Results of Electrical Resistivity Data Collected near the Town of Guernsey, Platte County, Wyoming

By Robert R. McDougal, Jared D. Abraham, and Robert J. Bisdorf

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Contents

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Abstract

As part of a study to investigate subsurface geologic conditions as they relate to ground-water flow in an abandoned landfill near the town of Guernsey, Wyoming, geophysical direct current (DC) resistivity data were collected. Eight vertical resistivity soundings and eight horizontal resistivity profiles were made using single channel and multi-channel DC instruments. Data collected in the field were converted from apparent resistivity to inverted resistivity with depth using a numerical inversion of the data. Results of the inverted resistivity data are presented as horizontal profiles and as profiles derived from the combined horizontal profile and vertical sounding data. The data sets collected using the single-channel and multi-channel DC systems provided for the resistivity investigation to extend to greater depth. Similarity of the electrical properties of the bedrock formations made interpretation of the resistivity profiles more difficult. High resistivity anomalies seen in the profiles are interpreted as quartzite lenses and as limestone or metadolomite structures in the eastern part of the study area. Terrace gravels were mapped as resistive where dry and less resistive in the saturated zone. The DC resistivity methods used in this study illustrate that multi-electrode DC resistivity surveying and more traditional methodologies can be merged and used to efficiently map anomalies of hydrologic interest in geologically complex terrain.

Introduction

In July 2003 the U.S. Geological Survey Crustal Imaging and Characterization Team conducted a direct current (DC) resistivity survey at an abandoned landfill near the town of Guernsey, and Camp Guernsey, Wyoming. The DC resistivity method is a geophysical technique that uses variations in electrical resistivity of the earth to help characterize subsurface hydrogeologic features. The survey was conducted to determine the subsurface resistivity distribution, thickness of alluvium, and location of faults or fractures that may act as ground-water conduits or as ground-water flow barriers. In addition to the DC resistivity survey, a gravity survey was completed to characterize bedrock topography and surficial deposits. This survey included detailed surface topography mapping using a real-time differential Global Positioning System (GPS).

Purpose and Scope

This report describes results of an investigation of subsurface geologic conditions as they relate to ground-water flow in an abandoned landfill near the town of Guernsey, Wyoming. DC resistivity data were collected using automated multi-channel and manual single-channel systems. Cross section profiles of resistivity produced using an inversion algorithm on the field data are presented and interpreted.

Site Location and Description

The Guernsey landfill is located on the southern flank of the Hartville uplift (Harris, 1997) on a terrace approximately 16 m above the North Platte River valley, north of the town of Guernsey (fig. 1). Immediately to the east of the landfill, dense metadolomite is quarried, primarily for gravel. Electrically resistive Precambrian and Paleozoic metadolomite and overlying metabasalt outcrops are found near-or-at the landfill, and to the north and east of the landfill. In the south central part of the landfill property an outcrop of limestone of the Pennsylvanian Hartville formation is found in a north trending ravine. The Hartville formation contains red and white sandstones, gray dolomite and limestone, and red shale, and lies on Precambrian basement rocks north of Guernsey. Most of the area is covered with Quaternary terrace gravels. A prominent set of north trending faults are observed near-or-in the study area (Harris, 1977). South of the landfill, and immediately south of the town of Guernsey, outcrops of upper Oligocene and lower Miocene sandstones and claystones of the Arikaree formation are prominent.

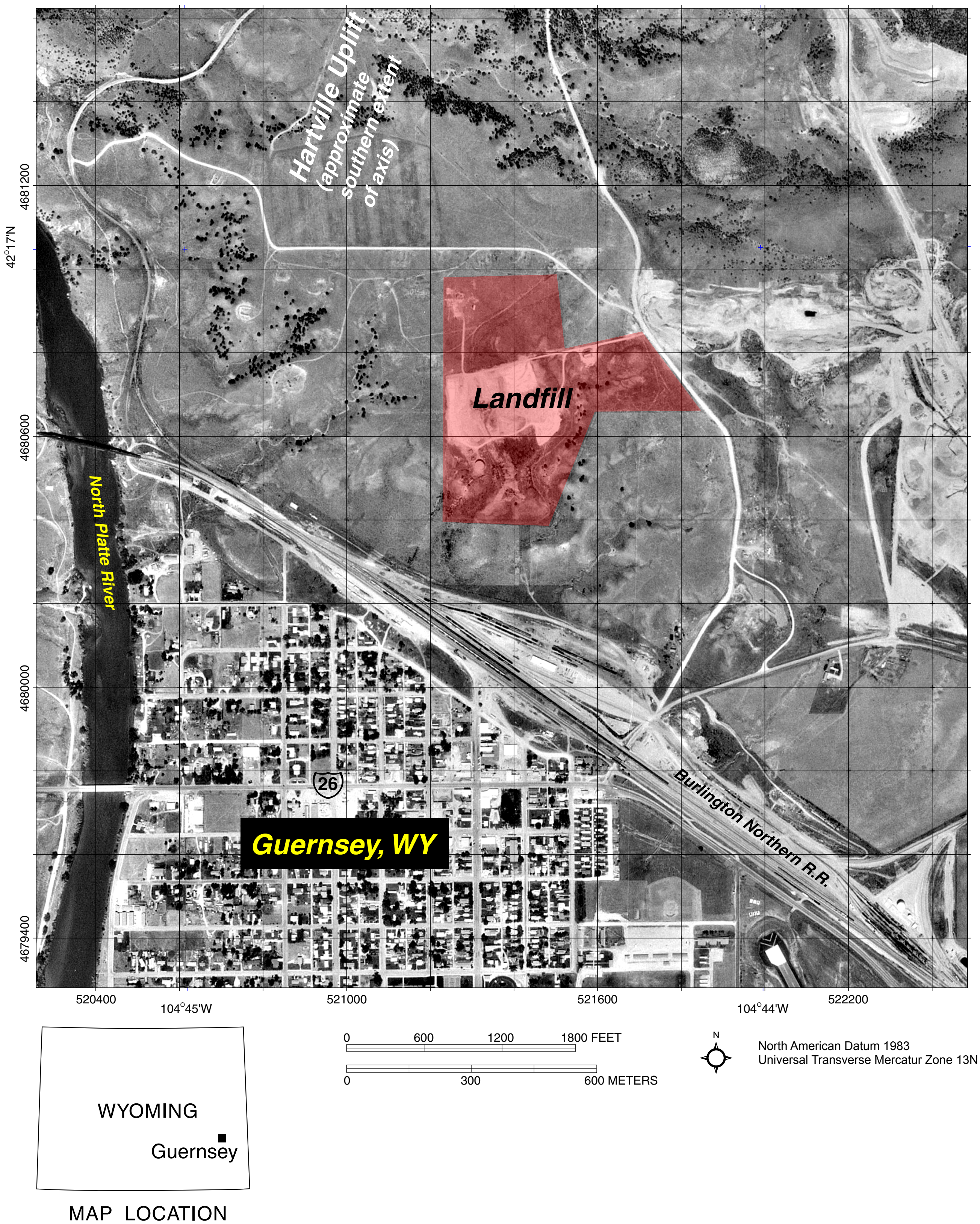

Figure 1. **Location map of the Guernsey Landfill (red) study area.**

Method of Investigation

Resistivity of Earth Materials

Electrical resistivity (which can be expressed as the inverse of electrical conductivity) varies with rock or sediment type, porosity, and the quality and quantity of water and is a fundamental property of earth materials. Electricity can be conducted in the earth electrolytically by interstitial fluids (usually water) and electronically by certain materials, such as clay minerals, by cation exchange. As a result, poorer quality ground water (that is, water with higher concentrations of dissolved solids) or sediments with higher clay content are usually more conductive (Zohdy and others, 1974). Resistivity is expressed in ohm-meters, and is an estimate of the earth resistivity calculated using the relationship between resistivity, an electric field, and current density (Ohm's Law), and the geometry and spacing of the current and potential electrodes. Where the earth is not homogeneous and isotropic, this estimate is called the apparent resistivity, which is an average of the true resistivity in the measured section of the earth (Dobrin, 1988).

DC Resistivity Data

Two DC resistivity systems and methods were used for this study. The first system, an ABEM SAS 300 single channel instrument, recorded electrical soundings to investigate the change in earth resistivity with depth at a particular location. Vertical soundings were made by arranging four (two current-transmitting and two voltage-sensing or potential) electrodes symmetrically about a center, with increasing distances between electrodes to explore deeper depths. Eight vertical sounding surveys were conducted using a Schlumberger array (Dobrin, 1988) (fig. 2).

The second system, an Advanced Geosciences, Inc. (AGI) SuperSting R8/IP eight channel multi-electrode instrument, was used to record horizontal electrical data to determine lateral variations in earth resistivity within a given depth range. For horizontal profiling, the electrode spacing and geometry are held constant and the array of electrodes is moved along a straight line. Multi-electrode systems have the capability of recording many channels of data simultaneously and allow for the collection of very dense DC resistivity data in a relatively short amount of time. The electrode array was connected to the resistivity meter, and consisted of 60 dual mode switches in contact with the ground using stainless steel stakes. The dual mode electrodes are automatically switched to allow each to operate as either current or potential electrodes in the array. Spacing between each electrode was 5 meters. A resistivity measurement uses from four to ten of the electrodes simultaneously, half of the electrodes on either side of a central point. In this study, the surveys were conducted using an inverse Schlumberger array (Telford and others, 1990). After the equipment finishes collecting data from the electrode array, a group of electrodes is moved from the beginning of the line to the end of the line and data collection is then re-initiated over the section of the line that had not been previously measured. This method allows for the collection of lines of data of effectively any length, without sacrificing resolution. Eight lines of multi-channel data were collected over the study area (fig. 2).

The data collected in the field were converted from apparent resistivity to inverted resistivity with depth using a numerical inversion of the data. The inversion routine used for this study was EarthImager 2D, a DC resistivity inversion program from Advanced Geosciences, Inc. The result of the inversion process is a highly detailed "cross section" of resistivity corrected for changes in topography along the profile.

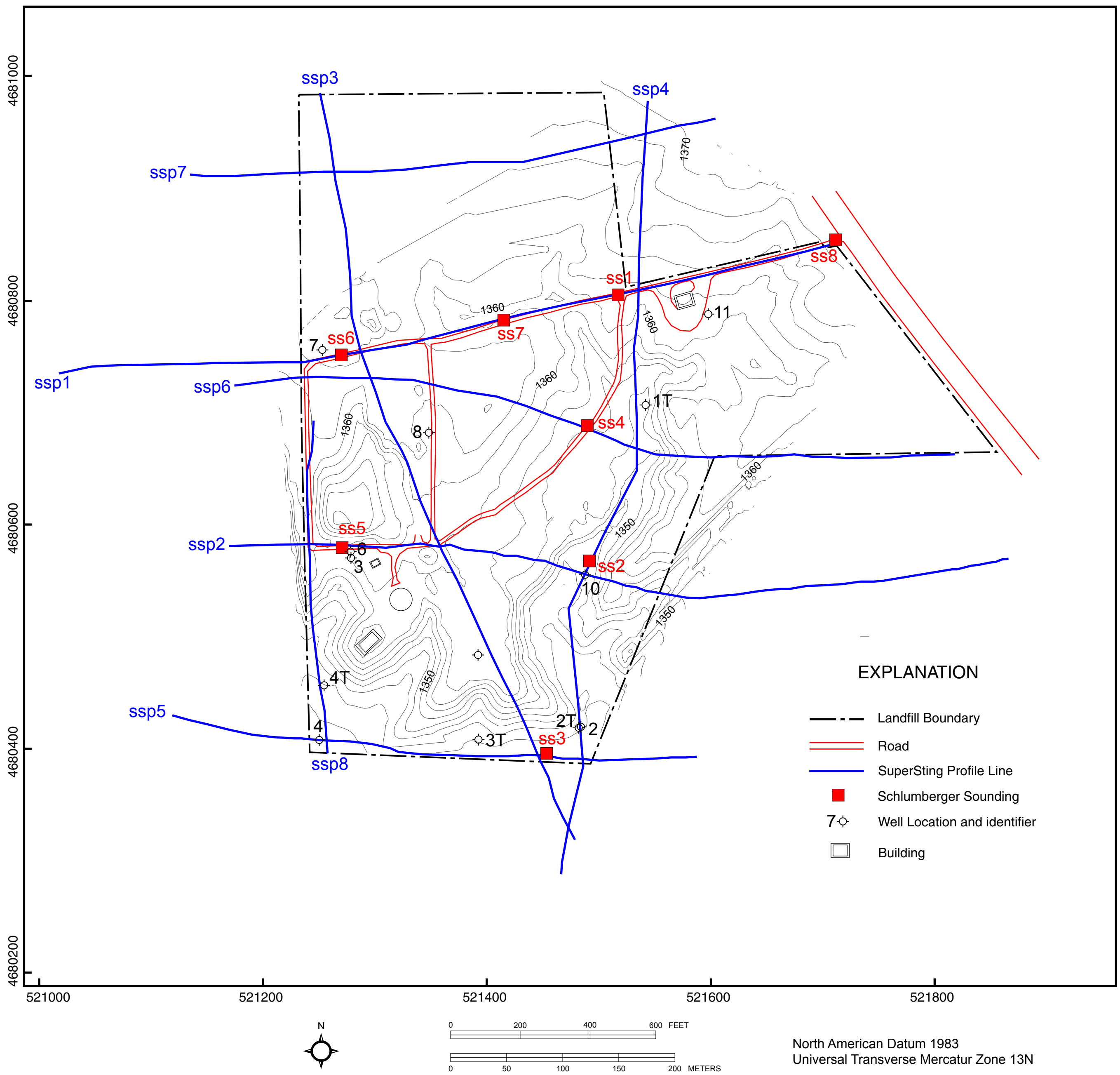

Figure 2. Site map of the Guernsey Landfill showing the location of Schlumberger soundings, SuperSting profile lines, and monitoring wells.

Resistivity Profiles

Results of the inverted resistivity data are presented as horizontal profiles derived from the SuperSting data (fig. 3 and fig.4), and as profiles derived from the combined SuperSting and vertical sounding data (fig. 5 and fig. 6). The merged data sets provide resistivity information extending to greater depth. However, vertical sounding data resolution tends to diminish with depth and with horizontal distance from the sounding point. Therefore, the maximum depth values shown in figure 5 and figure 6 should be considered as approximations and not true depths of investigation. No vertical soundings were made in the northern part of the study area, so profile 7 in fig. 5 does not extend as deep as the other profiles plotted from the combined data sets.

All of the profiles were plotted to the same horizontal and vertical scale and aligned to common Universal Transverse Mercator (UTM) easting and northing (UTM Zone 13N, North American Datum 1983). Data grids were calculated using the triangulation with linear interpolation method in Surfer v.8 from Golden Software, Inc., and plotted as image maps ranging from 10 to 2,000 ohm-m.

To provide an alternative and complimentary presentation of the merged resistivity profiles, three-dimensional section maps were made using the commercially available geophysical analysis software Profile Analyst v.4.0 from Encom, Inc. (fig. 7 and fig. 8). The combined profiles provide on-screen interactive manipulation and interpretation of all eight resistivity sections in a single three-dimensional image.

An important consideration in the interpretation of these three-dimensionally rendered images is that they are constructed from inverted resistivity data that was originally collected in a two-dimensional array with each line independent of one another. The data have been interpreted by a two-dimensional inversion that has no information from the other profiles, and therefore, are not constrained by adjacent data sets. This results in disagreement of resistivity values in some areas where the profiles cross.

Discussion

Initial field observations and available geologic mapping suggested a relatively simple geologic setting near the landfill study area. However, the resistivity profiles indicate a more complex structure in the subsurface. Interpretation of the profiles is complicated by the similarity of electrical properties of the bedrock formations. Additionally, dry gravels can also be characterized by high electrical resistivity.

Prominent features seen in the profiles include lens shaped resistive anomalies, shown in figure 3 and figure 4 (Qtzl), at elevations ranging from approximately 1,320 m to 1,350 m. These anomalies are interpreted as north trending electrically resistive quartzite lenses, similar to others that have been observed in the area of the Hartville uplift (personal communication, R.E. Harris, Wyoming State Geological Survey).

Another prominent resistive feature is seen where an outcrop of limestone (near well 10) was crossed by profile 2 and profile 4. The profiles show that the limestone has resistivities greater than 1000 ohm-m. Profile 2 (fig. 3 and fig. 5) and profile 4 (fig. 4 and fig. 6) indicate that this vertical anomaly extends to considerable depth. Profile 5, 2, and 6, respectively (fig. 3 and fig. 5) show that the vertical anomaly associated with the outcrop is likely oriented from southwest to northeast, and generally follows the direction of the ravine from well 2-2T to well 1-T (fig. 2). This suggests that the location of the ravine is structurally controlled. In terms of ground-water flow, this structure could act as a barrier to flow, or if fractured, could be a conduit for subsurface flow. Similar vertical anomalies are seen to the east, and are particularly prominent in the deeper soundings (fig. 5, profile 2 and profile 6). These anomalies could be additional limestone structures similar in composition to the ravine outcrop, or associated with the metadolomites found in the quarry to the east. Another resistive zone near the surface, possibly extending to depth, is seen in the western most extent of Profile 1 and profile 2 (fig.3 and fig. 5). The north-south profiles (fig. 4 and fig. 6) show no major resistive anomalies occurring to the south off of the landfill terrace. This material is likely valley fill and/or fluvial deposits.

On the terrace gravel bench, near the landfill, the terrace gravels are represented by resistivities greater than 300 ohm-m. These gravels are generally 15 to 30 m thick. Lower resistivities above the terrace gravels are presumed to indicate fill materials resulting from landfill operations. Because of the high resistivities attributed to the terrace gravels, they are assumed to be above the water table. Lower resistivities below the high resistivity zones could be water saturated gravels, or some finer grained more clay rich material such as found in the Arikaree formation. Zones with resistivities of less than 30 ohm-m are unlikely to be water saturated gravels unless the water is of poor quality. Profile 6, across a landfill cell, indicates terrace gravels about 15 m thick overlain by a maximum of 15 m of presumed fill material. The presumed landfill material can also be seen on profile 1 and the northern end of profile 8.

Conclusion

The DC resistivity methods used in this study illustrate that multi-electrode DC resistivity surveying can be used to efficiently map anomalies of hydrologic interest in geologically complex terrain. By merging these data with more traditionally acquired resistivity data, greater depths of investigation can be achieved. Changes in resistivity can correlate well with changes in moisture content as well as changes in lithology. However, differentiation of rock types with similar electrical properties can be problematic.

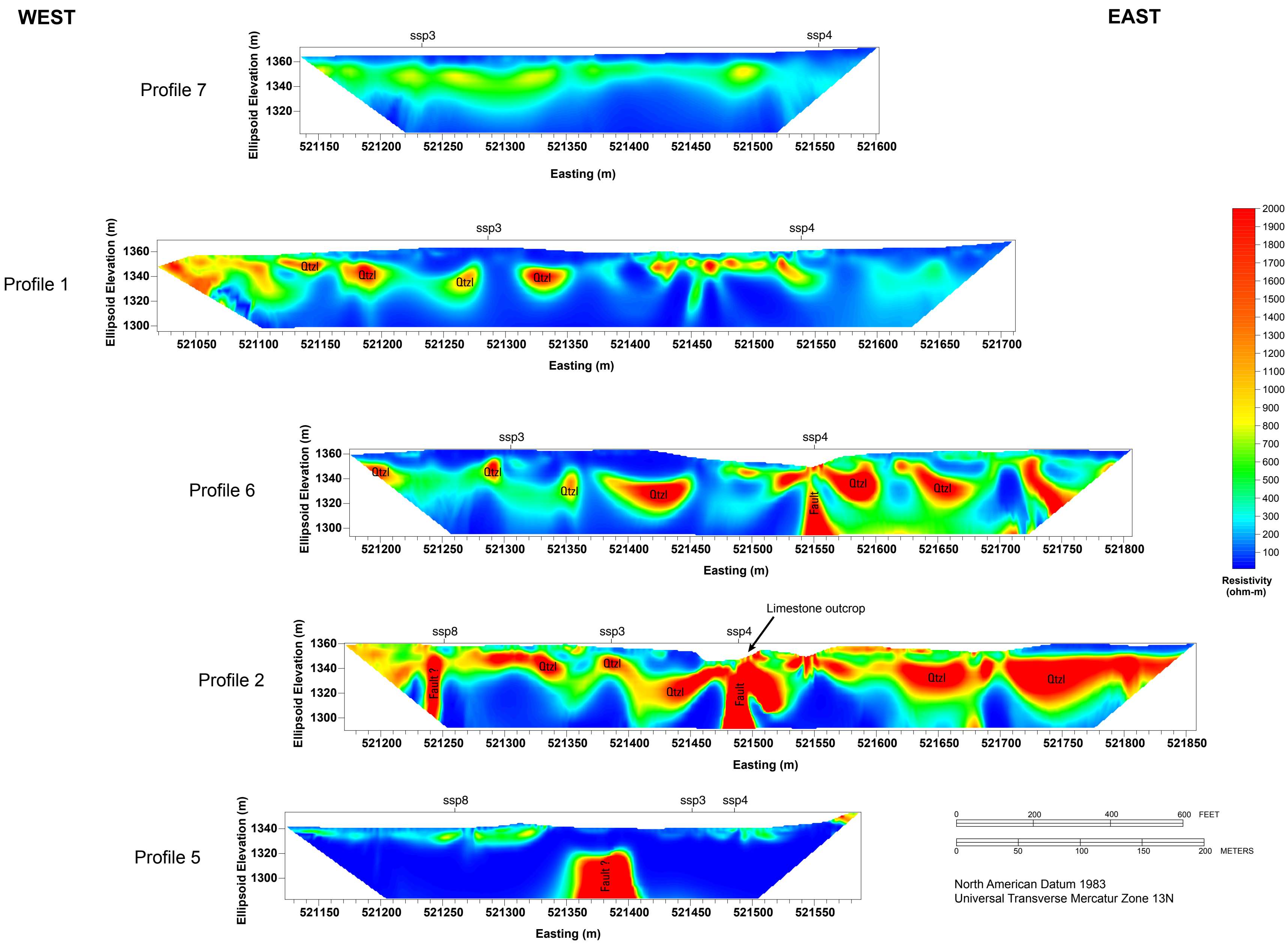

Figure 3. SuperSting east-west trending resistivity profiles. Profiles are aligned to common UTM easting coordinates. Intersection points with north-south lines (ssp) are labeled to correspond with map locations shown in figure 2. Resistive anomalies interpreted as quartzite lenses are labeled as Qtzl and anomalies interpreted as possible faults are also shown.

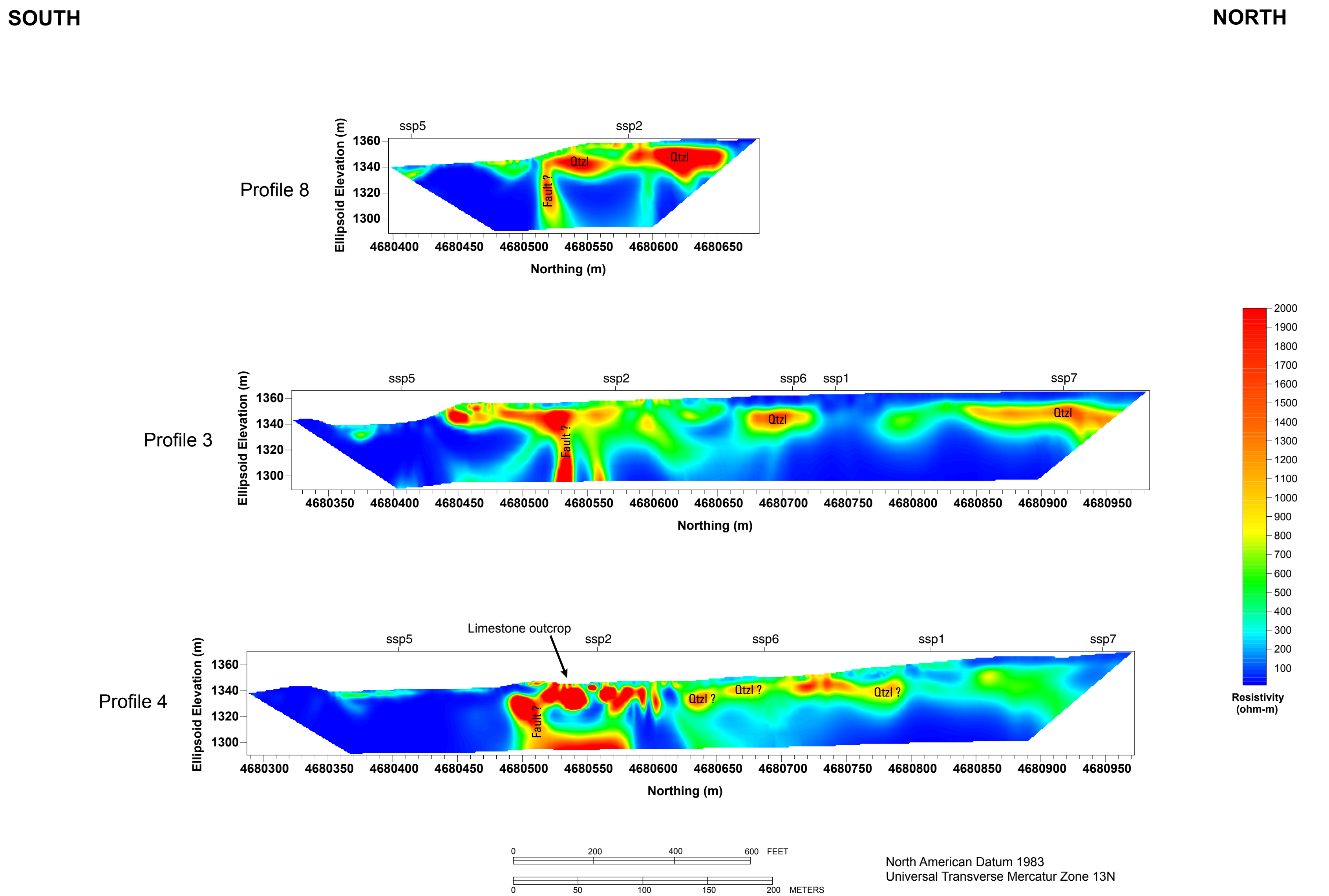

Figure 4. SuperSting north-south trending resistivity profiles. Profiles are aligned to common UTM northing coordinates. Intersection points with east-west lines (ssp) are labeled to correspond with map locations shown in figure 2. Resistive anomalies interpreted as quartzite lenses are labeled as Qtzl and anomalies interpreted as possible faults are also shown.

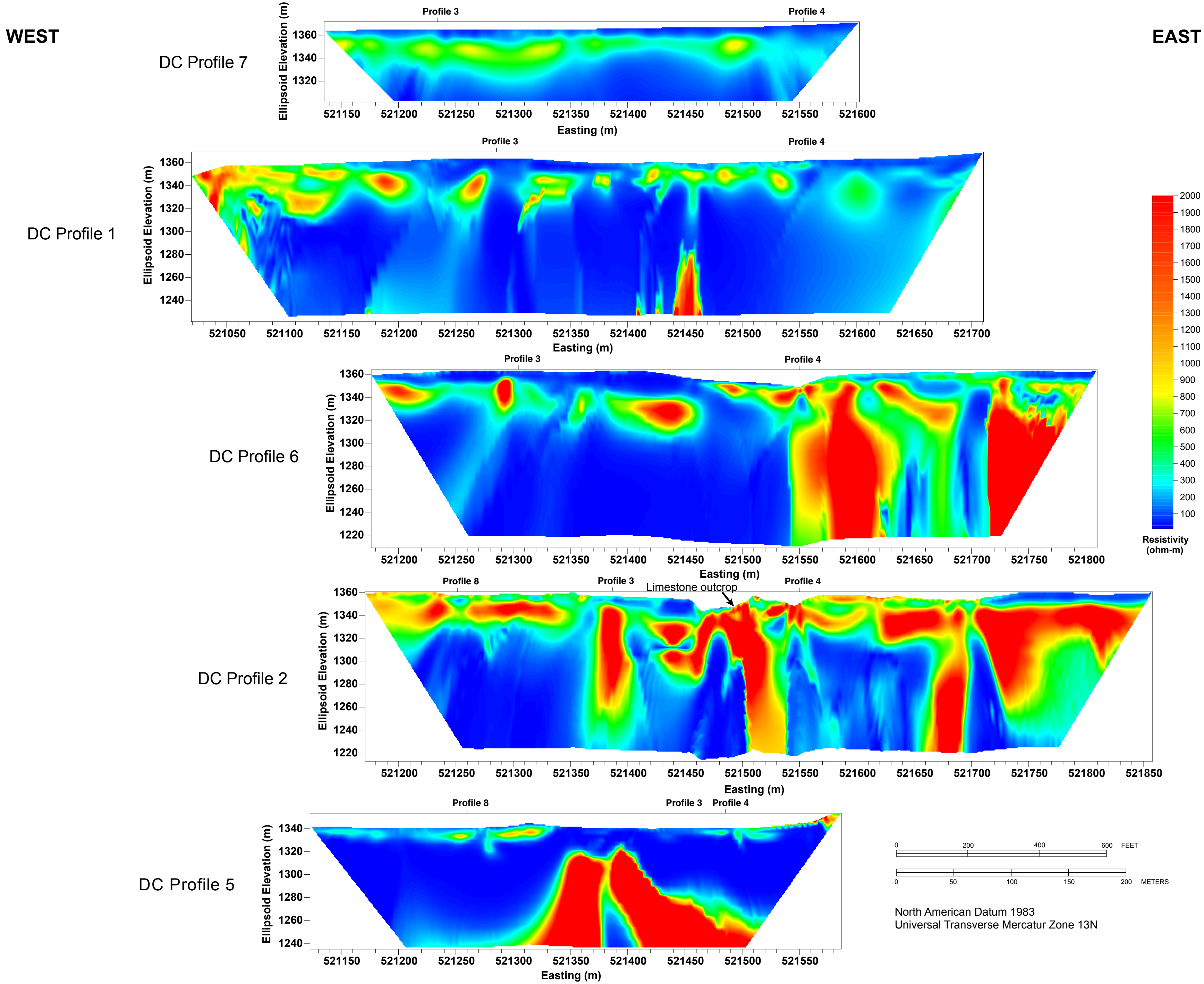

Figure 5. **East-west trending resistivity profiles from merged SuperSting and vertical sounding data. Profiles are aligned to common UTM easting coordinates. Intersection points with north-south lines are labeled to correspond with map locations shown in figure 2.**

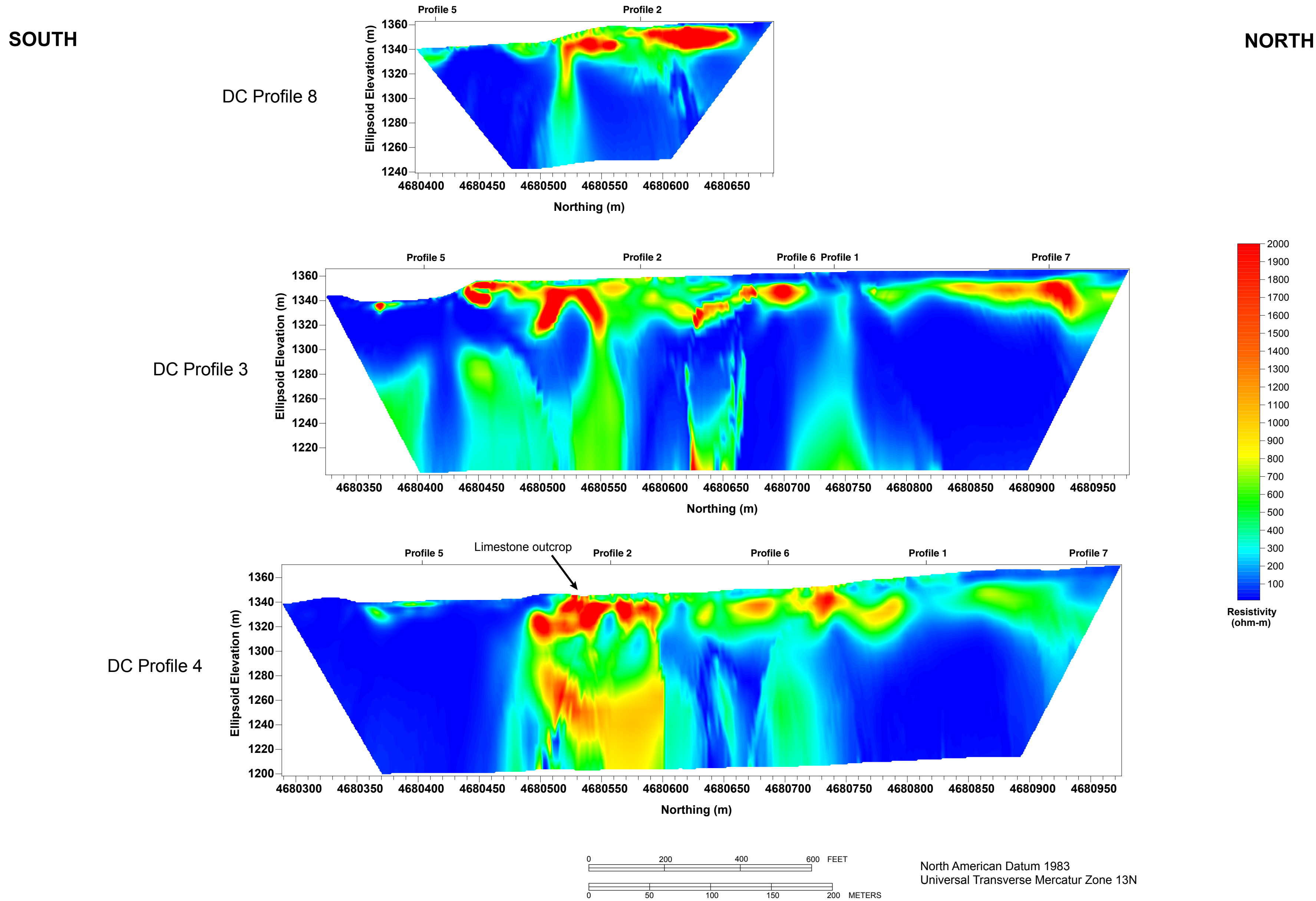

Figure 6. North-south trending resistivity profiles from merged SuperSting and vertical sounding data. Profiles are aligned to common UTM northing coordinates. Intersection points with east-west lines are labeled to correspond with map locations shown in figure 2.

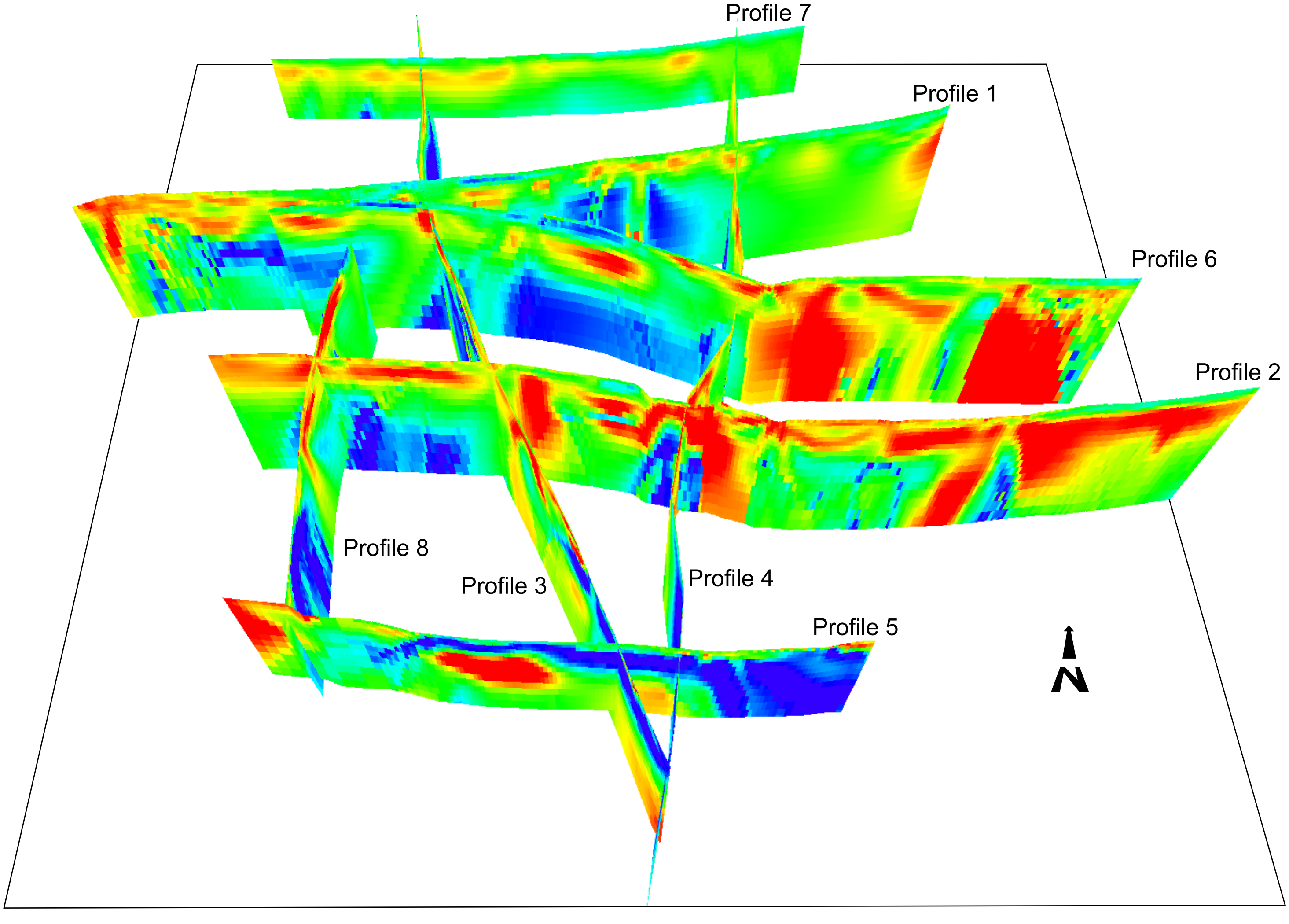

Figure 7. Three-dimensional view, looking north, of merged resistivity profiles and soundings. Map locations of profiles are shown in figure 2.

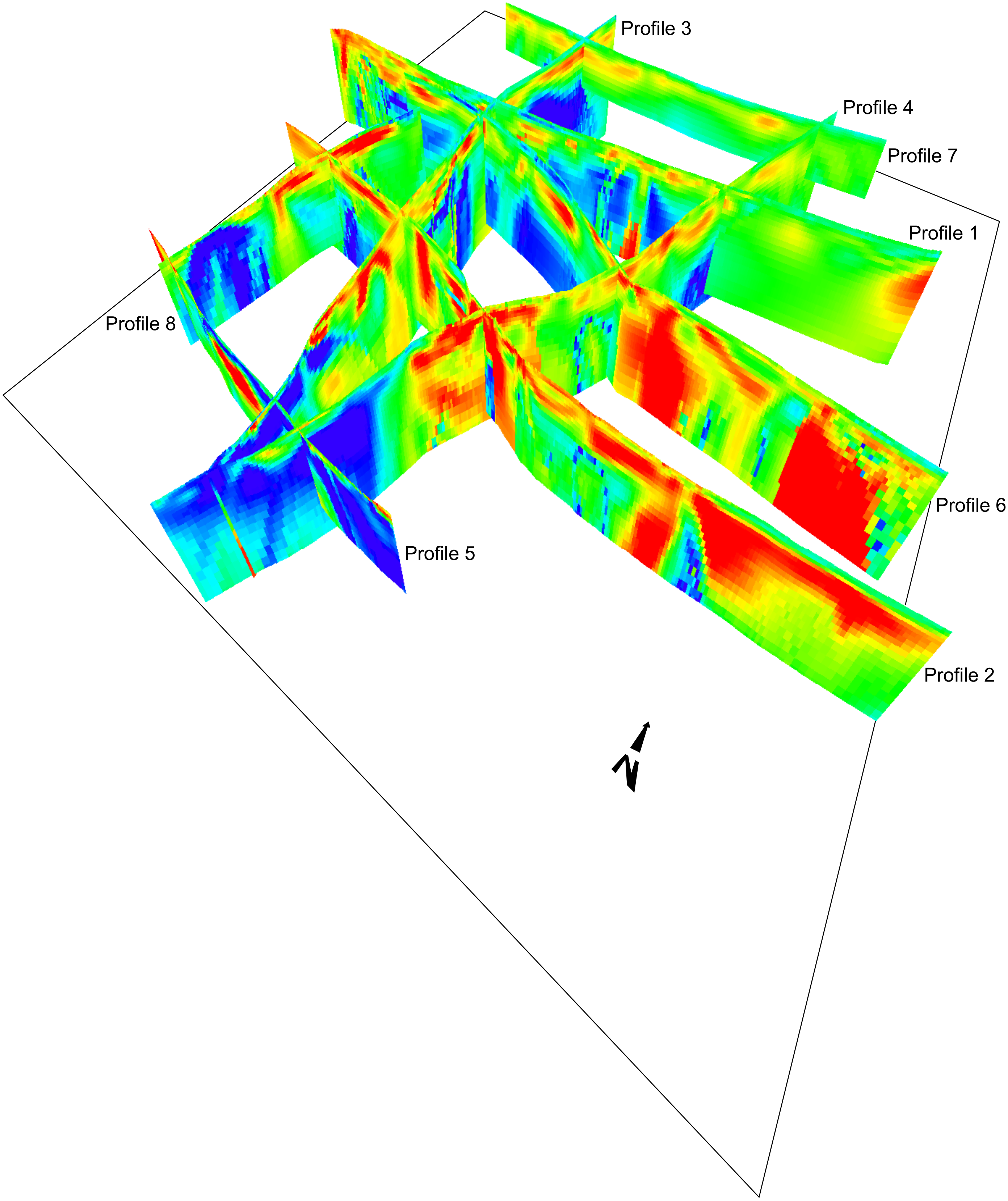

Figure 8. Three-dimensional view, looking northwest, of merged resistivity profiles and soundings. Map locations of profiles are shown in figure 2.

References

Dobrin, M.B. and Savit, C.H., 1988, Introduction to Geophysical Prospecting, fourth edition, McGraw-Hill, 630 p.

Harris, R.E., 1997, Preliminary geologic map of the Guernsey quadrangle, Platte and Goshen counties, Wyoming, Wyoming State Geological Survey Map 97-1.

Telford, W.M., Geldart, L.P., and Sheriff, R.E., 1990, Applied Geophysics, 2nd ed., Cambridge University Press, 770 p.

Zohdy, A.A.R., Eaton, G.P., and Mabey, D.R., 1974, Application of Surface Geophysics to Ground-Water Investigations, Techniques of Water-Resources Investigations of the United States Geological Survey, Book 2, Chapter D1: United States Geological Survey, Denver, CO, 116 p.

List of Figures

List of Data

All files used to produce the resistivity profiles in this report are included and listed by directory as follows:

sting_profiles – eight lines of resistivity data collected with the AGI SuperSting system. Each line directory includes: original .dat inverted resistivity data, Surfer v.8 plot files, .grd grid files, and .bln blanking files, and Excel spreadsheet of data and coordinates.

sounding_profiles – eight lines of combined resistivity data collected the AGI SuperSting system and ABEM single-channel system. Each line directory includes: original .dat inverted resistivity data, Surfer v.8 plot files, .grd grid files, and .bln blanking files, and Excel spreadsheet of data and coordinates.