Digital Airborne Time Domain Electromagnetic Data from Surveys over Cochiti Pueblo, Rio Puerco and Rio Rancho, New Mexico

by

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Introduction

The Albuquerque-Santa Fe region is rapidly growing. The Santa Fe Group aquifer in the Middle Rio Grande Basin (MRGB) is the main source of municipal water for the greater Albuquerque metropolitan area and is more limited than previously thought (Thorn et al., 1993). The MRGB, as defined hydrologically and used here, is the area within the Rio Grande Valley extending from Cochiti Dam downstream to the community of San Acacia (**Figure 1**). Because approximately 600,000 people (40 percent of the population of New Mexico) live in the study area (Bartolino, 1999), water shortfalls could have serious consequences for the state. Future growth and land management in the region depends on accurate assessment and protection of the region's groundwater resources. An important issue in understanding the ground water resources is a better understanding of the hydrogeology of the Santa Fe Group, the sedimentary deposits that fill the Rio Grande rift and contain the principal groundwater aquifers.

The U. S. Geological Survey (USGS) is presently doing a series of studies of the MRGB in north-central New Mexico. One objective of these studies is to improve the hydrogeologic models of the Middle Rio Grande so as to help land managers plan and develop water supplies. These studies involve a multi-disciplinary approach to better understand the critical aquifers in the intracontinental rift environment. Detailed geologic mapping, high-resolution airborne magnetic surveys, lithologic and geophysical logging of wells, surface-based electrical and magnetic surveys, enhanced satellite imagery, as well as hydrologic and hydrogeochemical data are being used to refine understanding of the aquifer systems in the MRGB (Cole et al., 1999). An airborne time domain electromagnetic (TEM) survey was flown for the USGS as part of this work. The primary purpose of the TEM survey was to map changes in electrical resistivity with depth that are related to lithologic variations important to the critical aquifers. This report presents preliminary results of an experimental interpretation of the airborne TEM survey. We begin with a description of the airborne TEM survey and method. Then we discuss the approach to our interpretation. Finally, we present maps of three-dimensional (3-D) distribution of resistivity.

Fixed-Wing Time Domain Electromagnetic Survey

Electromagnetic (EM) methods are used to map the electrical resistivity (or its inverse, electrical conductivity) of the subsurface (Palacky et al., 1991). Resistivities of sediments are primarily determined by rock porosity, the electrical resistivity of the pore substance, and the presence of certain electrically conductive minerals, such as clays (Keller, 1987). Mapping resistivity variations can help unravel complex geological problems and identify areas of hidden potential.

Airborne TEM data over Cochiti Pueblo, Rio Puerco river, and an area near the town of Rio Rancho, northwest of Albuquerque, New Mexico, were collected in February of 1997 by Geoterrex, Inc. on contract to the USGS (Sawyer et al., 1998; Deszcz-Pan et al., 1998) to help delineate facies changes within the basin fill that may control local and regional ground water flow and to help define the 3-D extent of the principal axial-river-channel aquifer in the subsurface Santa Fe Group sediments. The Rio Rancho survey covered approximately a 25 km x 40 km area (area A+B in **Figure 1**). The aircraft was flown at 120 m above ground level using 400-m flight-line spacing (**Figure 2**). Over urban areas, the flight height reached about 250 m above ground level. The Cochiti Pueblo survey covered approximately a 15 km x 20 km area (Area D in **Figure 1**) using 400-m flight line spacing approximately 120 m AGL. The Rio Puerco survey covered an "L" shaped area that was roughly made up of a 3 km x 20 km area and a 1 km x 3 km area (Area C in **Figure 1**).

In the GEOTEM system (operated by Geoterrex, see the contractor's report, C-REPORT.PDF file in the REPORT folder), an antenna mounted on the airplane generates a pulsed EM signal. In the receiver towed about 50 m below and 100 m behind the airplane, the arriving EM signal is recorded as a voltage at specific times after each pulse (TEM response). The received signal is affected by many factors, but, ideally, the shape and strength of the signal will reflect the resistivity distribution in the subsurface. Therefore, using appropriate algorithms, the measured voltages can be converted to the electrical resistivity distribution with depth. In general, a stronger signal indicates lower resistivity and a weaker signal indicates higher resistivity. Earlier arrival times provide information on shallower depths, and later arrival times provide information on deeper depths (Palacky et al., 1991).

Several factors dictated the decision to use the airborne TEM method for this investigation. First, airborne methods efficiently provide significant amounts of information over a wide area. The spatial sampling of the subsurface is determined by the line spacing (400 m for this survey) and by the sampling rate (about 10 to 15 m for this survey) along the flight lines. Second, airborne TEM can be used to infer the general distribution of the electrical resistivity up to a depth of several hundred meters from the surface, which is a greater penetration depth than is available in frequency domain airborne EM methods. Third, the method can also be applied in difficult terrain that may not be accessible with ground-based methods. This was a significant factor on the extreme west side of the survey.

One drawback of the method is that cultural features affect the response of the TEM system. Fences, pipelines, communication lines, railways and other man-made conductors can contaminate the responses. The areas affected by such cultural noise cannot be used for interpretation. The majority of cultural anomalies can be easily identified, but sometimes the cultural noise response is very subtle and can be mistaken for the earth response. Cultural noise severely affects portions of the Rio Rancho TEM data, especially in the central and southeastern part of the survey (**Figure 3**).

Discussion

The TEM survey objectives were based on the assumption that the axial-channel gravel deposits, which are the main aquifers in the MRGB, will have a higher electrical resistivity than surrounding finer-grained materials (Hearst and Nelson, 1985). However, the resistivities obtained from TEM are only indirectly related to the water content and the sediment grain size at depth, and need to be correlated with other geologic information. The conversion of recorded signal to resistivities is not unique and, as such, depends on the algorithms used. Even though the method has been used for many years as a geophysical prospecting tool, its use in hydrogeological mapping is recent. Thus, interpretive techniques to map subtle resistivity variations due to facies changes are not yet fully developed. Inversion of raw airborne TEM data into a credible interpretation of grain size facies requires numerically robust computer modeling algorithms and correlation of lithologic logs with induction logs using bulk average resistivities that are calculated from a moving average of the induction log resistivities (**Figure 4**), whose periodicity is based on a function of the varying layer thickness with depth of the TEM model.

There were only three logged wells within Rio Rancho survey area (**Figure 2**) that satisfied the criteria needed to make these correlations (Cochiti Pueblo and Rio Puerco areas had no well logs that satisfied these criteria), namely, 1) they were about 200 m horizontal distance to the nearest flight line, 2) they had an induction resistivity log in the same depth range as the TEM survey, 3) they had a lithologic log also in the same depth range, and, 4) they were about 200 m horizontal distance from cultural noise (using a cutoff value of 10,000 microvolts) due to power lines, pipelines, or other man-made electrical power sources. One-dimensional algorithms, developed and owned by BHP geophysical company, provided resistivity inversion cross sections that closely correlated with these well logs (**Figure 4**).

To make maps of resistivity at any given subsurface elevation, we first evaluated how deep the TEM inversions were reliable to, based on correlation with well logs and magnetotelluric (MT) soundings (Rodriguez et al., 1999). The inversion results on this CDROM are provided by courtesy of BHP World minerals, previously of Golden, Colorado, USA. BHP used two algorithms to invert the data. The first algorithm, written by Guimin Liu, uses a horizontal thin sheet approximation to produce a conductivity depth image (CDI) of the subsurface (Liu and Asten, 1993). This algorithm proved useful in setting maximum reliable depths (**Figure 5**) for the inversions generated by the second algorithm. The second algorithm used was a least-squares inversion program written by Robert Ellis; it produced resistivity layers of fixed thickness that varied with depth, but remained constant along the flight line (Ellis, 1998). The basement resistivity was fixed at 50 ohm-m. The inversion model at larger depths is not physically valid, because the thickness and basement were fixed. However, by comparing resistivity models calculated from MT soundings and bulk average resistivities calculated from induction logs with the inversion resistivity cross sections, we found that the maximum depth provided by the CDI cross sections could be used as the maximum valid depth limit for the least-squares resistivity inversion cross sections at any given point along the flight line (**Figure 6**). This maximum CDI depth appears as a dashed line on the inversion cross section images found in the INV folders on this CDROM. A comparison of MT soundings and one of the least-squares inversion cross sections (**Figure 6**) shows good correlation except in some instances near the maximum CDI depth limit and also in the upper 50 to 100 m where the least-squares inversion's extrapolation to the surface generally yields resistivities higher than the shallowest MT resistivities.

Using the line-by-line interpretations found by the above procedures, plan maps of resistivity were generated over the survey area by combining the least-squares inversion cross sections into a 3-D grid of resistivity. Resistivities below the maximum CDI depth limit were blanked. Horizontal slice-maps of resistivity, at selected 50 m elevation intervals, were generated from the stitched 3-D grid of resistivity least-squares inversion cross sections (**Figure 7**), and are given in the Cochiti and Rio Rancho MAPS folders on this CDROM. All blank areas on the elevation slice maps represent areas that were outside the survey region, elevations that were above the ground surface, or areas that were below the maximum depth obtained from the CDI image at any given point along the flight line. We did not use the CDI results to produce the elevation slice maps because the resistivities derived from the CDI algorithm generally did not correlate very well with the MT soundings, especially in the upper 50 to 100 m (**Figures 5 and 6**). For the Rio Rancho area, all blank areas in elevation slice maps below 1550 m above sea level represent either this cutoff depth limit or areas outside of the survey area (see page 1 of the file R-MAPS.PDF in the MAPS folder found in the RIORANCH folder). All blank areas in elevation slice maps above 1700 m represent either elevations above the ground surface or areas outside of the survey area. For elevation slice maps from 1550 m to 1700 m, only the southwest to northeast trending blank area (the Rio Grande valley) in the east-central region of the map represents elevations above the ground surface – all other blank areas represent either the cutoff depth limit or areas outside of the survey area. For the Cochiti Pueblo area, all blank areas in elevation slice maps below 1600 m represent either the cutoff depth limit or areas outside of the survey area (see page 1 of the file C-MAPS.PDF in the MAPS folder found in the COCHITI folder). All blank areas in elevation slice maps above 1750 m represent either elevations above the ground surface or areas outside of the survey area. For elevation slice maps from 1600 m to 1750 m, only the blank area in the central region of the map (the Rio Grande valley) represents elevations above the ground surface – all other blank areas represent either the cutoff depth limit or areas outside of the survey area.

Conclusion

The resistivity inversion maps presented on this CDROM appear to indicate that large 3-D variations in the inferred grain size of the Santa Fe deposit horizons occur over much of the northern Albuquerque area. These geophysical results can be used to place spatial limits on coarse-grained aquifers, especially the axial sand and gravel deposits of the ancestral Rio Grande. For this reason, the resistivity inversions on this CDROM in the form of elevation slice maps and cross sections provide a framework for predicting hydrologic conditions in areas less explored by drilling. These resistivity maps potentially can provide direct input to ground-water flow models that are critical to water management agencies.

Acknowledgments

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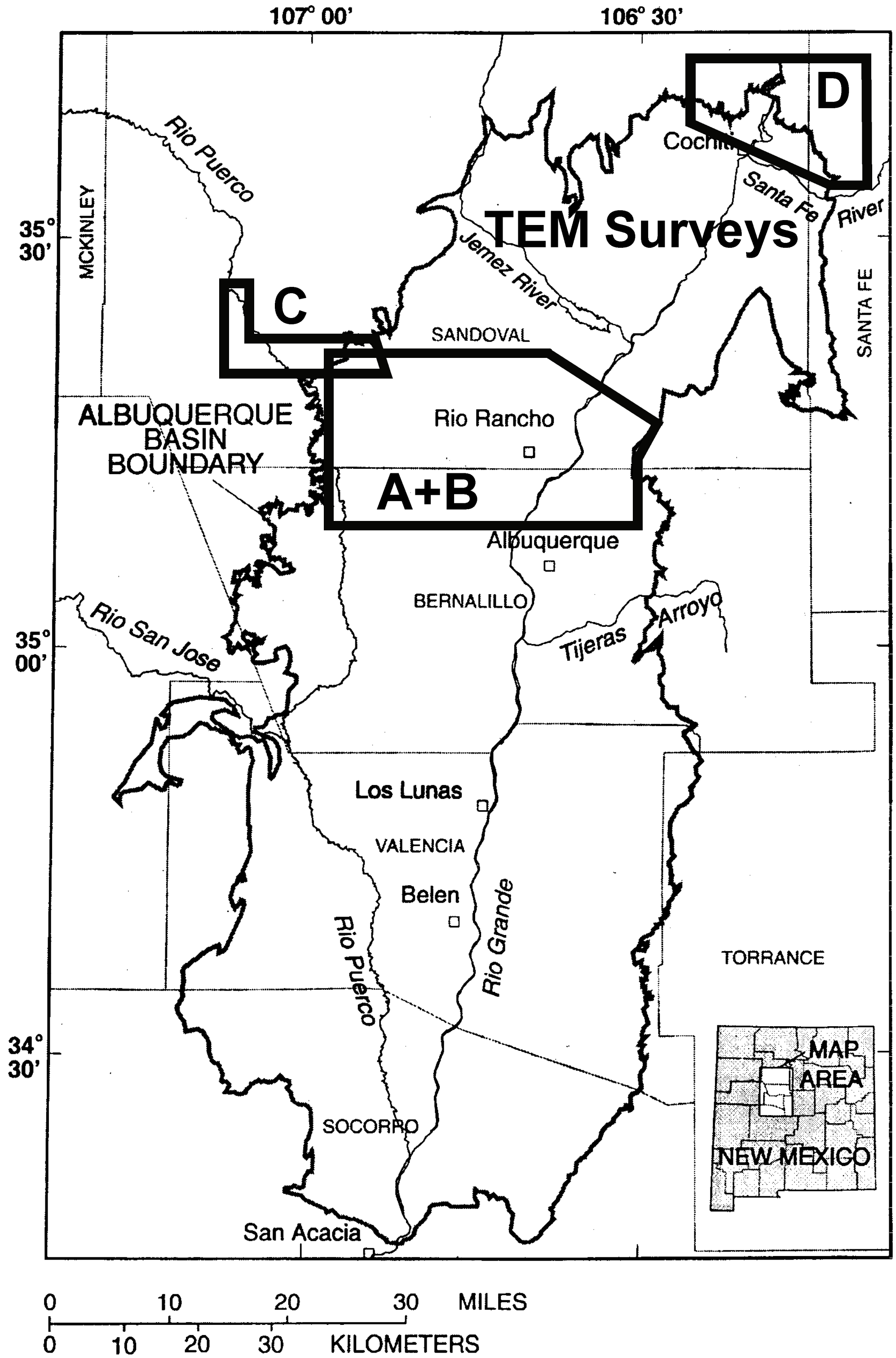


Figure 1. Airborne Time Domain Electromagnetic (TEM) index map in the Middle Rio Grande basin, New Mexico. Modified from Bartolino (1999).

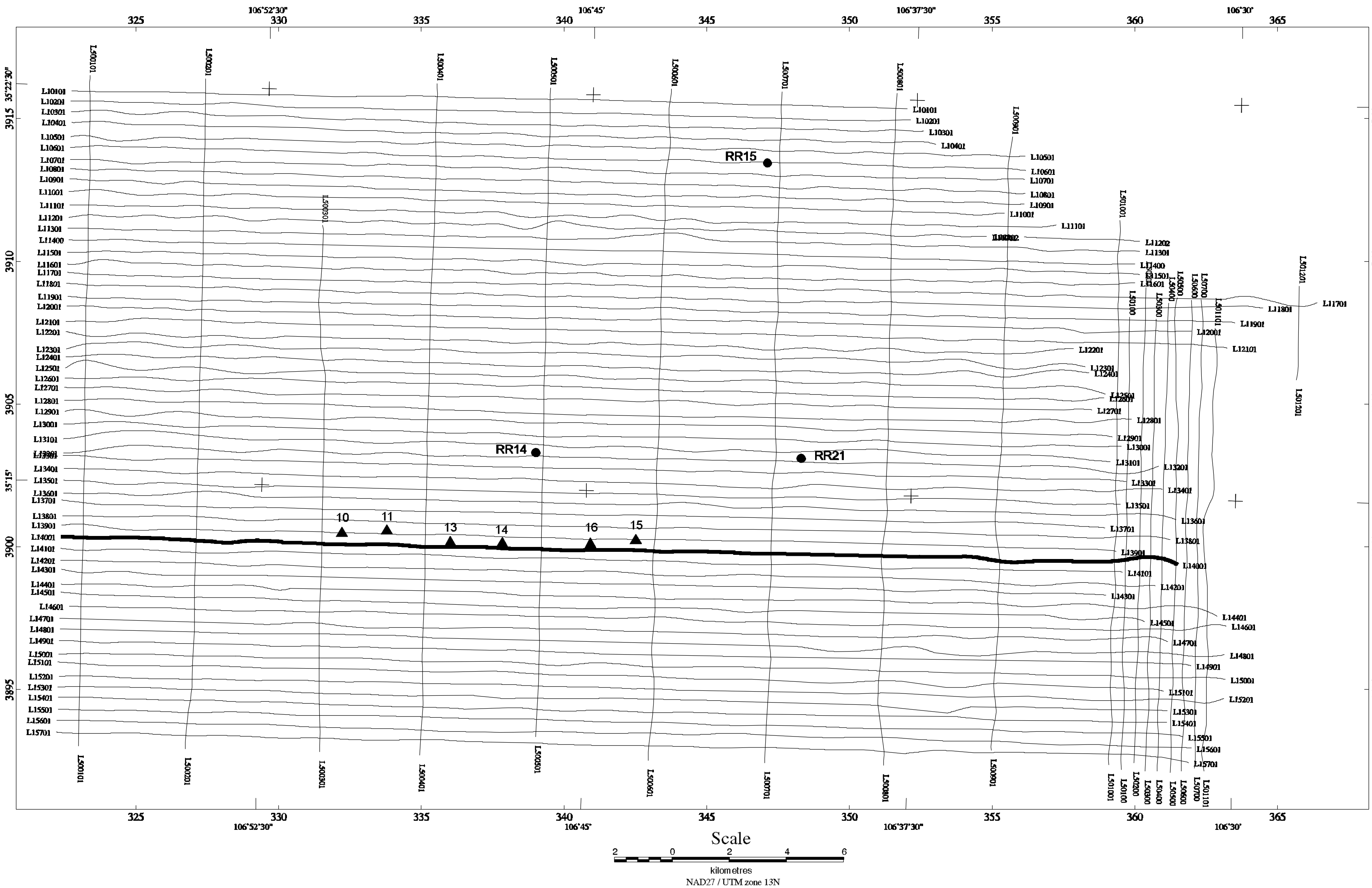


Figure 2. Airborne Time Domain Electromagnetic flight line map, Rio Rancho, New Mexico. Solid circles are wells used in lithologic correlation with resistivity inversions. Heavy black line is flight line 140 used in figures 5 and 6. Solid triangles are magnetotelluric sounding stations.

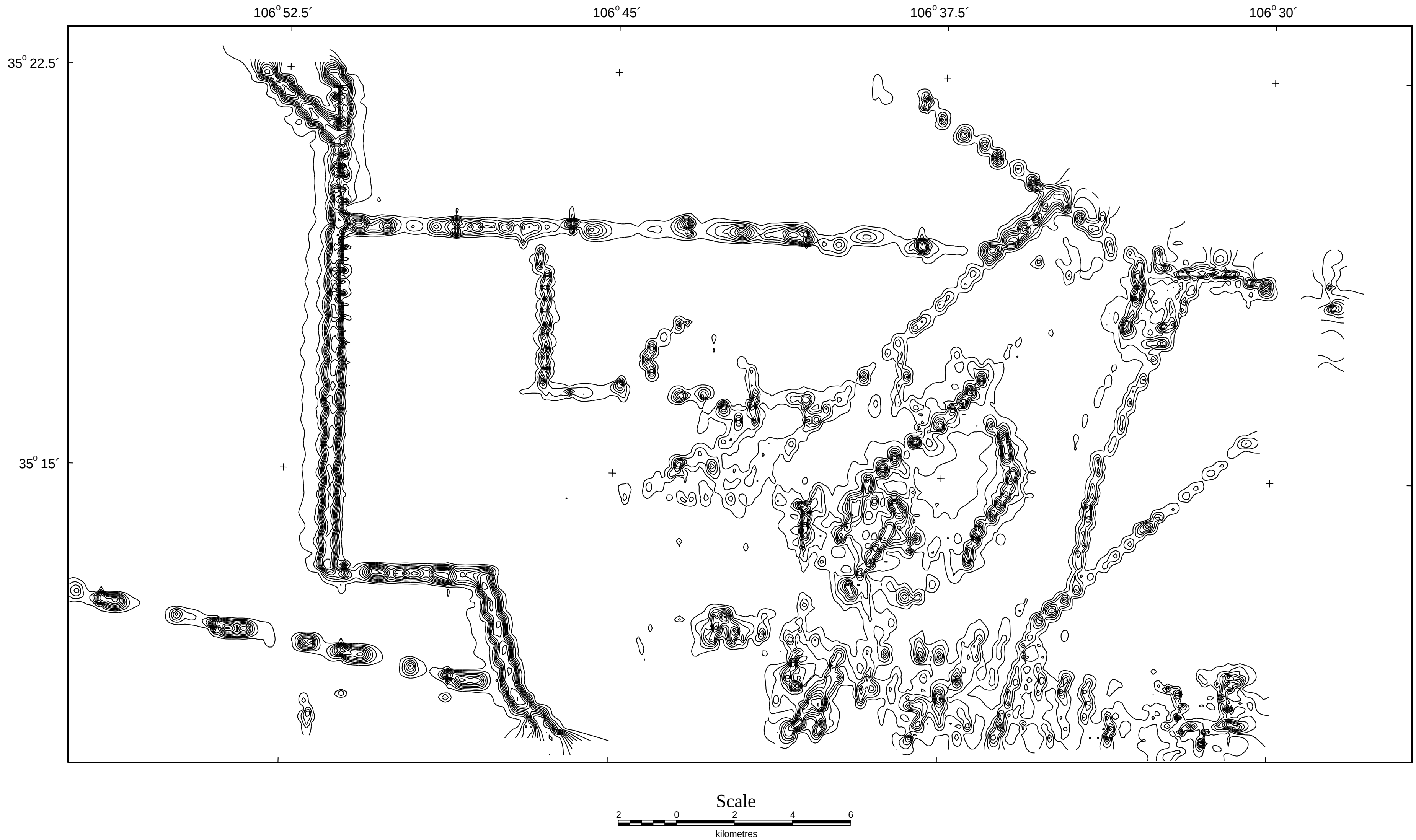
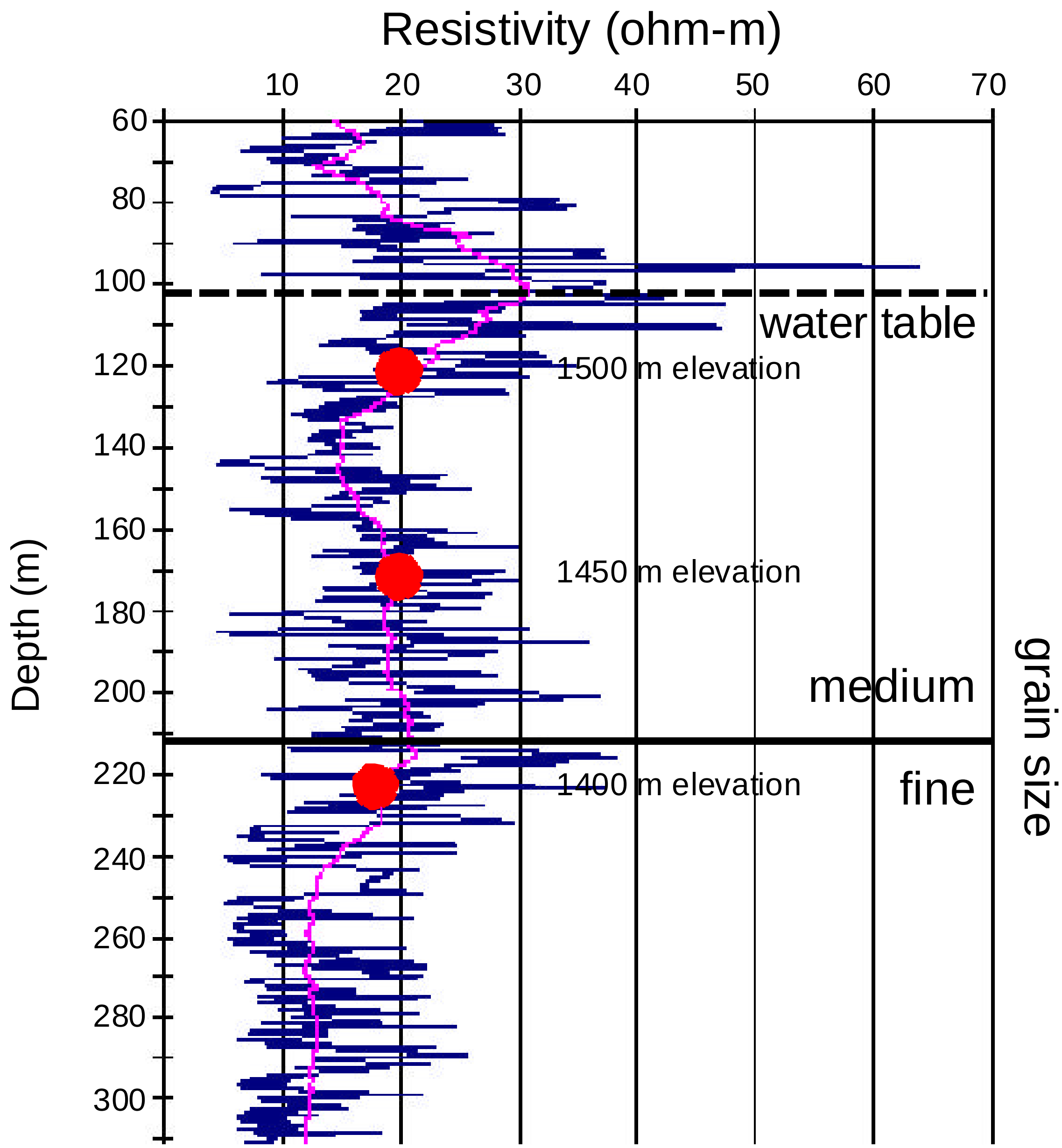


Figure 3. Power line monitor map, Rio Rancho, New Mexico. Contour interval is 10,000 microvolts.



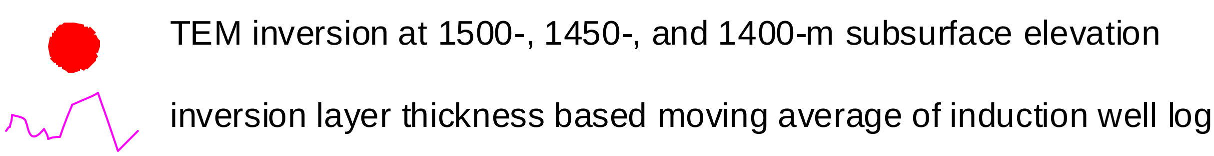


Figure 4. Induction resistivity well log of Rio Rancho 21 well, New Mexico. Variable moving average is a function of the least-squares resistivity inversion layer thickness for the given depth. Grain size labels refer to bulk average lithology of the Middle Rio Grande Basin Santa Fe Group sediments (Cole, 1999).

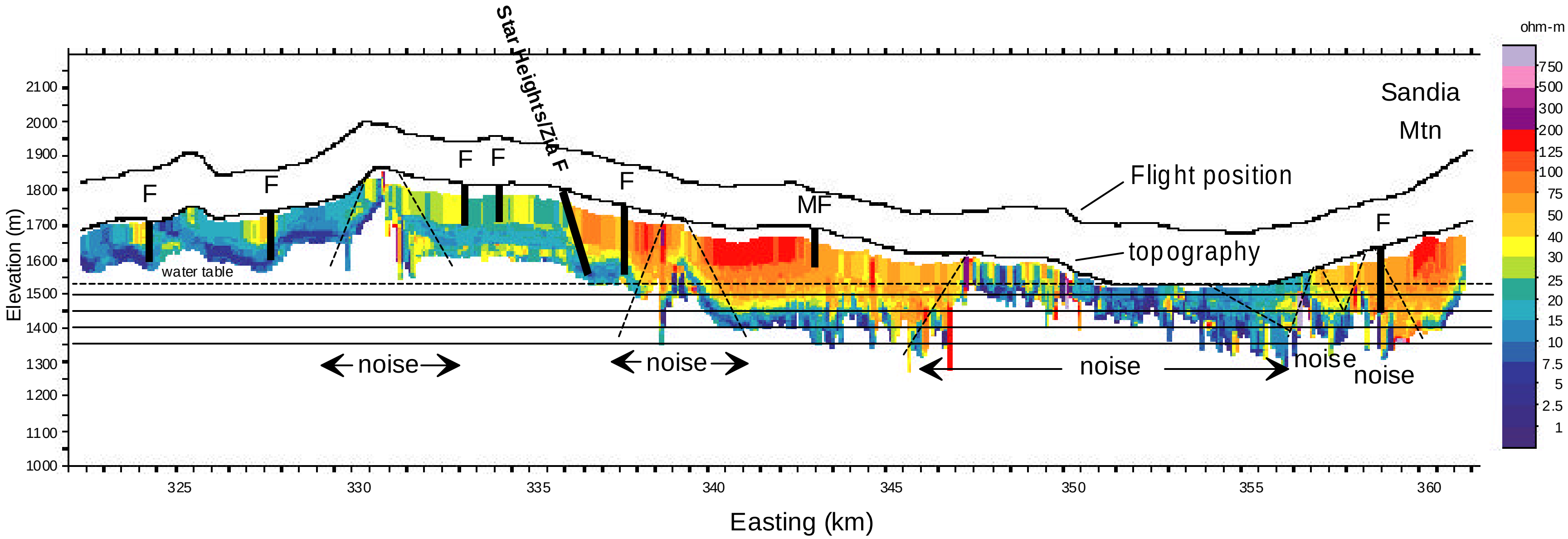


Figure 5. Resistivity cross section for flight line 140, Rio Rancho, New Mexico from conductivity depth image algorithm. Vertical and subvertical solid lines are mapped (F) and inferred (MF) faults from magnetic survey (Grauch, 1999). Horizontal dashed line represents water table. Solid horizontal lines represent 1500-, 1450-, 1400-, and 1350-m subsurface elevation. Powerline noise beneath affected areas have tilted dashed lines.

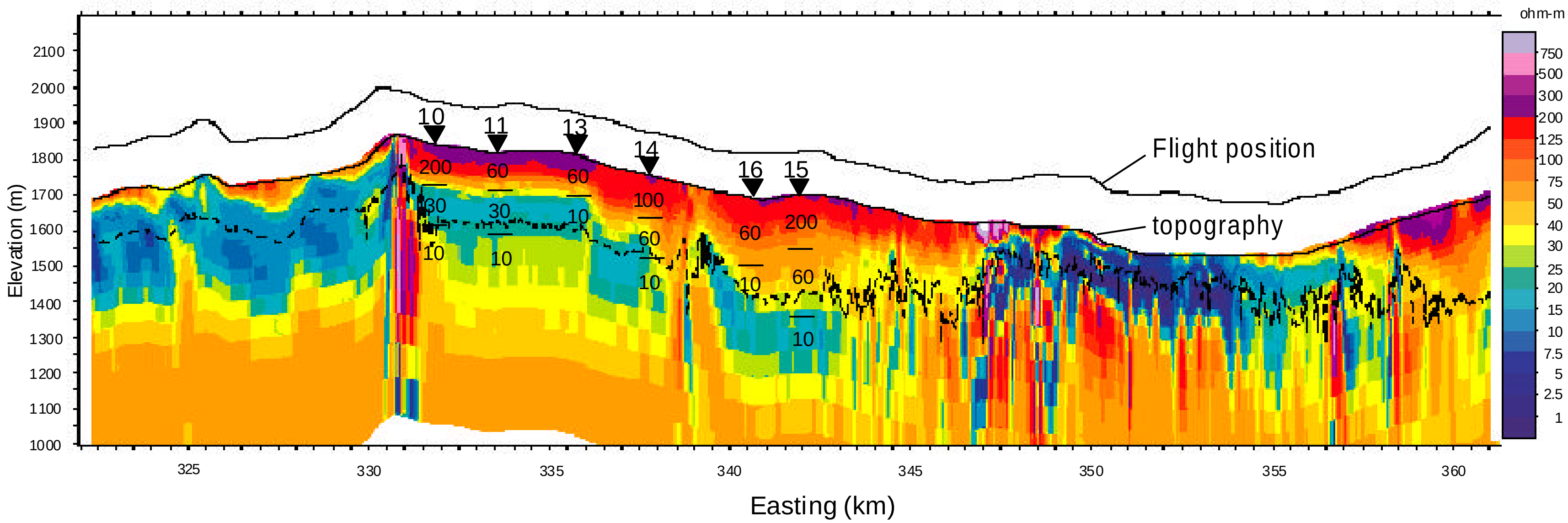


Figure 6. Resistivity cross section for flight line 140, Rio Rancho, New Mexico from least-squares inversion. Dashed line is maximum depth from conductivity depth image. Inverted triangles and labels are magnetotelluric (MT) stations. Two-dimensional layered resistivity model of MT data in ohm-m.

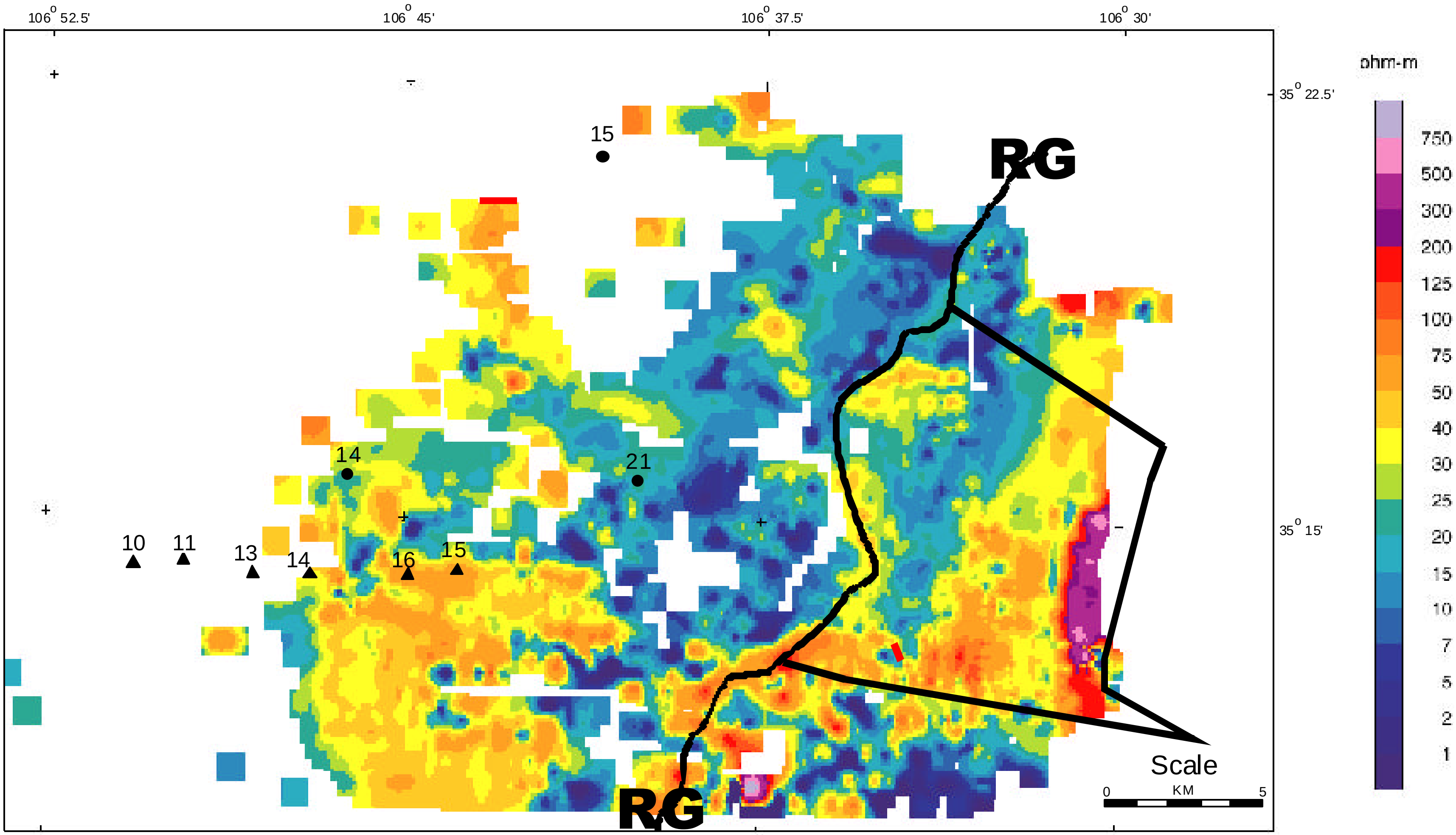


Figure 7. Resistivity inversion elevation slice map at 1500 m above sea level, Rio Rancho, New Mexico. Label RG is Rio Grande. Circle symbols are wells with lithologic descriptions. Triangle symbols are magnetotelluric stations. Heavy black line is Sandia Pueblo boundary and Rio Grande.