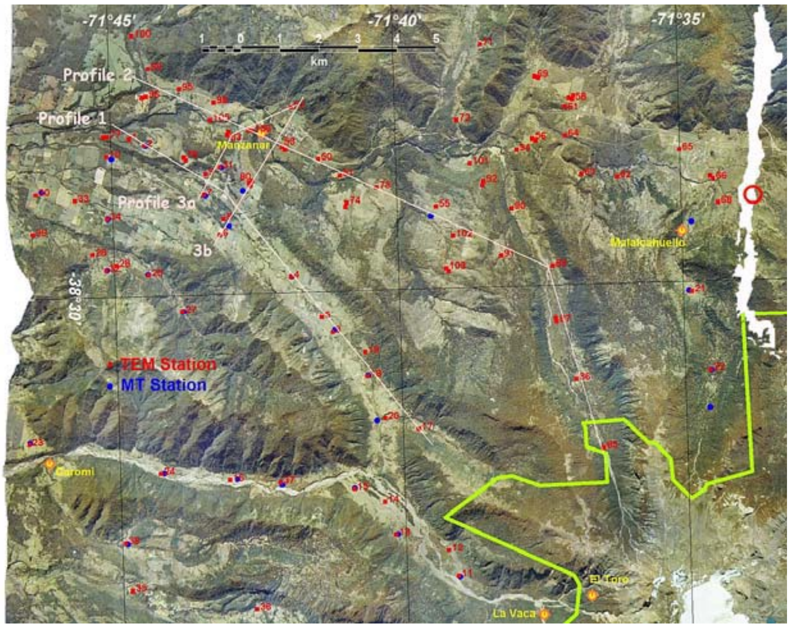
A TEM survey for exploring a hot water aquifer in South Chile

G. Reitmayr, BGR, Hannover (reitmayr@bgr.de)

Introduction

In the frame of the BGR project **GEOTHERM**, a project for promoting geothermal exploration in developing countries, the area NW of the Sierra Nevada, 9th region of Chile, was surveyed geophysically during a field campaign in 2006.

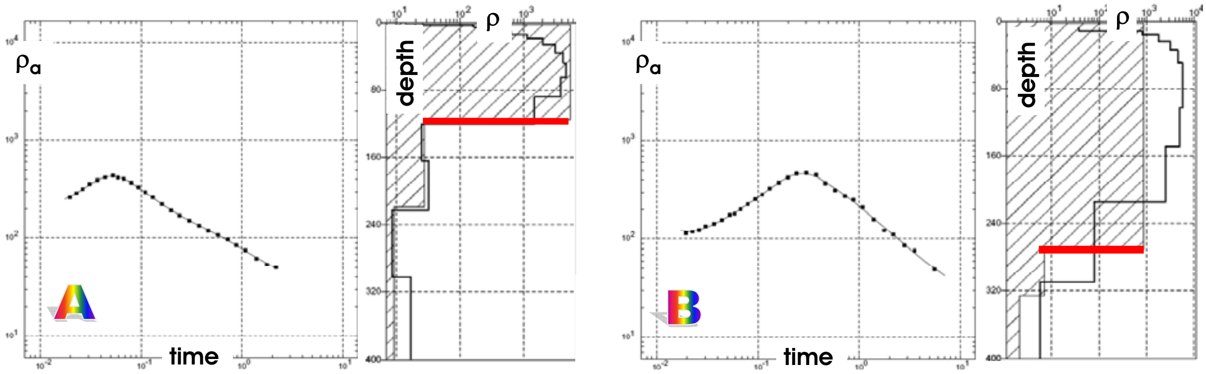
Transient-Electromagnetic (TEM) measurements were performed in order to support the interpretation of magnetotelluric (MT) data, which had been collected simultaneously (c.f. contribution of U. KALBERKAMP, this volume) and possibly to discover anomalous zones within the first hundreds of meters of the subsurface which might be caused by hot water reservoirs. One result of this survey was the clear indication of well conducting layers at depths ≥100 m at a few points close to the very northern and western borders of the area covered. We interpreted this observation that we are just seeing the edge of an aquifer with hot water which is used at the hotel complex of Manzanar, a few km farther to the north. As this aquifer is little known, in particular its extension, and as it might be of considerable economic interest to the local community we decided to realize a second field campaign in order to gather more information on this anomalous zone. The 38 points from 2006, just touching the margin of the Manzanar aquifer, could eventually be complimented with an additional 57 new points in 2007.



Aerial photo of the survey area. Thick blue dots are MT stations, small red squares TEM stations. Hot water wells are marked with their names in yellow and the light green polygon in the right low corner is the border of the national park

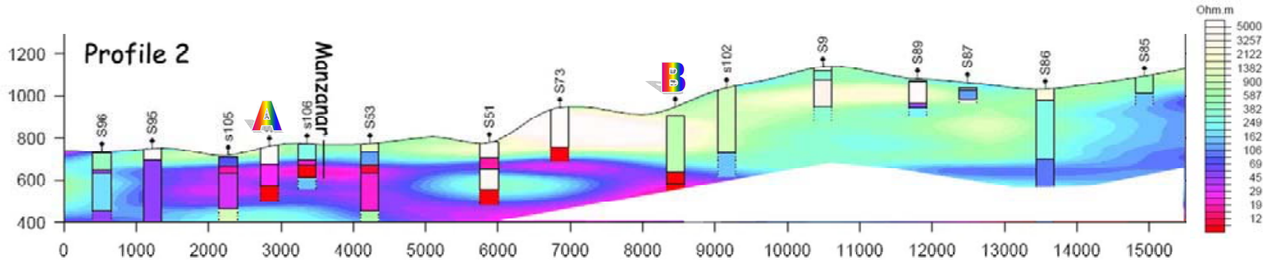
Field examples

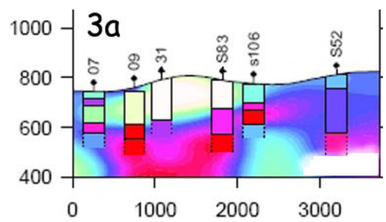
The survey has clearly proven the existence of a low resistivity (<10 -20 Ω*m) structure in the vicinity of the Manzanar well. Two sounding examples of points over the anomalous zone are shown in the figures below. The strong decrease of the apparent resistivity with increasing decay times indicates well conduct-



ing layers at depth. At sounding A (left) the decrease starts early at around 50 µs, i.e. the depth of the good conductor is relatively close to the surface at ~ 120 m; sounding B (to the right) shows the decrease much later at about 300 µs: the depth of the well conducting layer is ~ 250 m. The reason for this is the higher altitude of the second point of ~ 140 m. In the left part of the graphs the apparent resistivity is represented as function of the decay time double-logarithmically: discrete points are the measured values and the continuous curves are the responses for the models represented to the right beside it. The layer resistivities in Ω*m are thereby logarithmically plotted along the x axis and the depth of the layers in meters linearly downward.

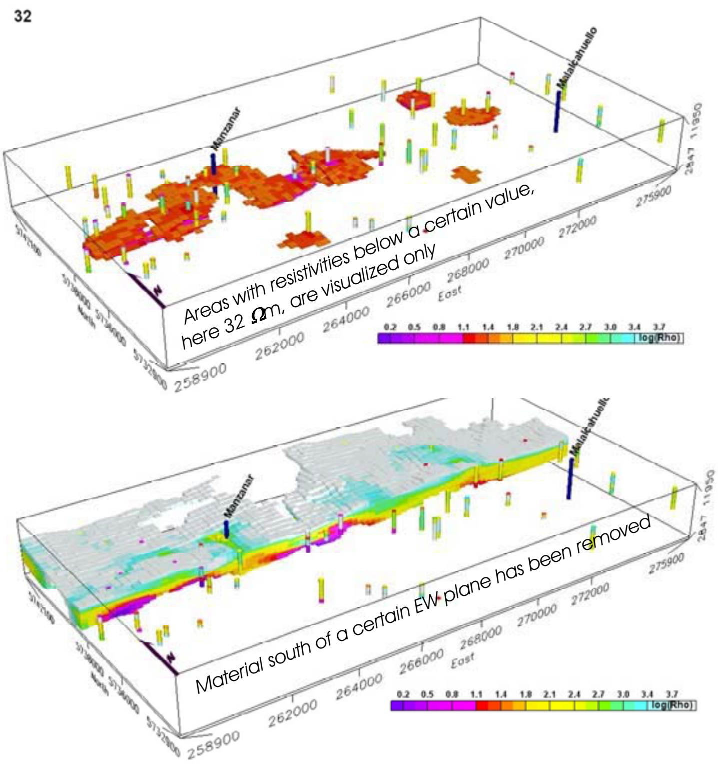
<u>Vertical sections</u>





The two soundings shown are lying on the NW-SE profile 2 (cf. the aerial photo above). The 1-D models together with the results of all points along this profile were used to produce a vertical resistivity section. The selected colour scale emphasizes ranges of low resistances by red or violet colouring. The Manzanar anomaly in the left (NW) half of the panel immediately attracts attention. It starts west of Manzanar and extends some km farther ESE. Its depth is ~ 80 to ~ 250 m below surface, depending on the altitude of the point, and it has a thickness of at least 100 m. Profile 3a (to the right) runs perpendicularly to the longitudinal profile 2. From this a width of the anomaly of ~ 1-2 km can be inferred.

3-dimensional visualization of the resistivity models found



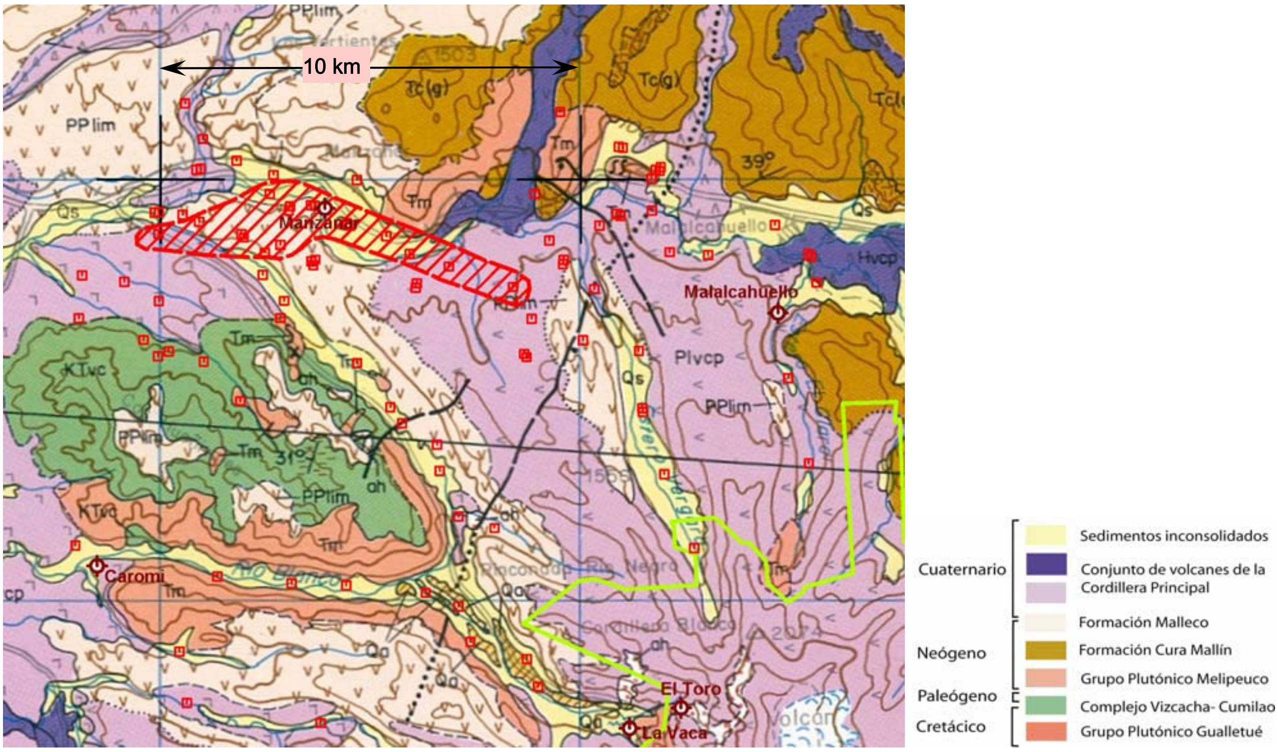
In order to better visualize the spatial distribution of the low resistivity structures a 3-dimensional presentation was attempted. The subsurface is portioned into so-called voxels, homogeneous prism shaped volume units, each which an electrical resistivity, calculated by interpolation from the interpreted TEM models. The voxels size used for the presentations shown to the left is 200 x 200 x 10 m. The view is from above and from the SW; the vertical exaggeration is five fold. The one-dimensional models found at each point measured are represented by small circular columns and the hot springs of Manzanar and Malalcahuello are labelled for a better orientation.

Results

The survey has clearly proven the existence of a low resistivity (< 10-20 Ω*m) structure in the vicinity of the Manzanar well. It lies at a depth of ~ 80 to 120 m below surface and has a thickness of at least 100 m. It starts ~ 2 km west of Manzanar and extends an additional ~ 5 km farther to the ESE. Its width is ~ 1.5 km. The first part of the structure seems to extend along the valley of the Cautín River. Farther on it apparently continues below the mountains south of the valley where it is logically at greater depth below surface. Because of the narrowing of the valley towards the East measurements were not possible for 2 to 3 km there. So the information is not sufficient to confirm the continuation of the low resistivity structure described along the valley. In any case it does not seem to be very simply shaped. The 3-dimensional presentations give the impression of two separate zones where Manzanar lies in between the both. There might be, however, a problem of interpolation due to the too sparse point density, as already indicated. Additional uncertainties in the interpretation arise of course from the intrinsic ambiguity of electromagnetic modeling due to the principle of equivalence.

The other important hot water occurrence in the area, the thermal springs of Malalcahuello in the very Eastern part of the area interestingly does not show any anomaly at all. There were only a few soundings accomplished in this area, admittedly, and in particular none in the immediate proximity of the hotel complex (due to artificial interferences suspected). A clear result is, however, that Malalcahuello and Manzanar are different hot water occurrences and continuity between both does obviously not exist.

There is little doubt that the low resistivity zone of Manzanar is due to mineralized hot waters. Resistivities below 10 Ω*m at depth can only be explained with elevated contents of ions. All the soundings confirm very high resistivities above the good conductor mentioned. Consulting the geological map (below) gives us immediately the explanation: the hot water aquifer is covered by volcanic layers of quaternary and Pliocene/Pleistocene ages mainly consisting of basaltic and andesitic lavas. The whole structure of the Manzanar aquifer can of course be verified by drilling holes only: locations one km west of Manzanar and one to two km east of it should be good selections. For evaluating the potential hot water resource pump tests have to be performed subsequently.



Geological map of the survey area. Small red squares are TEM stations. Hot water wells are marked by little brownish circles and their names. The Manzanar anomalous zone, hatched in red, lies below tertiary and quaternary lavas which came from the Sierra Nevada volcano some 20 km to the SE.

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