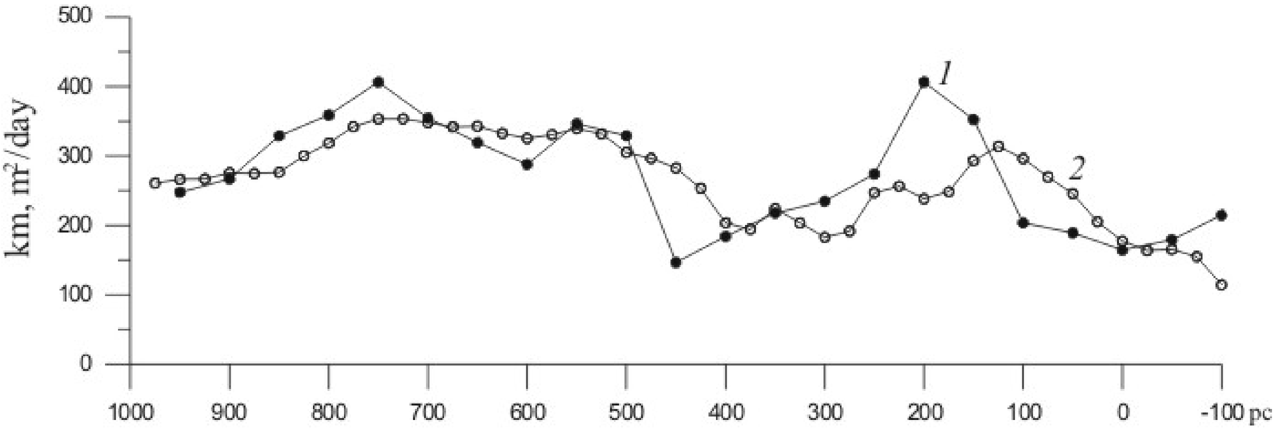

Fig. 3. Water conductivity of the aquifer: 1 - according to VES data, 2 - according to TEM data

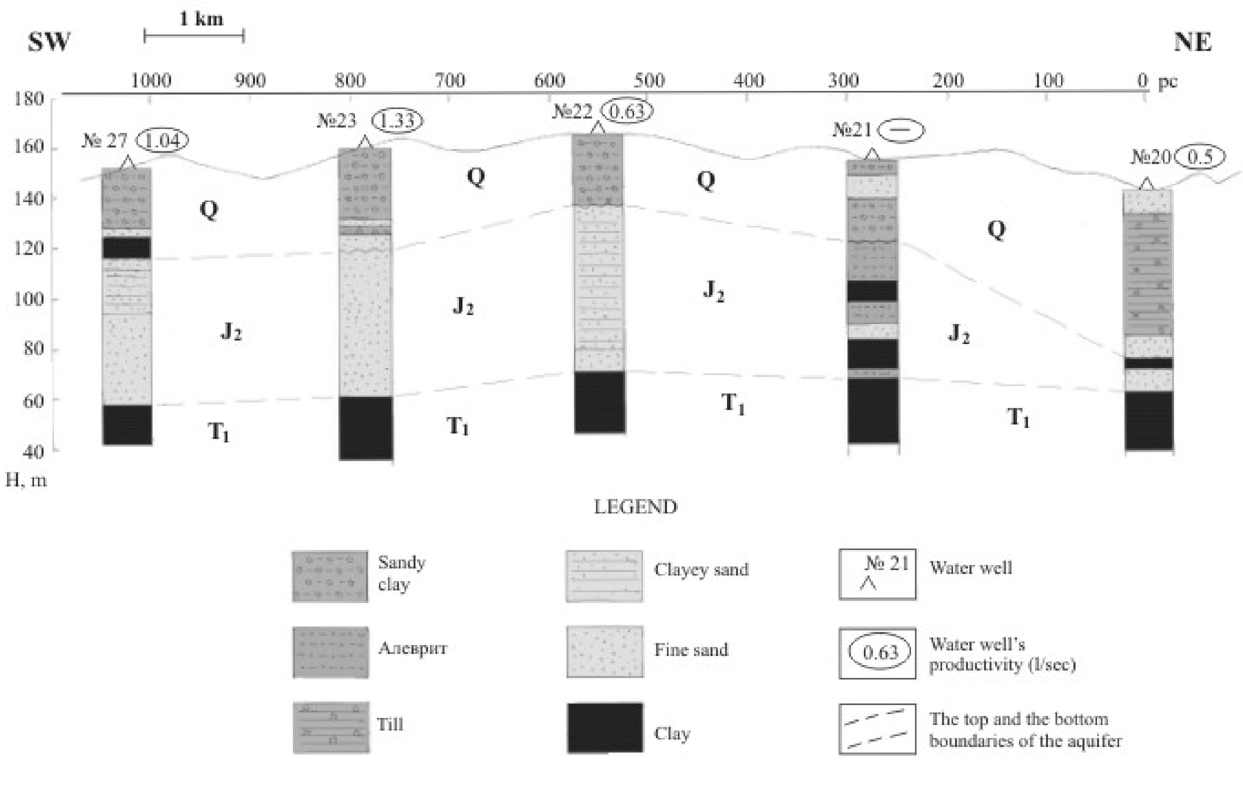

Fig. 4. Schematic geological section (after Vychegodskaya Geological Survey)