

# **SUPPLEMENTAL FIELD INVESTIGATION FOR NON-SELECT SOILS**

**Project No. BD-498**

## *FINAL REPORT*

By: Robert J. Werner, P.E.  
Principal Investigator

ARDAMAN & ASSOCIATES, INC.  
8008 South Orange Avenue  
Orlando, Florida 32809

Prepared for

FLORIDA DEPARTMENT OF TRANSPORTATION  
RESEARCH CENTER  
605 Suwannee Street  
Tallahassee, Florida 32399-0459

Project Manager: Dr. David J. Horhota, P.E.  
State Geotechnical Materials Engineer  
FDOT State Materials Office

January 2008

## **DISCLAIMER**

The opinions, findings, and conclusions expressed in this publication are those of the author and not necessarily those of the State of Florida Department of Transportation.

## METRIC CONVERSION TABLE

### APPROXIMATE CONVERSIONS TO SI UNITS

| SYMBOL                | WHEN YOU KNOW | MULTIPLY BY | TO FIND            | SYMBOL          |
|-----------------------|---------------|-------------|--------------------|-----------------|
| <b>LENGTH</b>         |               |             |                    |                 |
| <b>in</b>             | inches        | 25.4        | millimeters        | mm              |
| <b>ft</b>             | feet          | 0.305       | meters             | m               |
| <b>yd</b>             | yards         | 0.914       | meters             | m               |
| <b>mi</b>             | miles         | 1.61        | kilometers         | km              |
| <b>AREA</b>           |               |             |                    |                 |
| <b>in<sup>2</sup></b> | square inches | 645.2       | square millimeters | mm <sup>2</sup> |
| <b>ft<sup>2</sup></b> | square feet   | 0.093       | square meters      | m <sup>2</sup>  |
| <b>yd<sup>2</sup></b> | square yard   | 0.836       | square meters      | m <sup>2</sup>  |
| <b>VOLUME</b>         |               |             |                    |                 |
| <b>ft<sup>3</sup></b> | cubic feet    | 0.028       | cubic meters       | m <sup>3</sup>  |
| <b>yd<sup>3</sup></b> | cubic yards   | 0.765       | cubic meters       | m <sup>3</sup>  |

| MBOL                  | WHEN YOU KNOW      | MULTIPLY BY | TO FIND       | SYMBOL          |
|-----------------------|--------------------|-------------|---------------|-----------------|
| <b>LENGTH</b>         |                    |             |               |                 |
| <b>mm</b>             | millimeters        | 0.039       | inches        | in              |
| <b>m</b>              | meters             | 3.28        | feet          | ft              |
| <b>m</b>              | meters             | 1.09        | yards         | yd              |
| <b>km</b>             | kilometers         | 0.621       | miles         | mi              |
| <b>AREA</b>           |                    |             |               |                 |
| <b>mm<sup>2</sup></b> | square millimeters | 0.0016      | square inches | in <sup>2</sup> |
| <b>m<sup>2</sup></b>  | square meters      | 10.764      | square feet   | ft <sup>2</sup> |
| <b>m<sup>2</sup></b>  | square meters      | 1.195       | square yards  | yd <sup>2</sup> |
| <b>km<sup>2</sup></b> | square kilometers  | 0.386       | square miles  | mi <sup>2</sup> |
| <b>VOLUME</b>         |                    |             |               |                 |
| <b>m<sup>3</sup></b>  | cubic meters       | 35.314      | cubic feet    | ft <sup>3</sup> |
| <b>m<sup>3</sup></b>  | cubic meters       | 1.307       | cubic yards   | yd <sup>3</sup> |

| SYMBOL             | WHEN YOU KNOW               | MULTIPLY BY | TO FIND              | SYMBOL |
|--------------------|-----------------------------|-------------|----------------------|--------|
| <b>MASS</b>        |                             |             |                      |        |
| <b>g</b>           | grams                       | 0.035       | ounces               | oz     |
| <b>kg</b>          | kilograms                   | 2.202       | pounds               | lb     |
| <b>Mg (or "t")</b> | megagrams (or "metric ton") | 1.103       | short tons (2000 lb) | T      |

**Technical Report Documentation Page**

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |  |                                                             |  |                                                                                                |  |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|-------------------------------------------------------------|--|------------------------------------------------------------------------------------------------|--|
| 1. Report No.<br><b>Bd-498</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |  | 2. Government Accession No.                                 |  | 3. Recipient's Catalog No.                                                                     |  |
| 4. Title and Subtitle<br><b>Supplemental Field Investigation for Non-Select Soils</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |  |                                                             |  | 5. Report Date<br><b>January 10, 2008</b>                                                      |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |  |                                                             |  | 6. Performing Organization Code                                                                |  |
| 7. Author(s)<br><b>Robert J. Werner</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |  |                                                             |  | 8. Performing Organization Report No.<br><b>File No. 02-198</b>                                |  |
| 9. Performing Organization Name and Address<br><b>Ardaman &amp; Associates, Inc.<br/>8008 South Orange Avenue<br/>Orlando, Florida 32908</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |  |                                                             |  | 10. Work Unit No. (TRAIS)                                                                      |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |  |                                                             |  | 11. Contract or Grant No.                                                                      |  |
| 12. Sponsoring Agency Name and Address<br><b>Research Center<br/>Florida Department of Transportation</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |  |                                                             |  | 13. Type of Report and Period Covered<br><b>Final Report<br/>December 2002 to January 2008</b> |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |  |                                                             |  | 14. Sponsoring Agency Code                                                                     |  |
| 15. Supplementary Notes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |  |                                                             |  |                                                                                                |  |
| 16. Abstract<br><br><p>Difficult soils, such as highly compressible organic and soft clay soils, are often encountered in the shallow Florida subsurface, and warrant special attention in design and construction of transportation facilities. These problem soils frequently exist as localized pockets within otherwise suitable sandy soils. Unfortunately, such "problem soil" conditions too often go undetected in conventional geotechnical explorations and then result in costly change orders for differing site conditions when unexpectedly encountered during construction. In other cases, excessive maintenance or reconstruction costs are later realized when problem soils remain undetected during construction but become evident through poor performance. In many cases, frequency and magnitude of these construction or maintenance cost overruns could be substantially reduced through more routine use of continuous alignment geophysical surveys during the project planning and design phases to aid in selection of conventional test boring locations and in the interpretation and interpolation of their results.</p> <p>In an effort to encourage more routine use of supplemental field investigation techniques in conventional roadway geotechnical engineering practice, the Florida Department of Transportation sponsored a research study aimed at identifying and demonstrating the utility of conventional and emerging geophysical methods. The primary objective of this study is to demonstrate the utility and cost effectiveness of several "tools" that can be implemented to enable rapid assessment of subsurface variability and reliable detection of anomalous conditions along extended roadway alignments</p> <p>Several supplemental investigation methods were evaluated in terms of applicability, practicality, timeliness, utility of results by geophysical non-experts and cost. Surface geophysical methods, including ground penetrating radar, terrain conductivity, direct current and capacitively-coupled resistivity, and seismic methods were selected for testing. During an initial verification testing phase, the applicability of these methods was assessed at a number of sites known to have "problem" subsurface soil conditions. A validation testing phase was then undertaken using selected verified methods at two actual highway project sites in central Florida. During this phase, more than 30 kilometers (nearly 20 miles) of continuous alignment geophysical surveys were performed.</p> <p>This report presents findings from the study, including selection of candidate methods, results of field verification and validation testing phases and recommendations for further study and implementation. Based on the results presented herein, we are optimistic that more routine use of continuous alignment surface geophysics can provide the advanced notice of potential problem areas that the engineer needs in order to better plan and execute effective geotechnical investigations. The envisioned result is a decline in the number of change orders related to unforeseen problem soil conditions, improved performance, and reduced overall project and maintenance costs.</p> |  |                                                             |  |                                                                                                |  |
| 17. Key Word<br><b>Geophysical Methods<br/>Continuous Alignment<br/>Resistivity Survey</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |  |                                                             |  | 18. Distribution Statement<br><b>No restriction.</b>                                           |  |
| 19. Security Classif. (of this report)<br><b>Unclassified</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |  | 20. Security Classif. (of this page)<br><b>Unclassified</b> |  | 21. No. of Pages<br><b>218</b>                                                                 |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |  |                                                             |  | 22. Price                                                                                      |  |



## **EXECUTIVE SUMMARY**

### **Project Purpose**

Difficult soils, such as highly compressible organic and soft clay soils, are often encountered in the shallow Florida subsurface, and warrant special attention in design and construction of transportation facilities. These problem soils frequently exist as localized pockets within otherwise suitable sandy soils. Unfortunately, such “problem soil” conditions often go undetected in conventional geotechnical explorations and then result in costly change orders for differing site conditions when unexpectedly encountered during construction. In other cases, excessive maintenance or reconstruction costs are later realized when problem soils remain undetected during construction but become evident through poor performance. In many cases, frequency and magnitude of these construction or maintenance cost overruns could be substantially reduced through more routine use of supplemental investigations during the project planning and design phases to aid in selection of conventional test boring locations and in the interpretation and interpolation of their results.

In an effort to encourage more routine use of supplemental field investigation techniques in conventional roadway geotechnical engineering practice, the Florida Department of Transportation sponsored this research study aimed at identifying and demonstrating the utility of conventional and emerging geophysical methods. The primary objective of this study is to demonstrate the utility and cost effectiveness of several “tools” that can be implemented to enable rapid assessment of subsurface variability and reliable detection of anomalous conditions along extended roadway alignments. The study is focused on methods that can enable geotechnical engineers to better plan and execute more effective and reliable subsurface investigations by providing initial data from which the frequency and extent of potentially difficult subsurface conditions can be readily assessed.

### **Background**

Execution of well-planned geotechnical exploration programs is fundamental to the planning, design, and construction phases of roadway projects, both in terms of performance and cost effectiveness. Several past roadway projects in Florida have encountered unforeseen difficult soils such as peat, muck or clay in proposed foundation soils or planned

borrow excavations that went undetected in the geotechnical exploration phase. In these situations, change orders for differing site conditions resulted in substantial project cost overruns. In other cases, unplanned maintenance or reconstruction costs were realized when problematic conditions remained undetected but became evident through poor performance. In many cases, the magnitude of these construction and/or maintenance overruns would have justified substantial additional or supplemental subsurface exploration efforts and expenditures during the planning and design phases of the projects.

The FDOT Soils and Foundation Handbook provides guidelines to assist the engineer in formulating and implementing successful geotechnical field exploration and laboratory testing programs. Handbook guidelines for minimum roadway soil survey explorations include soil borings at a maximum spacing of 100 feet (30 meters), alternating left and right of the proposed centerline, or in the additional lane for widening projects. This spacing may be increased if pre-existing information indicates the presence of uniform subsurface conditions, but should be reduced as necessary to define the limited of undesirable materials or to better define stratification in areas of highly variable soil conditions. Hence, some understanding of the degree of variability along a given project alignment is needed to plan an effective geotechnical exploration, and the Handbook does provide some general guidance regarding potential use of a few supplemental geophysical methods for pre-determining the degree of variability. However, regular use of non-invasive geophysical techniques as geotechnical investigation tools has remained largely uncommon.

## **Process**

This study was aimed at identifying supplemental methods that are available to the engineer that can employ in advance to provide “pre-existing” data needed for more effective planning and execution of the conventional exploration. The supplemental techniques, therefore, are intended to initially be used for rapid continuous alignment anomaly detection and variability assessment. More detailed analysis and collective interpretation of the supplemental data for complimentary uses or to assess inter-boring stratigraphy or variation in soil properties could then be undertaken concurrent with or subsequent to the soil boring program. In addition, candidate methods should be complimentary to each other to constrain their individual and collective interpretation. Supplemental investigation techniques were selected for evaluation in this study according to the following general criteria.

- (i) reliability in identifying organic or clayey problem soils to depths on the order of 6 meters (20 feet);
- (ii) timeliness and cost of data collection and preliminary analysis for roadway alignments extending up to several kilometers;
- (iii) usefulness of preliminary minimally-processed results to geotechnical engineers, particularly for planning effective conventional explorations.

Because the majority of roadway construction projects, and hence geotechnical explorations, involve modification of existing facilities, preference was given to non-destructive methods compatible with paved surface conditions with relatively low sensitivity to cultural noise (powerlines, buried utilities, maintained vehicular traffic, etc.). Based on these requirements, and considering to some extent general availability within Florida, surface geophysical methods, including ground penetrating radar (GPR), electromagnetic terrain conductivity (EM), direct current and capacitively-coupled resistivity (CCR), and surface wave seismic methods (MASW) were selected for testing. During an initial verification testing phase, the applicability of these methods was assessed at a number of sites known to have “problem” subsurface soil conditions. A validation testing phase was then undertaken using selected verified methods at two actual highway project sites in central Florida. During this phase, more than 30 kilometers (nearly 20 miles) of continuous alignment geophysical surveys were performed.

In general, the terrain conductivity (EM) and GPR methods were less effective than the CCR and MASW surveys in terms of achieving the study objectives for the conditions encountered at the selected verification test sites. Results of the CCR surveys consistently exhibited the more clearly recognizable contrasts between background and target response relative to identification of the known problem soil conditions at the verification test sites. Since GPR data can be collected concurrently with CCR data, it is deemed worthwhile to collect since the incremental costs are very low, unknown buried features can be identified, and the data are then available for expert evaluation if warranted during the design phase. Results of the MASW test transects, in terms of shear wave velocity profiles, exhibited sharp contrasts between the organic soil anomalies and surrounding sandy background soil conditions at the test sites, consistent with the CCR results. However, even with the fabricated plate-mounted geophone land-streamer, application of the MASW method

remained significantly more time consuming. Therefore, application of the MASW for extended continuous alignment roadway surveys is probably too cost prohibitive for routine use at this time.

### **Risk Map Development**

In order to assist engineers in assessing the potential for non-select conditions and hence the need for supplemental exploration, a state-wide non-select soil “risk” map was developed in conjunction with this study. Digital GIS-compatible soil survey databases that have recently been released by the National Resource Conservation Service (NRCS) for all but one of Florida’s Counties were processed to develop this “risk” map. (Data for Gadsden County is expected to become available during calendar year 2008.) In addition to delineated near-surface soil types, the database files include. Maps for each FDOT District were generated on the basis of characteristic clay and organic content for the various soil units delineated by NRCS and incorporated into an ArcGIS database. Through the GIS database platform, these maps can be viewed as overlays and scaled with aerial photography to review project specific areas from a non-select soil potential standpoint.

### **Findings and Conclusions**

The goal of the study was to identify, test and evaluate viable investigation techniques that can be implemented on a regular basis near-term to supplement and enhance the effectiveness of conventional soil boring programs. Based on our evaluation of field tests and simulated implementation, the utility of selected non-invasive, continuous-alignment surface geophysical methods appears promising. Concurrent CCR-GPR with GPS positioning proved particularly viable for the test sites evaluated in this study.

In summary, results of validation test surveys using concurrent CCR-GPR with GPS positioning proved adequately reliable for use in planning effective conventional geotechnical explorations. Considering that nearly 27.5 kilometers (17 miles) of surveys were completed in less than 3 days, and that minimally-processed results were readily interpretable from an engineer’s perspective, near-term routine implementation of a supplemental field exploration appears viable. In particular, results of this study indicate that more routine implementation of supplemental exploration should be considered for

roadway projects within areas of the State where non-select subsoil conditions are generally more prevalent.

### **Recommendations for Implementation**

Based on finding from this study, an implementation plan for FDOT project alignments will include:

- i. Using state-wide NRCS-based non-select soil maps to identify areas of the state or specific project sites that warrant supplemental investigations.
- ii. Conducting or contracting supplemental investigations on a more routine basis, and expanding Department capabilities within FDOT State Materials Office to provide geophysical services to the Districts.
- iii. Incorporating more specific guidelines for use of supplemental geophysical investigations in the FDOT Soils and Foundations Handbook.

This report presents findings from the study, including selection of candidate methods, results of field verification and validation testing phases and recommendations for further study and implementation. Based on the results presented herein, we are optimistic that more routine use of continuous alignment surface geophysics can provide the advanced notice of potential problem areas that the engineer needs in order to better plan and execute effective geotechnical investigations. The envisioned result is a decline in the number of change orders related to unforeseen problem soil conditions, improved performance, and reduced overall project and maintenance costs.

## TABLE OF CONTENTS

|                                                     |     |
|-----------------------------------------------------|-----|
| DISCLAIMER .....                                    | ii  |
| METRIC CONVERSION TABLE .....                       | iii |
| TECHNICAL REPORT DOCUMENTATION PAGE .....           | iv  |
| EXECUTIVE SUMMARY .....                             | v   |
| 1. INTRODUCTION.....                                | 1   |
| 1.1 Background                                      |     |
| 1.2 Problem Statement                               |     |
| 1.3 Research Objectives                             |     |
| 2. LITERATURE REVIEW AND APPLICATION SURVEY .....   | 4   |
| 2.1 Conventional Exploration                        |     |
| 2.2 Supplemental Geotechnical Methods               |     |
| 2.3 Supplemental Geophysical Methods                |     |
| 2.3.1 Electromagnetic                               |     |
| 2.3.2 Resistivity                                   |     |
| 2.3.3 Ground Penetrating Radar                      |     |
| 2.3.4 Seismic                                       |     |
| 2.4 Application Survey                              |     |
| 2.5 Florida Soil Maps (NRCS)                        |     |
| 3. FIELD VERIFICATION TESTING PROGRAM .....         | 17  |
| 3.1 Overview of Testing Program Methods             |     |
| 3.2 Field Verification Test Sites                   |     |
| 3.2.1 Beauchamp Road, Hillsborough County           |     |
| 3.2.2 Glen Harwell Road, Hillsborough County        |     |
| 3.2.3 Reclaimed Phosphate Mine Site, Polk County    |     |
| 3.2.5 Sandlake Road (S.R. 482), Orange County       |     |
| 3.3 Field Verification Test Results                 |     |
| 3.3.1 Capacitively-Coupled Resistivity Test Results |     |
| 3.3.2 Surface Wave Analysis Results                 |     |
| 3.3.3 Terrain Conductivity Results                  |     |
| 3.3.4 Ground Penetrating Radar Results              |     |
| 3.3.5 Comparison Between Two Resistivity Methods    |     |

## TABLE OF CONTENTS (Cont'd.)

|       |                                          |    |
|-------|------------------------------------------|----|
| 4.    | FIELD VALIDATION TESTING PROGRAM.....    | 30 |
| 4.1   | Field Validation Test Sites              |    |
| 4.1.1 | S.R. 520, Orange County                  |    |
| 4.1.2 | S.R. 400 (I-4), Volusia County           |    |
| 4.2   | Test Methods                             |    |
| 4.3   | Validation Test Results                  |    |
| 4.3.1 | S.R. 520 Test Results                    |    |
| 4.3.2 | S.R. 400 (I-4) Test Results              |    |
| 5.    | SUMMARY AND PRACTICAL IMPLICATIONS ..... | 37 |
| 5.1   | Review of Conventional Practice          |    |
| 5.2   | Supplemental Investigation Methods       |    |
| 5.2.1 | Effectiveness and Reliability            |    |
| 5.2.2 | Availability, Time and Cost              |    |
| 5.2.3 | Potential Drawbacks and Limitations      |    |
| 5.4   | NRCS "Non-Select" Soil Maps              |    |
| 5.5   | Proposed Implementation Plan             |    |

|                  |    |
|------------------|----|
| REFERENCES ..... | 41 |
|------------------|----|

## APPENDICES

Appendix A - Maps  
Appendix B - Beauchamp Road Test Data  
Appendix C - Glen Harwell Road Test Data  
Appendix D - Phosphate Mine Test Site  
Appendix E - Sandlake Road Test Site  
Appendix F - S.R. 520 Test Data  
Appendix G - S.R. 400 (I-4) Test Data  
Appendix H - Photographs

## LIST OF FIGURES

| <b><u>Figure</u></b>                                                                                       | <b><u>Page</u></b> |
|------------------------------------------------------------------------------------------------------------|--------------------|
| 1 Schematic of Resistivity Inverse Modeling Technique .....                                                | 23                 |
| 2 GPR Penetration Depth Versus Soil Conductivity .....                                                     | 23                 |
| 3 Sample GIS Map of NRCS Clayey Soils in FDOT District 2 .....                                             | 23                 |
| 4 CCR Surveys Along Shoulder and Through Pavement .....                                                    | 24                 |
| 5 Dual Antenna GPR and GEM-2 Equipment .....                                                               | 25                 |
| 6 Plate-Mounted Geophone Land Streamer Fabricated for MASW Testing .....                                   | 23                 |
| 7 Results of Initial MASW Test Shot .....                                                                  | 23                 |
| 8 Results of CCR Surveys on Pavement and Shoulder at Beauchamp Road .....                                  | 24                 |
| 9 Results of CCR Survey at Glen Harwell Road .....                                                         | 25                 |
| 10 Results of Duplicate CCR Surveys Performed for Repeatability Assessment ....                            | 25                 |
| 11 Comparison of CCR and MASW Results from Beauchamp Road .....                                            | 23                 |
| 12 Comparison of CCR and EM31 Results from Glen Harwell Road .....                                         | 24                 |
| 13 Comparison of Conventional Multi-channel DC and CCR Resistivity Survey<br>Results (from S.R. 520) ..... | 25                 |
| 14 S.R. 520 Validation Test Site .....                                                                     | 23                 |
| 15 Uniform and Highly Variable CCR Results at S.R. 520 .....                                               | 24                 |
| 16 CCR Results Through Planned De-mucking Area of S.R. 520 Project .....                                   | 25                 |
| 17 GPR Results and S.R. 520 GPR Feature Map .....                                                          | 24                 |
| 18 S.R. 400 Validation Test Site and CCR Resistivity Overview .....                                        | 25                 |
| 19 CCR Results Near Western and Eastern Ends of S.R. 400 Site .....                                        | 24                 |
| 20 Near-Surface Resistivity Along a Portion of the S.R. 400 Site .....                                     | 25                 |
| 21 Construction Costs Reported by the Orlando-Orange County Expressway<br>Authority .....                  | 25                 |



## LIST OF SYMBOLS AND ABBREVIATIONS

| <u>Symbol</u> | <u>Description</u>                                                |
|---------------|-------------------------------------------------------------------|
| AASHTO        | American Associates of State Highway and Transportation Officials |
| CCR           | Capacitively-Coupled Resistivity                                  |
| CPT           | Cone Penetration Test                                             |
| cm            | centimeters                                                       |
| DC            | Direct Current                                                    |
| dS            | DeciSiemens                                                       |
| EM            | Electromagnetic Method (terrain conductivity)                     |
| ER            | Electrical Resistivity (DC)                                       |
| FDOT          | Florida Department of Transportation                              |
| ft            | feet                                                              |
| g             | grams                                                             |
| GIS           | Geographic Information System                                     |
| GPR           | Ground Penetrating Radar                                          |
| GPS           | Global Positioning System                                         |
| Hz            | hertz                                                             |
| kHz           | kilohertz                                                         |
| m             | meter                                                             |
| MASW          | Multi-channel Analysis of Surface Waves                           |
| MCPT          | Miniature Cone Penetration Test                                   |
| MER           | Multi-channel Electrical Resistivity                              |
| Mhz           | Megahertz (frequency)                                             |
| NRCS          | National Resource Conservation Service                            |
| ns            | nanosecond                                                        |
| SASW          | Spectral Analysis of Surface Waves                                |
| sec, s        | seconds                                                           |
| SMO           | State Materials Office (of FDOT)                                  |
| S.R.          | State Route                                                       |



## **SECTION 1 INTRODUCTION**

The FDOT initiated this research study to investigate the technical and economic viability of more routine use of supplemental field investigation techniques in conventional roadway geotechnical engineering design practice. In particular, the goal of the study was to identify, test and evaluate viable investigation techniques that can be implemented on a regular basis near-term to supplement and enhance the effectiveness of conventional soil boring programs.

### **1.1 Problem Statement**

Difficult soils, such as highly compressible organic and soft clay soils, are often encountered in the shallow Florida subsurface, and warrant special attention in design and construction of transportation facilities. These problem soils frequently exist as localized pockets within otherwise suitable sandy soils. Unfortunately, such “problem soil” conditions too often go undetected in conventional geotechnical explorations and then result in costly change orders for differing site conditions when unexpectedly encountered during construction. In other cases, excessive maintenance or reconstruction costs are later realized when problem soils remain undetected during construction but become evident through poor performance.

### **1.2 Background**

Execution of well-planned geotechnical exploration programs is fundamental to the planning, design, and construction phases of roadway projects, both in terms of performance and cost effectiveness. Several past roadway projects in Florida have encountered unforeseen difficult soils such as peat, muck or clay in proposed foundation soils or planned borrow excavations that went undetected in the geotechnical exploration phase. In these situations, change orders for differing site conditions resulted in substantial project cost overruns. In other cases, unplanned maintenance or reconstruction costs were realized when problematic conditions remained undetected but became evident through poor performance. In many cases, the magnitude of these construction and/or maintenance overruns would have justified substantial additional or supplemental subsurface exploration efforts and expenditures during the planning and design phases of the projects.

The FDOT Soils and Foundation Handbook provides guidelines to assist the engineer in formulating and implementing successful geotechnical field exploration and laboratory testing programs. Handbook guidelines for minimum roadway soil survey explorations include soil borings at a maximum spacing of 100 feet (30 meters), alternating left and right of the proposed centerline, or in the additional lane for widening projects. This spacing may be increased if pre-existing information indicates the presence of uniform subsurface conditions, but should be reduced as necessary to define the limited of undesirable materials or to better define stratification in areas of highly variable soil conditions. Hence, some understanding of the degree of variability along a given project alignment is needed to plan an effective geotechnical exploration, and the Handbook does provide some general guidance regarding potential use of a few supplemental geophysical methods for pre-determining the degree of variability. However, regular use of non-invasive geophysical techniques as geotechnical investigation tools has remained largely uncommon.

### **1.3 Research Objectives**

In an effort to encourage more routine use of supplemental field investigation techniques in conventional roadway geotechnical engineering practice, the Florida Department of Transportation sponsored a research study aimed at identifying and demonstrating the utility of conventional and emerging geophysical methods. The primary objective of this study is to demonstrate the utility and cost effectiveness of several “tools” that can be implemented to enable rapid assessment of subsurface variability and reliable detection of anomalous conditions along extended roadway alignments.

The study is focused on methods that can enable geotechnical engineers to better plan and execute more effective and reliable subsurface investigations by providing initial data from which the frequency and extent of potentially difficult subsurface conditions can be readily assessed. In the study, preference was given to investigation techniques that involve rapid data collection and require limited initial data processing for the specific purpose of identifying and delimiting apparent anomalies in a timely manner. Upon further processing, calibration and expert interpretation, the collective supplemental data should also provide complimentary information to help “fill the gaps” between boreholes, detect unrecorded utilities or buried debris, or reveal areas that may warrant special investigation.

Several supplemental investigation methods were evaluated in terms of applicability,

practicality, timeliness, utility of results by geophysical non-experts and cost. Surface geophysical methods, including ground penetrating radar, terrain conductivity, direct current and capacitively-coupled resistivity, and seismic methods were selected for testing. During an initial verification testing phase, the applicability of these methods was assessed at a number of sites known to have “problem” subsurface soil conditions. A validation testing phase was then undertaken using selected verified methods at two actual highway project sites in central Florida. During this phase, more than 30 kilometers (nearly 20 miles) of continuous alignment geophysical surveys were performed.

The envisioned result is a decline in the number of change orders related to unforeseen problem soil conditions, improved performance, and reduced overall project and maintenance costs. This report documents findings from the study, including selection of candidate methods, results of field verification and validation testing phases and recommendations for further study and implementation.

## **SECTION 2**

### **LITERATURE REVIEW AND APPLICATION SURVEY**

A review of prior research reports, technical publications, case histories and testing equipment product literature was conducted during the initial phase of this study to assist in selection of candidate supplemental investigation methods for field verification and validation testing. In addition, the FDOT Soils and Foundation Handbook was reviewed to establish a benchmark for current conventional subsurface exploration practice for roadway projects. In addition, an application survey was undertaken to assess the viability of candidate supplemental investigation methods in terms of availability of experienced service providers within the State of Florida. Findings from the literature review and application survey are summarized in the following sections.

#### **2.1 Conventional Exploration**

Execution of well-planned geotechnical exploration programs is fundamental to the planning, design, and construction phases of roadway projects, both in terms of performance and cost effectiveness. The FDOT Soils and Foundation Handbook provides guidelines to assist the engineer in formulating and implementing successful geotechnical field exploration and laboratory testing programs.

Most commonly, subsurface investigations consist mainly of reviewing available existing data (topographic maps, aerial photographs, soil surveys, etc.), undertaking a field reconnaissance site visit, and performing a number of soil borings which may incorporate in situ testing (primarily standard penetration testing) and collection of samples for classification and laboratory testing. Handbook guidelines for minimum roadway soil survey explorations include soil borings at a maximum spacing of 100 feet (30 meters), alternating left and right of the proposed centerline, or in the additional lane for widening projects. This spacing may be increased if pre-existing information indicates the presence of uniform subsurface conditions, but should be reduced as necessary to define the limited of undesirable materials or to better define stratification in areas of highly variable soil conditions.

Conventional subsurface exploration methods (i.e., test borings) alone may not provide sufficient data to characterize conditions with an adequate level of confidence, particularly when

boring locations are more or less arbitrarily designated according to a predetermined starting position and uniform spacing. Consider an example where borings are performed at the FDOT maximum 100-foot (30-meter) interval alternating between right, center and left along the alignment of a 15-meter (50-foot) wide roadway section. As shown by Benson (1993), the probability of detecting a 15 by 10 meter anomaly, assuming random conditions, is only about 40 percent. If the boring spacing is halved, doubling the number of borings, the probability increases to 75 percent, which one may still consider unacceptable. Review of available existing information such as aerial photographs, soil surveys, etc. might be used to improve ones chances. However, if conditions are “random” (or otherwise highly variable), a boring spacing on the order of 10 meters would be required to detect the 15 by 10-meter hypothetical anomaly at the 90 percent confidence level.

Clearly, the scope and detail of subsurface explorations are constrained, primarily by limited time and budget resources. Too often, adequate data density is sacrificed for reduced exploration costs, which has resulted in “false” or temporary savings that are ultimate lost and overrun by otherwise avoidable costs associated with subsequent change orders, corrective actions or premature maintenance, or socioeconomic costs of sub-standard performance (Benson, 2000). Several past roadway projects in Florida have encountered unforeseen difficult soils such as peat, muck or clay in proposed foundation soils or planned borrow excavations that went undetected in the geotechnical exploration phase. In these situations, change orders for differing site conditions resulted in substantial project cost overruns. In other cases, unplanned maintenance or reconstruction costs were realized when problematic conditions remained undetected but became evident through poor performance. In many cases, the magnitude of these construction and/or maintenance overruns would have justified substantial additional or supplemental subsurface exploration efforts and expenditures during the planning and design phases of the projects. Accordingly, the FDOT has initiated this research study to investigate the technical and economic viability of more routine use of supplemental field investigation techniques in conventional roadway geotechnical engineering design practice. In particular, the goal of the study is to identify, test and evaluate viable investigation techniques that can be implemented on a regular basis near-term to supplement and enhance the effectiveness of conventional soil boring programs.

## **2.2 Supplemental Geotechnical Methods**

Several established supplemental geotechnical exploration methods, including electric cone

and electric piezocone soundings, dilatometer soundings and pressure meter tests, have been in use for many years, primarily to characterize the behavior of known difficult subsurface conditions. Use of these less invasive geotechnical field tests, particularly electric cone soundings, as a supplement or compliment to soil borings for roadway projects has been gaining popularity in recent years. Although these investigation tools are very valuable for vertical profiling, they ultimately can suffer from the same drawbacks inherent in soil boring programs; they provide information at one given location which must be pre-selected and may not be representative. With this in mind, use of in-house supplemental geotechnical methods for this study was generally limited to providing ground-truth data in conjunction with the field verification testing phase.

One geotechnical device that is particularly well-suited for supplemental investigations when used in concert with the geophysical method discussed below is the miniature piezocone (MCPT). This device is minimally invasive and can be mounted and operated from a heavy-duty pickup truck that allows relatively easy access and rapid mobilization between sounding locations.

## **2.3 Supplemental Geophysical Methods**

Although use of supplemental geotechnical testing methods, particularly electric cone soundings, to supplement soil borings has been gaining popularity in recent years, regular use of non-invasive geophysical techniques as geotechnical investigation tools has remained largely uncommon. Geophysical methods are covered in the FDOT Soils and Foundations Handbook, but no specific guidelines are provided related to their use on a production basis.

A literature review was performed to identify supplemental methods that are available to the engineer that can be employed in advance to provide “pre-existing” data needed for more effective planning and execution of the conventional exploration. The supplemental techniques, therefore, are intended to initially be used for rapid continuous alignment anomaly detection, or “exception reporting”. More detailed analysis and collective interpretation of the supplemental data for complimentary uses or to assess inter-boring stratigraphy or variation in soil properties could then be undertaken concurrent with or subsequent to the soil boring program. In addition, candidate methods should be complimentary to each other to constrain their individual and collective interpretation. Supplemental investigation techniques were selected for application in this study according to the following requirements.



- (i) reliability in identifying problem soils to depths on the order of 6 meters (20 feet);
- (ii) timeliness and cost of data collection and preliminary analysis for roadway alignments extending up to several kilometers;
- (iii) usefulness of preliminary minimally-processed results to geotechnical engineers, particularly for planning effective conventional explorations.

Because the majority of roadway construction projects, and hence geotechnical explorations, involve modification of existing facilities, preference was given to non-destructive methods compatible with paved surface conditions with relatively low sensitivity to cultural noise (powerlines, buried utilities, maintained vehicular traffic, etc.). Based on these requirements, and considering to some extent general availability within Florida, the methods briefly described below were selected for field verification.

#### 2.3.1 Electromagnetic

The frequency domain electromagnetic method (EM) was selected for testing since it was expected that contrasts between low conductivity sandy-soil background conditions and higher conductivity non-select organic or clayey soil targets could be detected within the 6-meter depth range of interest. In addition, EM surveying services are widely available, data collection is relatively easy and fast, particularly with newer devices equipped with GPS-compatible automated data loggers, and the data can be used for exception reporting purposes with minimal data processing. Potential drawbacks include relatively high susceptibility to cultural interference. Three electromagnetic surveying devices were tested, namely the EM-31, EM-61 and GEM-2.

The EM31-MK2 is manufactured by Geonics Limited of Ontario, Canada. The instrument maps variations in the ground conductivity using an electromagnetic inductive technique that makes the measurements without electrodes or ground contact. The effective depth of exploration is about six meters (20 feet). For this study, data points were collected at 5-foot intervals along each test transect. Each transect was scanned in 100 foot sections with the data from each 100-foot section saved as a separate line within the transect file. This made any spacing errors easy to identify and prevented spacing errors from affecting the entire transect. Duplicate test transects were performed, one with the instrument in the horizontal position oriented parallel to the road and the other with the

instrument oriented perpendicular to the road (except where traffic was too frequent to safely conduct the perpendicular pass). The survey data, in terms of specific conductance versus distance, were stored and plotted using a common spreadsheet program.

The EM61-MK2 is also manufactured by Geonics. The EM61-MK2 consists of a powerful transmitter that generates a magnetic field, which in turn induces eddy currents in nearby metallic objects (see Figure H4 in Appendix H). Two 1-meter loop receiver coils measure the decay of the eddy currents. The instrument is designed to minimize interference from nearby metal objects on and above the ground surface. The EM61-MK2 has a depth range of about 3 to 4 meters (10 to 13 feet). For this study, an electronic measuring wheel was used to record the relative position of the instrument as each measurement was collected. Transects were scanned in 100 foot sections with the data from each 100-foot section saved as a separate line within the transect file, and the transects were performed with the instrument in the horizontal position oriented perpendicular to the road.

The GEM-2, manufactured by Geopex, is a multi-frequency broadband electromagnetic sensor that operates in a frequency range of about 300 Hz to 48 kHz (Figure H4; Appendix H). This device transmits an arbitrary waveform containing multiple frequencies, hence earth conductivity to three exploration depths can be measured simultaneously. Operating frequencies on the order of 7.5, 17 and 39 kHz, i.e., the upper end of the available range, were selected in an attempt to minimize interference from cultural metallic features.

### 2.3.2 Resistivity

Considering that the non-select soil targets exhibit low resistivity in contrast to otherwise resistive sandy soils, resistivity methods were expected to be effective. Further, resistivity survey results, which are commonly presented as a 2-dimensional inverse model depth sections, can be readily interpreted with respect to delineating portions of test alignments having more or less apparent variability. This feature in particular was deemed to render the results very useful even to non-experts for use in planning and executing conventional geotechnical field explorations. Unfortunately, conventional direct current resistivity surveying, even when using state of the art high speed computerized multi-channel analog-to-digital conversion, multiplexing hardware and software, and “smart electrodes” (that can act alternatively as current or potential electrodes) is relatively labor intensive and time consuming. Moreover, galvanic coupling with metal-staked

electrodes can be problematic in highly resistive surficial soils and can not be accomplished non-destructively through existing pavement. Fortunately, the more recently developed capacitively-coupled resistivity (CCR) method overcomes these drawbacks.

In the capacitively-coupled resistivity (CCR) method, subsurface electrical properties can be measured along continuous alignments using coaxial cable line electrodes rather than the galvanically-coupled point electrodes used in conventional DC resistivity surveys. Capacitive-coupling refers to the ability to cause a charge to move in and out of one conductor by applying an alternating voltage to another nearby conductor. The CCR transmitter uses capacitive coupling from its electrode to the soil to induce the current to flow within the soil. The CCR receiver detects the voltages in the soil because of the capacitive coupling between the soil and the receiver's line electrode. The transmitter and receiver are deployed in a dipole-dipole configuration where the transmitter and receiver are placed in line and separated by an integer number of dipole lengths using a non-conductive tow link, or rope (see Figures H1, H2 and H3; Appendix H).

The "OhmMapper", manufactured by Geometrics, Inc., one of only a few commercially available CCR systems, was selected for field verification testing. The OhmMapper TR-4 consists of one ungrounded dipole transmitter and four dipole receivers that are pulled along the ground as a streamer (Figure H3). The OhmMapper uses a modulation scheme, in which the transmitter's AC current is communicated by a lower-frequency signal such that the transmitter current is encoded in the transmitter signal itself. At the receiver, the measured voltage is demodulated to "decode" the transmitter signal and thus extract the current information. Over-sampling is used to allow digital filtering of noise signals at frequencies more than 2Hz above or below the transmitter's frequency such that noise outside the narrow bandwidth of the transmitter is rejected. The array of receivers is connected to the data recorder via a fiber optic isolator and each receiver delivers measurement data at a rate of 2 Hertz. The maximum depth of investigation for the OhmMapper is limited, being approximately 15 percent of the transmitter-receiver dipole separation.

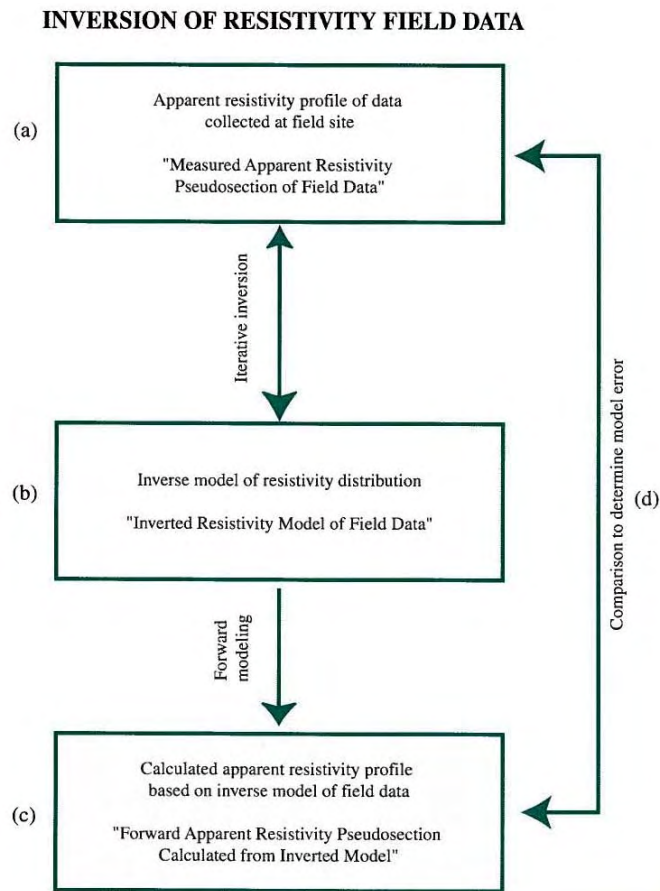
According to Geometrics, comparative testing at several study areas has shown that the OhmMapper's response is generally within 2% of traditional dipole-dipole DC resistivity measurements provided the transmitter-receiver separation does not exceed one skin-depth, i.e., approximately 500 times the square root of the bulk resistivity in ohm-meters divided by the 16 kHz operating frequency. Hence, the maximum receiver-transmitter dipole separation for a soil having a bulk resistivity of 100 ohm-m would be about 40 meters (130 feet) with a corresponding the

maximum investigation depth of about 6 meters (20 feet). Good agreement between CCR and conventional DC resistivity survey data was also reported by Bernstone and Dahlin (1999), Doll, et al. (2001) and Moller (2001).

CCR resistivity surveys for this study were performed by SEI using an OhmMapper TR-4 device rented from Geometrics. (The SEI geophysicist and field staff had several years experience conducting conventional resistivity surveys and had more recently become trained and certified by Geometrics in use of the OhmMapper.) As with a DC resistivity system, an apparent resistivity is calculated by multiplying the appropriate geometric factor by the received voltage and then normalizing this quantity by the transmitter current. Data are plotted in a pseudo-section wherein the depth scale is a function of the array separation which correlates to depth. The data are processed using a two-dimensional inversion technique (Loke and Barker, 1996) to convert to true depth section. In particular, data processing of each 1,000-foot alignment segment was performed using a computer program called MAGMAP 2000, version 4.47b supplied by Gometrics, and then two-dimensional inverse modeling was performed using the computer program RES2DINV, version 3.47 supplied by Advanced Geosciences Inc., (AGI) of Austin Texas.

The modeling method, as illustrated in Figure 1, consists of estimating the true resistivity of the ground at points arranged in a grid on a vertical plane, calculating corresponding apparent resistivity values, and then comparing then to the actual measured resistivity values. Iterative adjustments to the estimate resistivities are made until the calculated apparent resistivity values converge to the measured values. The modeling progresses toward better estimates of the true resistivity by iteration using the least-squares method. The iteration process is carried out until either to root mean square (RMS) error was less than 10 percent or the convergence between iterations approached about 1 percent. RWM error less than 10 percent is generally considered good, but this can not always be achieved. RMS error greater than 50% is generally considered unacceptable.

The estimated true resistivity values are contoured to produce a two-dimensional virtual cross section for the vertical plane beneath the survey line. A small, semi-logarithmic contour interval is commonly used to show minor variations in the low resistivity values while covering the entire range of values. It should be noted that the resistivity modeling program contours the modeled data points in a manner that tend to show gradual gradational changes when, in fact, abrupt contacts may be present between layers of earth materials.



*Figure 1 – Schematic Illustration of Resistivity Inverse Modeling Technique*

### 2.3.3 Ground Penetrating Radar

The ground penetrating radar (GPR) method was selected for testing considering its wide availability, the ability to detect contrasts between low conductivity sandy-soil background conditions and higher conductivity organic- and clay-soil targets, relative ease of data collection with minimal processing, and the complimentary ability to detect buried pipes, utilities, etc. Besides limitations in depth of penetration in conductive soils and shallow groundwater conditions, potential drawbacks of using GPR a supplemental exploration tool for Florida roadway projects include problems performing radar surveys through existing pavement, and relative difficulty of interpretation by “non-expert” users. Nonetheless, GPR was evaluated in verification tests since, from a near-surface anomaly detection standpoint, a lack of reflections in isolated portions of a

transect that otherwise exhibits fairly strong reflections could be indicative of the presence of non-select organic or clay-soils. This lack of reflections would occur since, as indicated in Figure 2, GPR signals are attenuated (or lost) in clayey soils due to their characteristically high effective conductivities (which increase with moisture content and the amount and type clays in the soil matrix) resulting in absorption of the electromagnetic pulses.

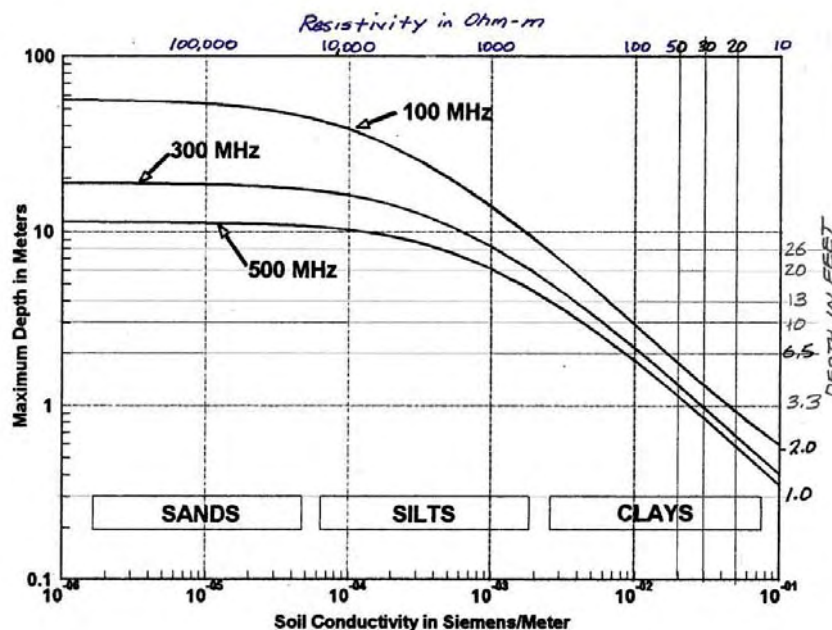


Figure 2 – GPR Penetration Depth Versus Soil Conductivity  
(for a rough plane reflector; R.M. Morey, ARA, Inc.)

GPR pulses are reflected at changes in conductivity or electrical properties (dielectric constant). Between transmission pulses, the receiver records the reflected signals and the time between pulse transmission and reception of the reflected pulse (two-way travel time). The time-based measurements of the GPR provide only relative depths. In order to compute the depth to a particular interface reflection, either the velocity of propagation or the dielectric constant of the medium must be known. The depth to a given GPR reflection can be computed by multiplying the speed of light (1 ft/ns) by the product of the square root of the dielectric constant and half the two-way travel time.

Characteristic Dielectric Constant (dimensionless):

|                |                                      |
|----------------|--------------------------------------|
| Water:         | 81                                   |
| Dry Sand:      | 3 to 5                               |
| Wet Sand:      | 20 to 30                             |
| Silts & Clays: | 5 to 40 (higher values for wet clay) |

2.3.4 Seismic

Conventional seismic reflection and refraction methods were not selected for field testing because destructive direct ground coupling in paved areas would be required and problems associated with sensitivity to cultural noise and vibrations, such as passing traffic, were anticipated. Moreover, because reported typical ranges of P-wave velocities in wet sand were similar to the those of clayey soils, i.e., both in the range of 1,000 to 2,500 m/s, reliable detection of non-select soil anomalies was not expected.

An emerging seismic method, namely the spectral analysis of surface waves (SASW) method, from which near-surface shear wave velocity profiles can be developed, was selected considering: (i) reliable detection of soft clays and organic soils was expected since their characteristic shear wave velocities are less than half the shear wave velocity of medium to dense sandy soil; (ii) geophone receivers require only simple ground contact and thus can be deployed non-destructively in paved areas; (iii) surface waves can be generated fairly easily and the relatively high-amplitude nature of surface waves (in comparison to body waves) allow measurement in areas with elevated levels of mechanic/acoustic noise. In particular, the multi-channel analysis of surface waves method (MASW; Park et al., 1999) was selected for field testing.

The expected contrast between shear wave velocities of generally favorable sandy “background” soil conditions and potential organic or clayey non-select soils was the primary reason that this emerging method was selected for testing. As indicated below, both of these non-select targets should display shear wave velocities that are much lower than that of soil normally considered select or suitable.

Characteristic Shear Wave Velocity (m/sec):

|             |            |
|-------------|------------|
| Very Stiff: | > 300      |
| Stiff:      | 185 to 300 |
| Soft:       | 110 to 150 |
| Very Soft:  | 85 to 110  |

Results of tests reported by Berge, et al. (1999) also indicate a substantial reduction in shear wave velocity in sand-peat mixtures with increasing organic content. For instance, the average shear wave velocity of a clean sand decreased from 175 to 90 m/sec as peat was mixed into the sand to achieve an organic content of 20 percent.

The MASW method incorporates advanced multi-channel data acquisition devices and common mid-point style roll-along surveying, i.e., consecutive multiple receiver data collection along a survey line by moving both the source and receiver string simultaneously by a fixed incremental distance after each shot. The measured surface waves, i.e., fundamental-mode Rayleigh waves, are analyzed using a procedure that involves an initial 1-dimensional spectral analysis of the surface wave as a dispersion curve (seismic frequency as a function of wave energy) that is then used to generate a 2-dimensional shear wave velocity profile by an inverse modeling procedure. In an attempt to limit the potentially prohibitive time required to apply the MASW method to long roadway alignments, a 24-geophone land-streamer array was developed and fabricated specifically for this study that can be pulled along paved alignments to enable more rapid data collection (see Figures H7 and H8).

## **2.4 Application Survey**

A statewide survey of geophysical exploration service providers was undertaken during the summer of 2003 to assess availability of technically viable supplemental exploration methods. Survey forms were predominantly sent via electronic mail. A total of thirty positive responses were received, along with eight additional responses from regional geophysical equipment providers. The survey inquired about all types of geophysical methods practiced by each provider, and requested specific information pertaining to ground penetrating radar (GPR), conventional multi-channel electrical resistivity (MER) and capacitively-coupled resistivity (CCR) methods including equipment manufacturer and model(s), years of experience, typical daily production rates, position control, etc.

The most commonly available method, practiced by 25 of the 30 respondents, was GPR. The most common antenna frequencies ranged from 200 to 400 kHz, although several providers also utilized frequencies as high as 1,500 Mhz. In general, electronic survey wheels are used for position control, with GPS start- and end-point control.

After GPR, electrical methods were the next most commonly available. Twelve of the 30



respondents conduct resistivity surveys and 11 perform terrain conductivity (EM) surveys. Electromagnetic surveys are performed almost exclusively using EM-31 and EM-34 terrain conductivity equipment manufactured by Geonics Limited. Conventional resistivity is most commonly performed using a multi-electrode MER system manufactured by AGI (i.e., the Sting/Swift or SuperSting equipment). This is the same type of MER equipment owned by the FDOT and operated by the State Materials Office (SMO). Reported daily field data collection rates for MER surveys ranged from 600 to 2,500 feet per day, generally varying with the cable length and number of electrodes used. In fact, the reported daily production rates typically corresponded closely with the cable length which suggests that it usually takes nearly a day for each set-up of the multi-electrode array.

Five of the respondents reported that they have been performing CCR surveys, all using the Geometrics OhmMapper, since about the year 2000. All but one respondent rent the equipment on an as needed basis. Interestingly, one of the service providers reported that rental CCR equipment is used instead of in-house MER equipment when surveys through pavements are required. Reported field data collection rates using the OhmMapper ranged from 3,000 to 15,000 feet per day, where the lower rate was reported by the respondent that utilizes an owned TR-1 (single-receiver) system that requires multiple passes. Typical production rates for the more recently developed (and rented) four-receiver systems ranged from 7,000 to 15,000 feet per day.

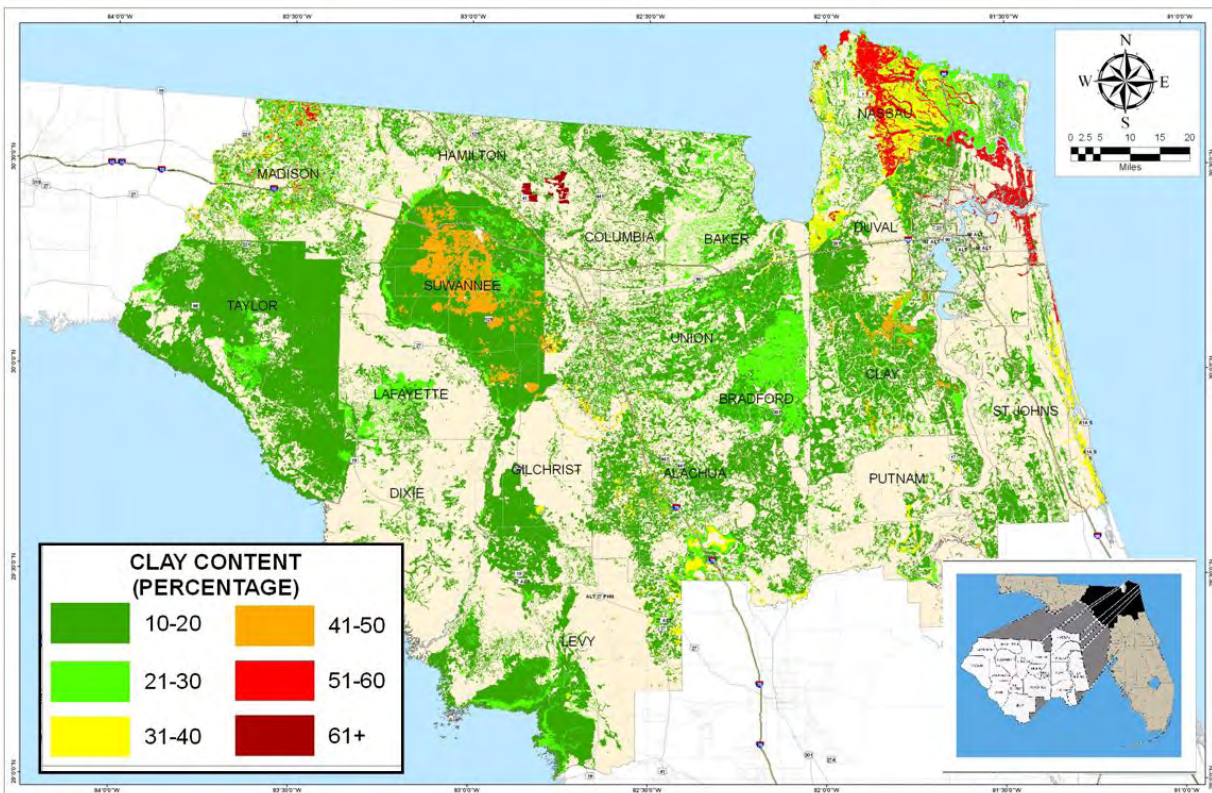
A total of six respondents reported that they provide seismic reflection and/or refraction survey services, but none specifically indicated that routinely utilize the surface wave analysis (MASW) method. It should be noted, however, that the application survey conducted as part of this study is somewhat dated, and the author expects that at least a few of the survey respondents have since developed MASW testing capabilities.

## **2.5 Florida Soil Maps (NRCS)**

In order to assist engineers in assessing the potential for non-select conditions and hence the need for supplemental exploration, a state-wide non-select soil “risk” map is being developed in conjunction with this study. Fortunately, the National Resource Conservation Service (NRCS) is currently in the process of generating a digital GIS-compatible database of the soil surveys for all Florida counties which served as the basis for development of the “risk” map. To-date, soil survey information for all Florida counties is available, except for Gadsden County which is expected to be

available during calendar year 2008.

In addition to delineated near-surface soil types, the database files include characteristic ranges for soil properties which enables classification according to clay content, organic content, etc. A state-side non-select soil map, and sub-maps for each FDOT District, were generated from the NRCS soil survey data and incorporated into an ArcGIS database. Figure 3 shows an example of a clayey soil distribution map for the currently available data in FDOT District 2. Through the GIS database platform, these maps can be viewed as overlays and scaled with aerial photography to review project specific areas from a non-select soil potential standpoint. Potential non-select soil maps, based on NRCS designations for organic content and clay content, for each FDOT District are presented in Appendix A (Figures A1 through A18).



*Figure 3 – Sample GIS Map of NRCS Clayey Soils in FDOT District 2*

## **SECTION 3 FIELD VERIFICATION TESTING PROGRAM**

Several supplemental investigation methods were evaluated in terms of applicability, practicality, timeliness, utility of results by geophysical non-experts and cost. Surface geophysical methods, including ground penetrating radar, terrain conductivity, direct current and capacitively-coupled resistivity, and seismic methods were selected for testing. During an initial verification testing phase, the applicability of these methods was assessed at a number of sites known to have “problem” subsurface soil conditions. The field validation testing phase described in Section 4 of this report was then undertaken using selected verified methods at two actual highway project sites in central Florida. During the validation phase, more than 30 kilometers (nearly 20 miles) of continuous alignment geophysical surveys were performed.

### **3.1 Overview of Verification Testing Program**

A series of field verification tests was undertaken in June 2003 to evaluate each candidate supplemental exploration methods in terms of effectiveness and reliability, applicability to typical roadway applications, relative intensity of effort and time required for data collection and analysis, and general usefulness of results to geotechnical engineers from the standpoint of planning and executing effective conventional geotechnical field explorations.

Geophysical data collection and reduction services for the project were provided by Subsurface Evaluations, Inc. of Tampa, Florida under the direction of Ardaman & Associates, Inc. In addition, duplicate GPR surveys were performed by Ardaman, and one conventional DC resistivity transect was undertaken by the FDOT’s State Materials Office using Department-owned equipment. It should be noted that all of the geophysical testing results presented herein reflect minimally-processed data intended, as would be the case in practice, for preliminary site screening and planning of a conventional exploration.

### **3.2 Field Verification Test Sites**

At three of the test sites, buried pockets or layers of soft, compressible organic soils were expressed at the surface as failures or subsidence features (two of which had been recently repaired). These sites are located along Beauchamp and Glen Harwell Roads in Hillsborough County and

along Sandlake Road in Orange County, Florida. At a third verification test, loose spoil piles and waste phosphatic clay slimes were known to exist in a reclaimed phosphate mine site within an area subsequently backfilled with clean tailings sand.

### 3.2.1 Beauchamp Road, Hillsborough County

At this lightly-traveled two-lane county roadway site, EM, GPR and CCR surveys extended approximately 760 meters (2,500 feet) along the south edge of the road section encompassing a section where recent reconstruction with reinforcing geo-grids was undertaken to mitigate effects of existing underlying organic soil deposits (see appendix Figures A19 and H9). In addition, a MASW transect was subsequently performed over a 90-meter (300-foot) long transect that encompassed the west edge of the known problem soil area where soft peat soils having a thickness on the order of 1.5 meters (5 feet) were encountered in soil borings performed in conjunction with the repair work.

A total of eight OhmMapper CCR surveys were performed (for a total of about 6.5 meters or nearly 4 miles) during a period of about 4 hours at the Beauchamp Road site. Four of the surveys were performed through the pavement and four were performed on the grassed shoulder a few meters south of the pavement edge (Figure 4). Different dipole lengths and transmitter-receiver tow rope lengths were used (i.e., 5- and 10-m dipoles with 5- & 10-m ropes) for each pass to evaluate variations in depth of exploration and target resolution. Locations were recorded using a Trimble GPS receiver as well as with pre-surveyed distance reference marks at which electronic “ticks” were manually stored in the field data file as a back-up to the GPS data. The data was analyzed the afternoon of the field testing and preliminary inverse model resistivity depth sections were available the next morning.

Ground penetrating radar surveys were performed using Geophysical Survey Systems, Inc. (GSSI) antenna and a SIR-20 digital control (Figure H2; Appendix H). Data was recorded at a rate of about 30 scans per meter, and locations were recorded using an electronic distance measuring wheel and Trimble GPS receiver.



*Figure 4 – CCR Surveys Along Shoulder and Through Pavement*

Terrain conductivity or EM surveys were performed using three different devices, namely Geonics EM61-MK2 and EM31-MK2 instruments having effective depths of exploration on the order of 3 and 6 meters, respectively, and a GEM-2 system more recently developed by Geophex, Inc. (Figure 5). Each of these devices can be used to map variations in the ground conductivity using an electromagnetic inductive technique that makes the measurements without electrodes or ground contact. The GEM-2 is a multi-frequency broadband electromagnetic sensor that operates in a frequency range of about 300 Hz to 48 kHz (Figure 3). Operating frequencies of 7.5, 17 and 39 kHz were selected in an attempt to minimize interference from cultural metallic features.



*Figure 5 – Dual Antenna GPR and GEM-2 Equipment*



Readings for the EM31 were collected at 1.5-meter (5-foot) intervals with instrument in the horizontal position oriented parallel to the road and then perpendicular to the road. The EM61 transects were performed with the instrument in the horizontal position oriented perpendicular to the road. An electronic measuring wheel was used to record the relative position of the instrument as each measurement was collected.

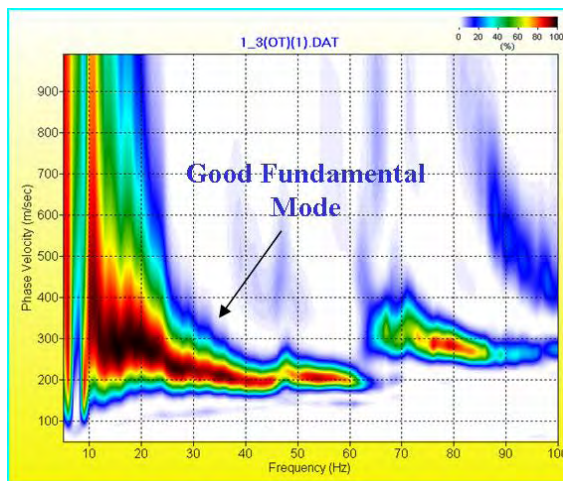
A land-streamer array was developed and fabricated specifically for this study to enable more rapid collection of MASW data (Figure 6). The land-streamer array consisted of twenty-four, 4.5-hertz vertical reflection Geometrics geophones, each mounted to a 4.5-kilogram (10-pound) steel plate. The steel plates were connected by steel cable to achieve a geophone spacing interval of 0.5 meters (1.6 feet) for an overall land-streamer length of 11.5 meters (38 feet).



*Figure 6 – Plate-Mounted Geophone Land Streamer Fabricated for MASW Testing*

The MASW array was connected to a Geometrics Geode Seismograph which interfaced with a laptop computer for recording the seismic data (see Figure H8; Appendix H). The array was towed behind a truck along the center of the east-bound lane. The seismic source was a 4.5-kilogram sledge-hammer impacting a 5-centimeter thick, 23-centimeter diameter steel plate located 5 meters (16.4 feet) from the first geophone in the array. The array was towed along the alignment in 2-meter intervals and three shots were recorded at each interval position. After three shots were collected, the array was moved 2 meters (4 stations) and the next set of three shots was collected. This procedure was repeated 53 times, covering a linear distance of approximately 115 meters (about 380 feet) along the roadway. The data were collected in standard SEG-2 format and was then formatted and

modeled using the software program SurfSeis, Version 1.5, developed by the Kansas Geologic Survey. Two-dimensional inverse modeling was performed using SurfSeis to develop 2-dimensional shear wave velocity profiles derived from extracted dispersion curves (Figure 7). The estimated true velocity values were contoured to produce a two-dimensional virtual cross-section for the plane beneath the survey line.



*Your data are in very good quality. All show well-developed fundamental mode with valid frequencies in 15-40 Hz range. This should resolve S-velocities in depth Range of 2-10 m.*

*You are in good shape! Choon.*

*Figure 7 – Results of Initial MASW Test Shot (and Note from Choon Park, KGS)*

### 3.2.2 Glen Harwell Road, Hillsborough County

The entire 1.6-kilometer (1-mile) length of Glen Harwell Road, which contained an approximately 25-meter section of repaired pavement at the location of apparent problem subsoil conditions (see appendix Figures A20 and H10), was surveyed using the GPR, CCR and EM methods described above. In addition, a MASW transect was performed over a 90-meter (300-foot) long transect that encompassed the apparent problem area. The CCR surveys were performed using two transmitter-receiver dipole lengths, one short dipole for shallow resolution on the outgoing, and a longer dipole arrangement for greater exploration depth on the return pass. The GPR survey was performed concurrently with the CCR survey using the same tow vehicle such that more than 3 kilometers (nearly 10,000 feet) of CCR and GPR survey obtained in less than 2 hours.

### 3.2.3 Reclaimed Phosphate Mine Site, Polk County

Several CCR surveys were undertaken along four different transect lines within a former strip mine site in central Florida where the pit containing soft waste phosphatic clays and loose overburden spoil piles had been reclaimed by backfilling with clean sand tailings (Figure H11; Appendix H).

Along one of the test alignments that transected loose remnant overburden spoils overlain by hydraulically deposited clean sand tailings, duplicate CCR surveys were performed, one in each direction along the transect, to assess repeatability.

### 3.2.4 Sandlake Road (S.R. 482), Orange County

A series of four CCR transects were performed during the early evening hours using different transmitter-receiver dipole lengths along the westbound shoulder of an approximately one kilometer (3,000-foot) section of Sandlake Road (see Figure A21; Appendix A). A GPR survey was also performed concurrently with the first CCR pass, however, battery power failures led to a loss of data. An independent GPR survey was subsequently performed about a week later (Figure H5). The test transect encompassed a section of the roadway where extensive excavation and replacement of non-select organic soils have been undertaken during a prior widening project, but also included an isolated shallow depression that had since developed in the pavement at one location. More than 3.5 kilometers (about 12,000 feet) of CCR surveying was completed in three hours, including setup time.

## 3.3 **Field Verification Test Results**

Results of the field verifications testing program are presented and discussed in the following sections. As stated above, the primary objective of these field tests was to determine if the selected surface geophysical methods were useful and reliable for detection of non-select conditions known to exist (or suspected to exist) within the test alignments. In addition, the verifications testing phase was used to develop procedural protocols for full-scale application of a supplemental investigation and to assess the usefulness in terms of time, cost effectiveness and utility of the selected methods.

It is important to realize that detailed interpretation of the supplemental geophysical testing results, as may undertaken to correlate geophysical properties to engineering properties, or to

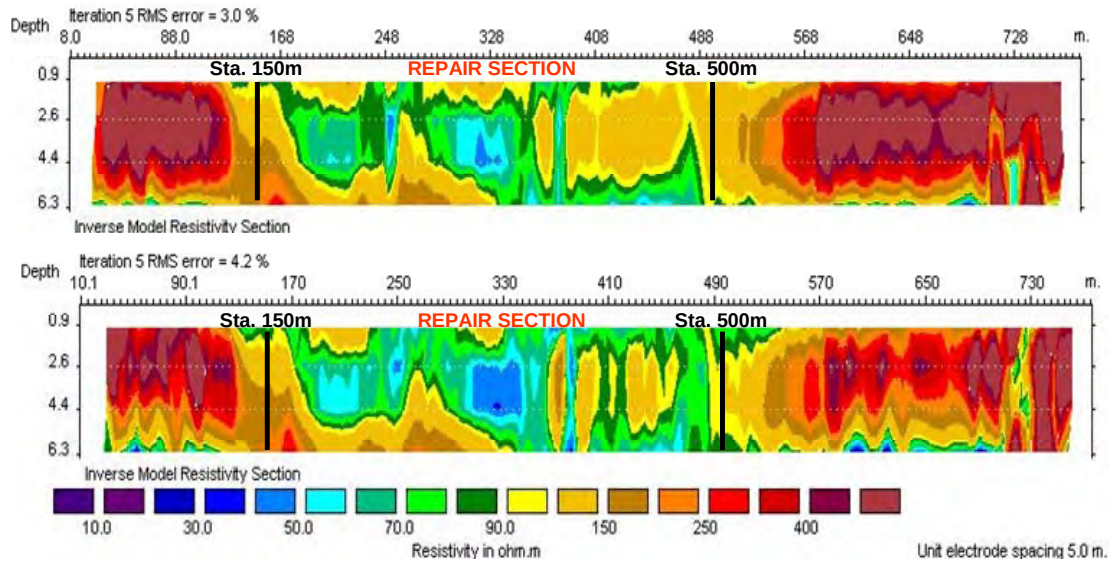


interpret the physical significance of particular observations, was beyond the scope of this study. Accordingly, the field testing results presented and evaluated herein represent minimally processed data that can be made available within one or two days after field data collection. Detailed interpretation, with substantial conventional geotechnical data necessary to constrain more sophisticated modeling, could be undertaken during the design phase of the project. However, for the purpose of this study, the methods are being evaluated in terms of their utility towards planning an effective conventional exploration.

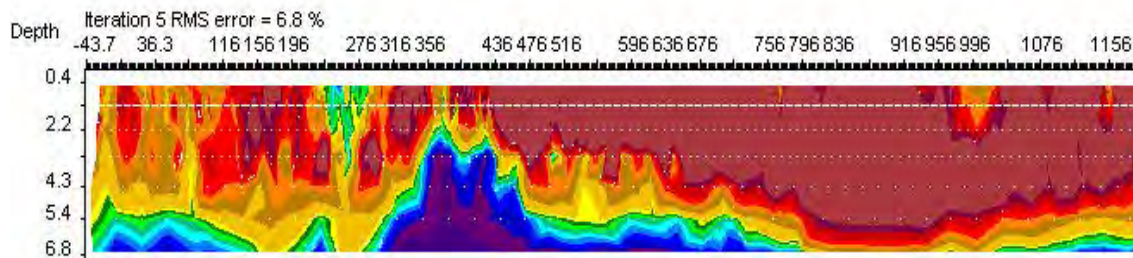
### 3.3.1 Capacitively-Coupled Resistivity

Results of the CCR surveys consistently exhibited clearly recognizable contrasts between background and target response relative to identification of the known problem soil conditions at the verification test sites. Higher resistivity values were typically measured along portions of the test transects underlain by “background” sandy soils, and contrastingly lower resistivity values were consistently exhibited along portions containing the “target” non-select conditions. Each of the CCR surveys performed along the Beauchamp Road transect, whether on or off the existing pavement, and regardless of the trial transmitter-receiver dipole lengths, effectively characterized the presence and lateral extent of the known problem soils (see Figures B1 through B15; Appendix B). Two typical profiles are presented in Figure 8. Based on results of the Beauchamp Road CCR trials, it was observed that use of 10-meter dipoles and a 5-meter separation between the transmitter dipole and first receiver dipole provided a good balance between survey resolution and depth of investigation (Figures B4 and B11). With a few exceptions, this configuration was used thereafter for CCR surveys at the remaining test sites.

Results of one of the two CCR surveys performed along the Glen Harwell Road transect are shown in Figure 9 (also see Figures C1 through C6 in Appendix C). As indicated by the low near-surface resistivity values near the 250-meter station, the pavement repairs at this location can be attributed to isolated problem subsoil conditions. Results of a cone sounding subsequently performed in the area just downstation of the repair section confirmed that the very low resistivity materials at depth reflect the presence of plastic clay soils (not known to exist at the time this test section was selected).



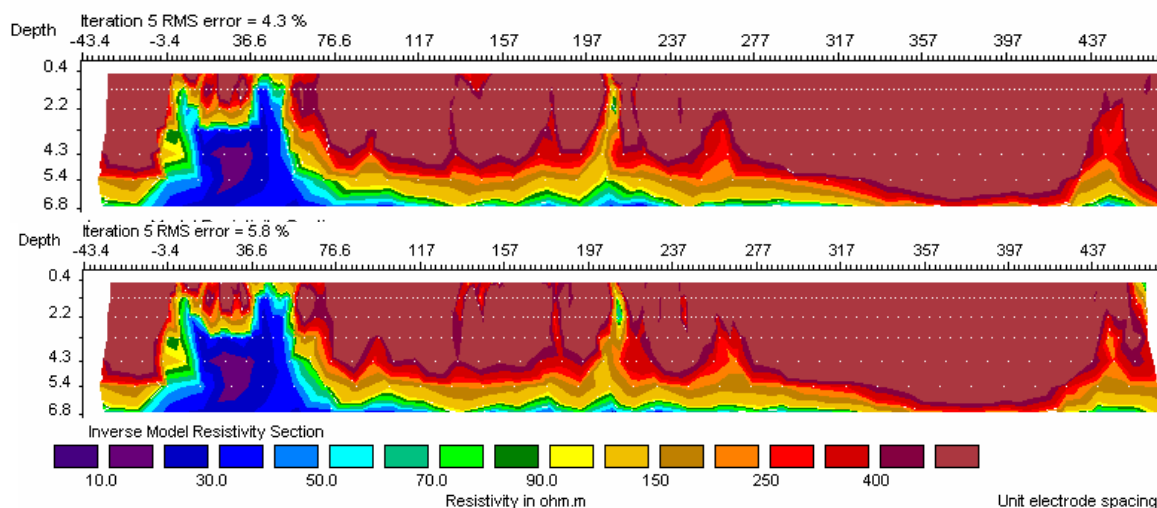
*Figure 8 – Results of CCR Surveys on Pavement (Top) and Shoulder (Bottom) at Beauchamp Road*



*Figure 9 – Results of CCR Survey at Glen Harwell Road (Same contour scale as in Figure 7)*

Several CCR surveys were undertaken along four different transect lines within a former strip mine site in central Florida where the pit containing soft waste phosphatic clays and loose overburden spoil piles had been reclaimed by backfilling with clean sand tailings (see Figure H11 in Appendix H). Along CCR transect Line B (Figures D7 and D8; Appendix D), the sharp contrast between the high resistivity clean, dry sand tailings and underlying loose clayey cast overburden materials piled during the strip mining operation (see photo in Figure H11), is remarkably distinct. Based on prior conventional explorations for the site owner, it was found that phosphatic waste clays had been deposited between some of the buried cast spoil rows at the site. These depth of these clays corresponds to the sharp resistivity contrast observed in CCR transect Line C (Figure D13).

Along one of the test alignments at the mine site that transected loose remnant overburden spoils overlain by hydraulically deposited clean sand tailings, triplicate CCR surveys were performed (see Figures D16, D17 and D18 in Appendix D), to assess repeatability. As shown in Figure 10, the resulting inverse model resistivity profiles were found to be nearly identical.



*Figure10 – Results of Duplicate CCR Surveys Performed for Repeatability Assessment*

Results of the CCR test transects performed along the paved shoulder at Sandlake Road are presented in Appendix E. Based on review of prior cone sounding and test boring results, as well as the record drawings for the widening project completed in the 1980's, the contrast between the higher resistivity surficial soils and underlying lower resistivity soils that can be seen in Figures E3, E5 and E6 (Appendix E) corresponds fairly closely to the design demucking depth. Even though it was known that this major de-mucking has occurred during construction) and hence the formerly existing non-select soils had long ago been replaced with structural soil fill, the test site was selected to investigate a “dip” in the pavement that had developed near transect station 840 meters. As can be seen in Figure E4 (Appendix E), results of the CCR survey, when presented using a “narrow” contour interval, indicated lower resistivities in the near-surface soils at the “dip” location.

The verification testing along Sandlake Road, which had been widened to three lanes in each direction and is very heavily traveled (even in the evening when the surveys were performed), also enabled assessment of some of the potential safety and logistical issues with performing CCR

surveys. Firstly, a rolling barrier vehicle was required and additional personnel were needed for safety reasons, which need to be considered in planning and budgeting CCR investigations. Secondly, CCR configurations involving long dipole lengths and long transmitter-to-receiver spacing, which provides for the greatest depth of investigation, can be problematic along busy roadways. This is primarily because the overall length of the streamer can exceed 200 feet, and it can be difficult and potentially unsafe to prevent motorists desiring to turn off the road from crossing its path.

### 3.3.2 Surface Wave Analysis Results

Results of the MASW test transects, in terms of shear wave velocity profiles, exhibited sharp contrasts between the organic soil anomalies and surrounding sandy background soil conditions at both the Beauchamp and Glen Harwell Road test sites, consistent with the CCR results (see Figure B19 and C14). As shown in Figure 11, the organic soil deposits exhibited shear wave velocities that were roughly three-fold less than velocities computed for the adjacent sandy soils. Based on these limited field tests, application of the MASW method appears very promising from a reliability standpoint. However, even with the fabricated plate-mounted geophone land-streamer, application of the MASW method remained significantly more time consuming. In fact, it required about the same amount of time to perform the two 90-meter MASW test surveys than for it required to conduct roughly 3.5 kilometers of survey using one or more of the applied methods (about a 50-fold difference). Therefore, application of the MASW for extended continuous alignment roadway surveys is deemed cost prohibitive at this time, except where confirmation or complimentary data extended to greater depths of investigation are needed to characterize conditions within limited portions of project alignments.

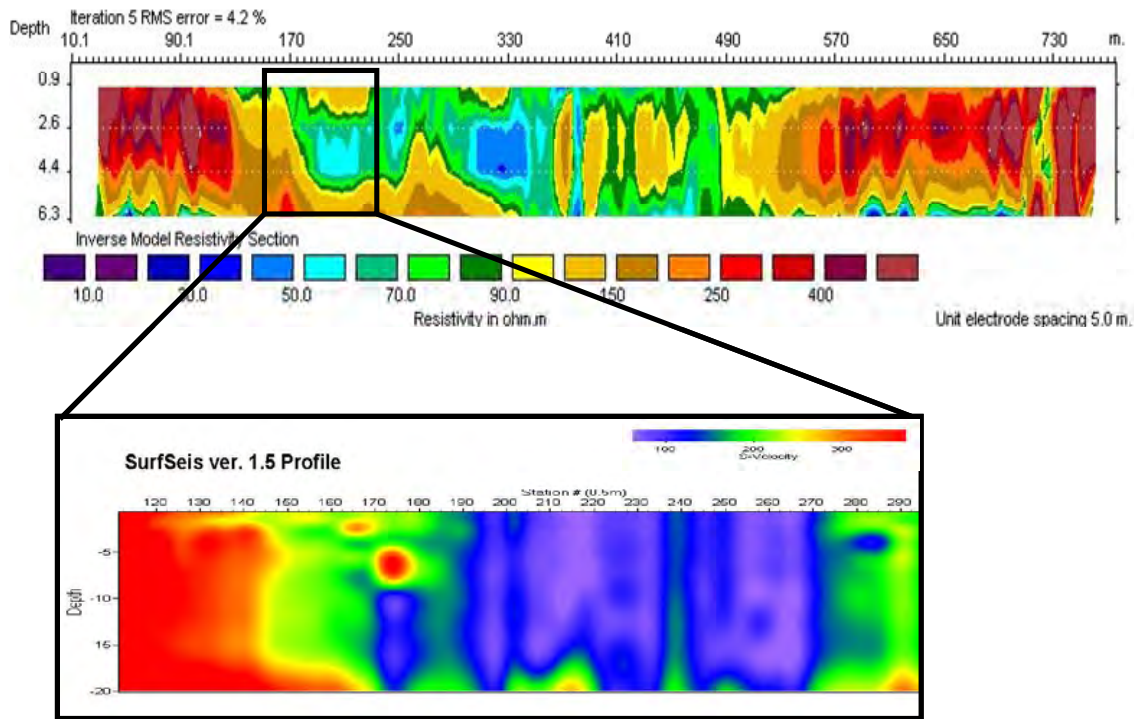


Figure 11 – Comparison of CCR and MASW Results from Beauchamp Road

### 3.3.3 Terrain Conductivity

Transects along the Beauchamp Road site using the EM31 device were generally inconclusive and actually suggested that the sandy soils at the either end of the transect were slightly more conductive than the target peaty wetland area (Figures B17 in Appendix B). With the exception of buried utilities, the overall variability of the conductivity readings measured along the transect were relatively small. No significant difference in the results was observed between surveys performed with the instrument parallel versus perpendicular to the road. The EM61 data shown on Figure B18 in Appendix B generally showed greater variability than that observed in the EM31 data, primarily because its smaller antennas tend to amplify small variations in the subsurface which are averaged by the EM31.

The Glen Harwell Road EM31 and EM61 data were also generally consistent with each other; however, the general trends of peaks and valleys did not occur at exactly the same locations (Figures C10 and C11 in Appendix C). In general, the EM31 data were in good agreement the resistivity results as far as identifying generally conductive portions of the alignment, however, no clear contrast was observed within the isolated problem area where near-surface organic soils were

encountered (Figure 12). Based on results of the verification test surveys, along with results of a GEM-2 survey included at the S.R. 520 validation test site discussed in the following section, EM methods may be useful in preliminary supplemental explorations to identify areas containing clayey soils, but do not appear promising for detection of isolated non-select organic soils.

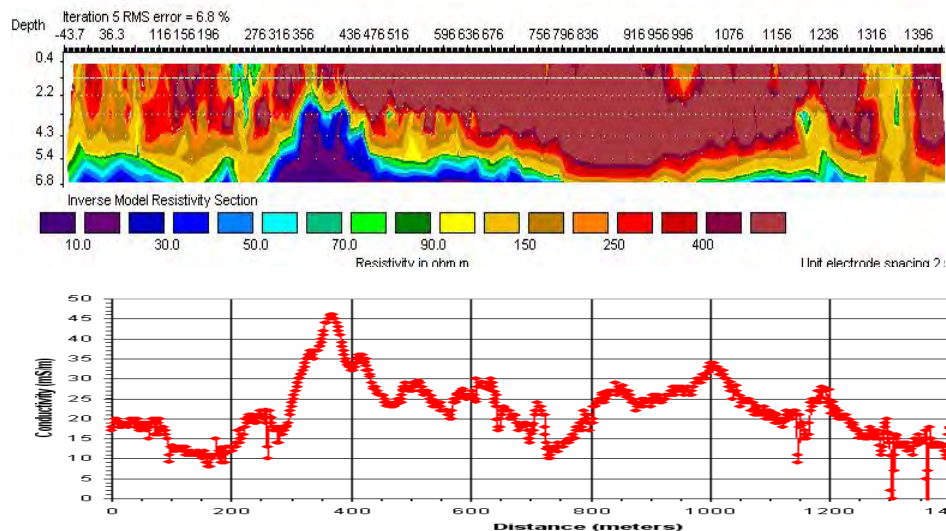


Figure 12 – Comparison of CCR and EM31 Results from Glen Harwell Road

### 3.3.4 Ground Penetrating Radar

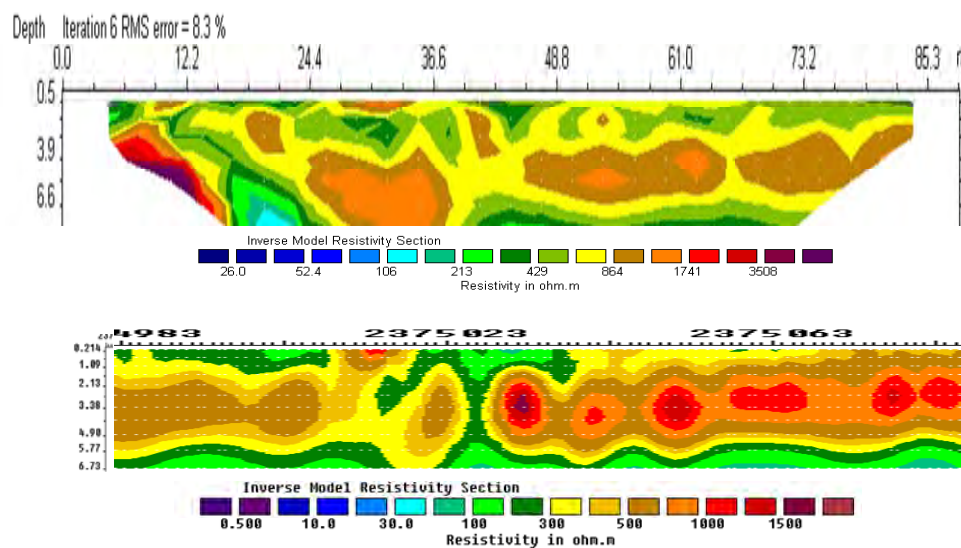
In general, results of the GPR surveys at the verification test sites did not provide clear contrasts between background and target response relative to identification of the known problem soil conditions at the verification test sites (see Figures B16, C7, C8, E7 and E8). There was typically a lack of strong reflections throughout the surveys, with the exception of reflections from buried utilities, likely due to the generally conductive nature of the soils and relatively shallow groundwater conditions. Hence, it appears that detection of non-select soils via lack of strong reflections may only be definitive where the soil deposits exist in otherwise highly resistive dry soil conditions (a circumstance that is likely not prevalent in most areas of the state). Further, the GPR test data were generally found to be more difficult and cumbersome to evaluate, at least from a geotechnical engineer's perspective, than results of the other methods tested. Nonetheless, since GPR data can be collected concurrently with CCR data, it is deemed worthwhile to collect since the



incremental costs are very low, unknown buried features can be identified, and the data are then available for expert evaluation if warranted during the design phase.

### 3.3.4 Comparison Between Two Resistivity Methods

A conventional DC resistivity survey was performed for comparison with the CCR data in conjunction with the validation testing undertaken at the S.R. 520 test alignment in June 2004 (see Section 4 of this report). The DC resistivity transect was conducted by the FDOT State Materials Office using the Department's 56-electrode AGI Sting-Swift system resistivity equipment. Results of that comparison are illustrated in Figure 13, and indicated good general agreement, particularly in terms of variations in resistivity versus depth along the transect.



*Figure 13 – Comparison of Conventional Multichannel DC and CCR Resistivity Survey Results (S.R. 520)*

## **SECTION 4**

### **FIELD VALIDATION TESTING PROGRAM**

The surface geophysical methods deemed most viable and effective for supplemental field exploration and detection of non-select soil conditions along extended roadway project alignments were utilized at two actual planned project sites for validation testing.

As conceived, the validation test program was included in the study to provide an opportunity to demonstrate the utility and cost effectiveness of the selected supplemental exploration methods at actual FDOT project sites. To enable timely execution and evaluation of the results, however, the validation tests were actually performed at sites where the field exploration and design phases were already substantially completed. In order to simulate actual implementation, the supplemental surface geophysical surveys were performed and reviewed prior to obtaining the available contract documents.

#### **4.1 Field Validation Test Sites**

In July 2004, continuous alignment surface geophysical surveys were performed along a 6.75-kilometer (4.2-mile) portion of the proposed widening alignment for S.R. 520 in Orange County, Florida. In July 2005, supplemental investigation surveys were performed just beyond the existing embankment of the eastbound and westbound lanes along a 9.6-kilometer (6-mile) portion of the proposed widening alignment for S.R. 400 (i.e., Interstate 4) in Volusia County, Florida.

For both verification tests, the supplemental investigations were performed prior to review of the project contract documents, however, it was generally known that subsoil conditions within the S.R. 520 site were generally not nearly as problematic as within S.R. 400 project alignment where excavation and replacement of a substantial volume, i.e., over 190,000 cubic meters, of existing non-select organic and clayey subsoils is planned.

#### **4.2 Field Validation Test Methods**

At both of the validation test sites, Concurrent CCR surveys were performed using the Ohm-mapper TR-4 configured with 10-meter transmitter and receiver dipole lengths and a 5-meter separation between the transmitter and first receiver. This is the Ohm-mapper configuration deemed to offer the best combination of resolution and penetration depth based on results of the initial



verification testing discussed above. Real-time Trimble differential GPS locations were recorded by the Ohm-mapper data logger

At both validation test sites, 200 and 500 MHz GSSI radar antenna were concurrently used and set at ranges of 102 and 204 nanoseconds, respectively (with corresponding estimated provide maximum penetration depths of about 8 and 14 meters, respectively, in dry sand).

Concurrent GPR-CCR data collected at average rates ranging from 1.6 to 2.4 kilometers per hour (5,000 to 8,000 feet per hour). Datasets were generally stored and analyzed as a series of consecutive 1,000-foot (305-meter) transects.

### **4.3 Field Validation Test Results**

#### **4.3.1 S.R. 520 Test Results**

Results of approximately 6.7 kilometers (22,000 feet) of continuous alignment CCR and GPR surveys were reviewed and then compared to results of the conventional soil boring exploration that had previously been undertaken in conjunction with the planned widening project. (A copy of the contract plans was obtained and reviewed after completion of the geophysical surveys.) Due primarily to safety and access considerations, the alignment surveys were performed along the eastbound side for the first 4 kilometers transects L1, L2 and L3; Figure 14), with the remainder performed along the westbound side. Results of the CCR and GPR surveys are presented in Appendix F.

Based on review of the project plans and field observations, the first 1.5 kilometers of the eastbound survey traversed the lower slope of the existing roadway embankment. The remainder of the eastbound survey was along a natural ground area offset about 25 meters (80 feet) from the existing roadway centerline. The 2.75-kilometer westbound survey was performed approximately along or just beyond the toe of the existing roadway embankment. Soil types encountered at locations of soil borings performed at conventional 100-foot (30-meter) intervals were generally classified as AASHTO A-3 type fine sands or A-2-4 type silty sands, except where sandy organic muck was encountered near the surface within an isolated area at the east end of the alignment.



*Figure 14 – S.R. 520 Validation Test Site*

Results of the CCR surveys, which typically exhibited moderate resistivity values, were consistent with the general characterization determined by the conventional exploration. However, as illustrated in Figure 15, the degree of variability in resistivities varied substantially within different sections of the alignment. Hence, if the supplemental CCR results had been available during the planning phase of the conventional exploration, a more reliable characterization might have been realized through use of variable borehole spacing, i.e., by reducing the spacing in the more variable areas and perhaps increasing in the more uniform areas. Note that the profiles in Figure 15 each represent 1,000 feet (305 meters) of the test alignment, so a conventional exploration would normally include 10 uniformly-spaced test borings along each profile. One can appreciate that the shallow subsurface reflected in the upper profile in Figure 15 could potentially be characterized with 10 or less, while a greater number of boring locations might be needed to reliably characterize conditions reflected in the highly variable profile.

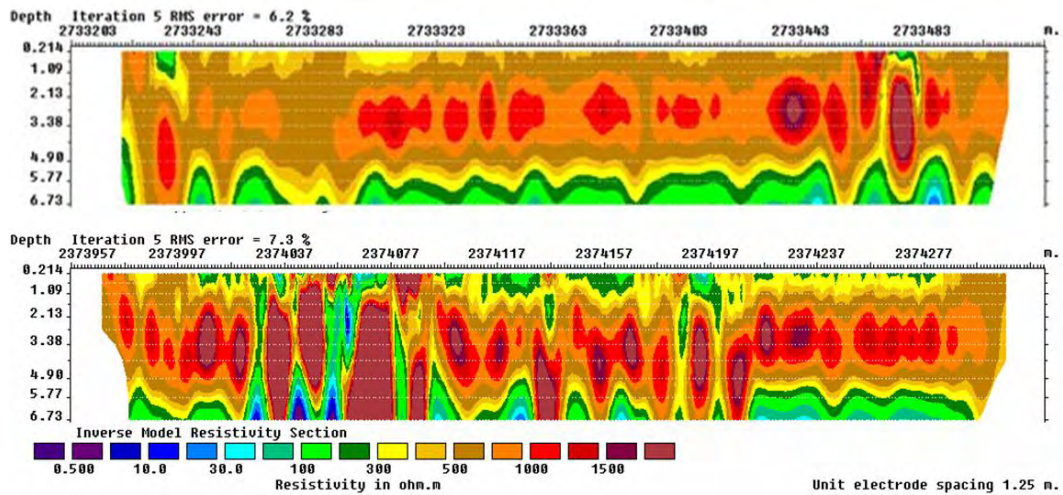


Figure 15 – Uniform (Top) and Highly Variable (Bottom) CCR Results at S.R. 520

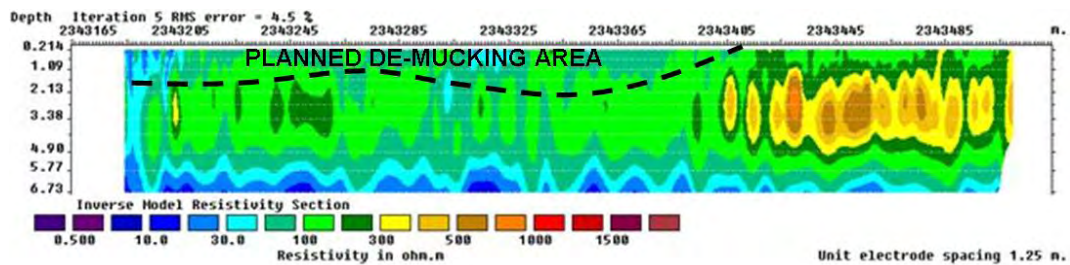
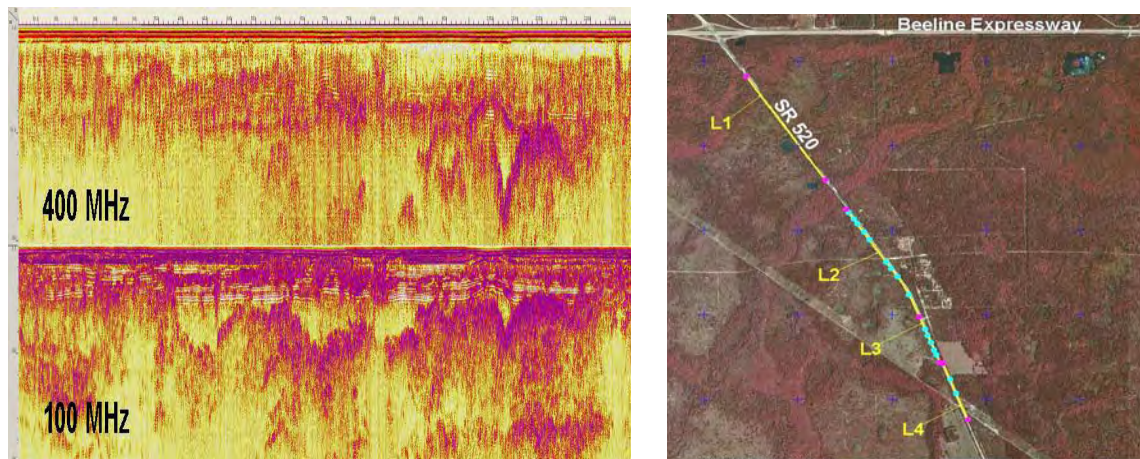


Figure 16 – CCR Results Through Planned De-mucking Area of S.R. 520 Project

The lowest resistivity values within the 6.75-kilometer study section were measured near the east end of the CCR survey alignment, i.e., the southern end of line L6 shown on Figure 16. As illustrated in Figure 16, the low resistivity values correspond to non-select organic soils encountered in a few of the test borings that are to be removed and replaced with select sand fill in conjunction with the roadway widening project.

Review of the dual-GPR results for this test site revealed a number of locations that exhibited data potentially indicative of shallow subsurface geologic features that could warrant consideration in the planning stage of a conventional exploration. Using the real-time GPS positioning data, the locations of these potential features were plotted to develop a GPR feature map (Figure 17).





*Figure 17 – Example of Dual Receiver GPR Results and S.R. 520 GPR Feature Map*

Results of the GEM-2 terrain conductivity survey performed along the S.R. 520 test site are presented on Figures F14 through F22 in Appendix F. The GEM-2 survey results were found to be in general agreement with the CCR data. Measured conductivities were generally found to increase with depth (i.e., higher values were measured at lower frequencies). As indicated in Figure F22, the GEM-2 device was able to detect the highly conductive soils near the south end of the transect that were observed in the CCR survey and that correspond to the materials to be removed and replaced according to the project plans.

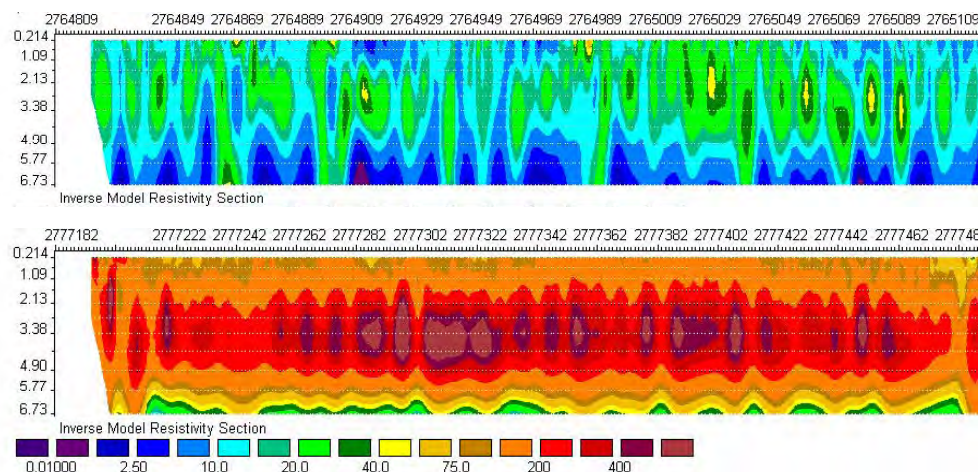
#### 4.3.2 S.R. 400 (I-4) Test Results

Results of nearly approximately 9.5 kilometers (6 miles) of continuous alignment CCR and GPR surveys were performed along both the eastbound and westbound sides of S.R. 400 (Interstate 4). The CCR survey results are presented in Appendix G (Figures G1 through G32). The project involves significant excavation and replacement of non-select organic and clay soils, particularly within the western half of the surveyed alignment. Due to the conductive nature of the subsurface at this test site, GPR data was found to be inconclusive beyond confirmation of some of the buried box culverts indicated on the project plans. On the other hand, the CCR was found to be in good agreement with the general characterization based on soil borings. An overview of range in measured surface resistivity values is illustrated in Figure 18 with very low values along the western half and higher values along the eastern half of the eastbound and westbound survey alignments.



Figure 18 – S.R. 400 Validation Test Site and CCR Resistivity Overview

Results of the CCR surveys, in terms of inverse model resistivity profiles, were found to be in good general agreement with the soil boring results. Portions of the survey alignment that exhibited the lowest resistivity values generally corresponded to areas where A-8 type organic soils or muck and A-7-6 type sandy clays were encountered. Within the eastern half of the study site, where sandy soils were generally encountered at the soil boring locations and where little subsoil excavation was planned, the CCR results typically indicated fairly uniform and consistently higher values that those observed along the eastern side (Figure 19). The location of the observed change from generally poor to characteristically good subsoil conditions reflected in Figure 18 was also found to be in good agreement with the published soil survey maps for Volusia County.



*Figure 19 – CCR Results Near Western (Top) and Eastern (Bottom) Ends of S.R. 400 Site*

As was the case at the S.R. 520 test site, it appears that supplemental CCR data could have been very valuable if available during the planning phase of the conventional exploration for the S.R. 400 project. As illustrated in Figure 20, it appears that the resistivity results would have provided valuable complimentary data during the initial project planning phase in terms of providing a broad perspective on the general extent to which non-select subsoil excavation and replacement was likely to be required. Based on results of the S.R. 400 validation testing, an initial exploration consisting of continuous alignment surface geophysical testing along with a limited number of conventional soil borings would have led to the development of a very effective phased exploration and even may have enabled preliminary estimation of subsoil improvement requirements and costs for various roadway widening designs.



*Figure 20 – Near-Surface Resistivity Along a Portion of the S.R. 400 Test Site*

## **SECTION 5**

### **SUMMARY AND PRACTICAL IMPLICATIONS**

The FDOT initiated this research study to investigate the technical and economic viability of more routine use of supplemental field investigation techniques in conventional roadway geotechnical engineering design practice. In particular, the goal of the study was to identify, test and evaluate viable investigation techniques that can be implemented on a regular basis near-term to supplement and enhance the effectiveness of conventional soil boring programs.

#### **5.1 Review of Conventional Practice**

The FDOT Soils and Foundation Handbook provides guidelines to assist the engineer in formulating and implementing successful geotechnical field exploration and laboratory testing programs. Most commonly, subsurface investigations consist mainly of reviewing available existing data (topographic maps, aerial photographs, soil surveys, etc.), undertaking a field reconnaissance site visit, and performing a number of soil borings which may incorporate in situ testing (primarily standard penetration testing) and collection of samples for classification and laboratory testing. Handbook guidelines for minimum roadway soil survey explorations include soil borings at a maximum spacing of 100 feet (30 meters), alternating left and right of the proposed centerline, or in the additional lane for widening projects. This spacing may be increased if pre-existing information indicates the presence of uniform subsurface conditions, but should be reduced as necessary to define the limited of undesirable materials or to better define stratification in areas of highly variable soil conditions.

Conventional explorations, when properly planned and executed, are effective in providing the Engineer with the information needed to formulate an effective and efficient design. However, a reliable perspective regarding the potential degree of variability and possible presence of localized non-select subsurface conditions is critical to success, particularly when field exploration schedule and budget constraints limit the scope and extent of the conventional exploration to that corresponding to the minimum guidelines reflected in the Handbook.



## 5.2 Effectiveness of Supplemental Methods

Results of validation test surveys using concurrent CCR-GPR with GPS positioning proved adequately reliable for use in planning effective conventional geotechnical explorations. Considering that nearly 27.5 kilometers (17 miles) of surveys were completed in less than 3 days, and that minimally-processed results were readily interpretable from an engineer's perspective, near-term routine implementation of a supplemental field exploration appears viable. In particular, results of this study strongly suggest that more routine implementation of supplemental exploration should be considered for roadway projects within areas of the State where non-select subsoil conditions are generally more prevalent.

## 5.2 Availability, Time and Cost

Based on results of the application survey discussed in Section 2.4, and the demonstrated success in achieving very rapid field data collection and preliminary data reduction during the verification and validation testing phases, it appears that near-term use of surface geophysical investigations as a routine supplement to conventional geotechnical explorations is practical from project schedule and budget perspectives. This is particularly true if one considers the cost of the geotechnical investigation phase relative to rapidly escalating construction costs (Figure 21).

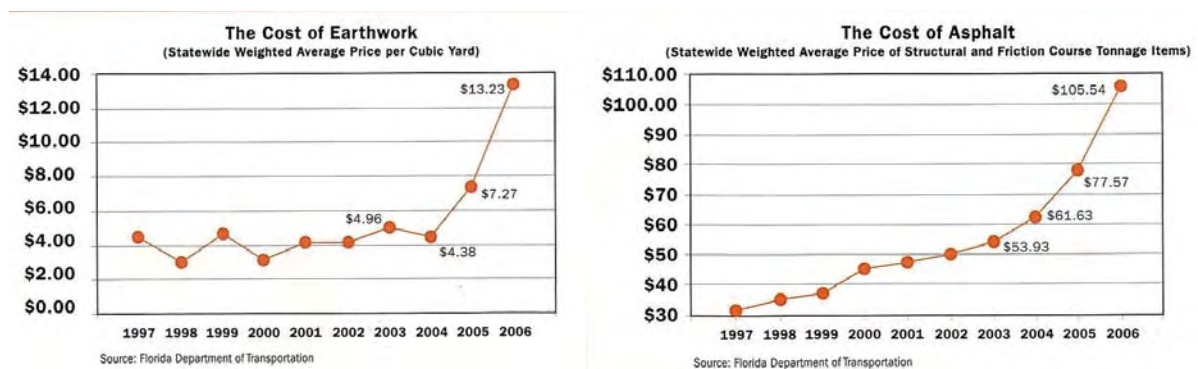


Figure 21 – Roadway Construction Costs Reported by the Orlando-Orange County Expressway Authority (Summer 2006 Expressway Navigator)

In addition to determining the general stratigraphy, soil types and properties characteristic of a roadway project for use in developing an efficient and effective design, the



geotechnical Engineer need to be able to address the potential for, and plan contingency actions against, the discovery of changed or unexpected conditions during the final design and construction phases of the project. Considering the escalating construction costs, and hence escalating exposure to potential cost over-runs related to post-award discovery of changed conditions, it seems reasonable to conclude that the value of reliable site characterization has likewise escalated. In this light, an increase in the minimum exploration guidelines contained in the Handbook would be justified, except that the time required for proportionately increased conventional exploration could be prohibitive from a project schedule standpoint. Based on results of this study, it is evident that serious consideration needs to be given to more routine use of supplemental investigation methods, and the Handbook may need to be updated to provide additional guidance towards use of continuous alignment surface geophysical methods.

### **5.3 Proposed Implementation Plan**

Based on our evaluation of field tests and simulated implementation, the utility of selected non-invasive, continuous-alignment surface geophysical methods appears promising. Concurrent CCR-GPR with GPS positioning proved particularly viable for the sites evaluated to-date. Based on findings from this study, an implementation plan for FDOT project alignments should include:

- i. Encouraging use of state-wide NRCS-based non-select soil maps to identify high-risk areas of the state that warrant supplemental investigations.
- ii. Conducting or contracting supplemental investigations on high profile roadway alignments based on project length, cost and local geotechnical engineer's experiences of problematic soils in the area of the project.
- iii. Expanding in-house capabilities within FDOT State Materials Office to provide geophysical services to the Districts.

- iv. Incorporating minimum guidelines in the Soils and Foundations Handbook for geophysical testing to be incorporated into routine roadway soils survey investigations.

Based on the results presented herein, we are optimistic that more routine use of continuous alignment surface geophysics can provide the advanced notice of potential problem areas that the engineer needs in order to better plan and execute effective geotechnical investigations. The envisioned result is a decline in the number of change orders related to unforeseen problem soil conditions, improved performance, and reduced overall project and maintenance costs.

## SECTION 6 REFERENCES

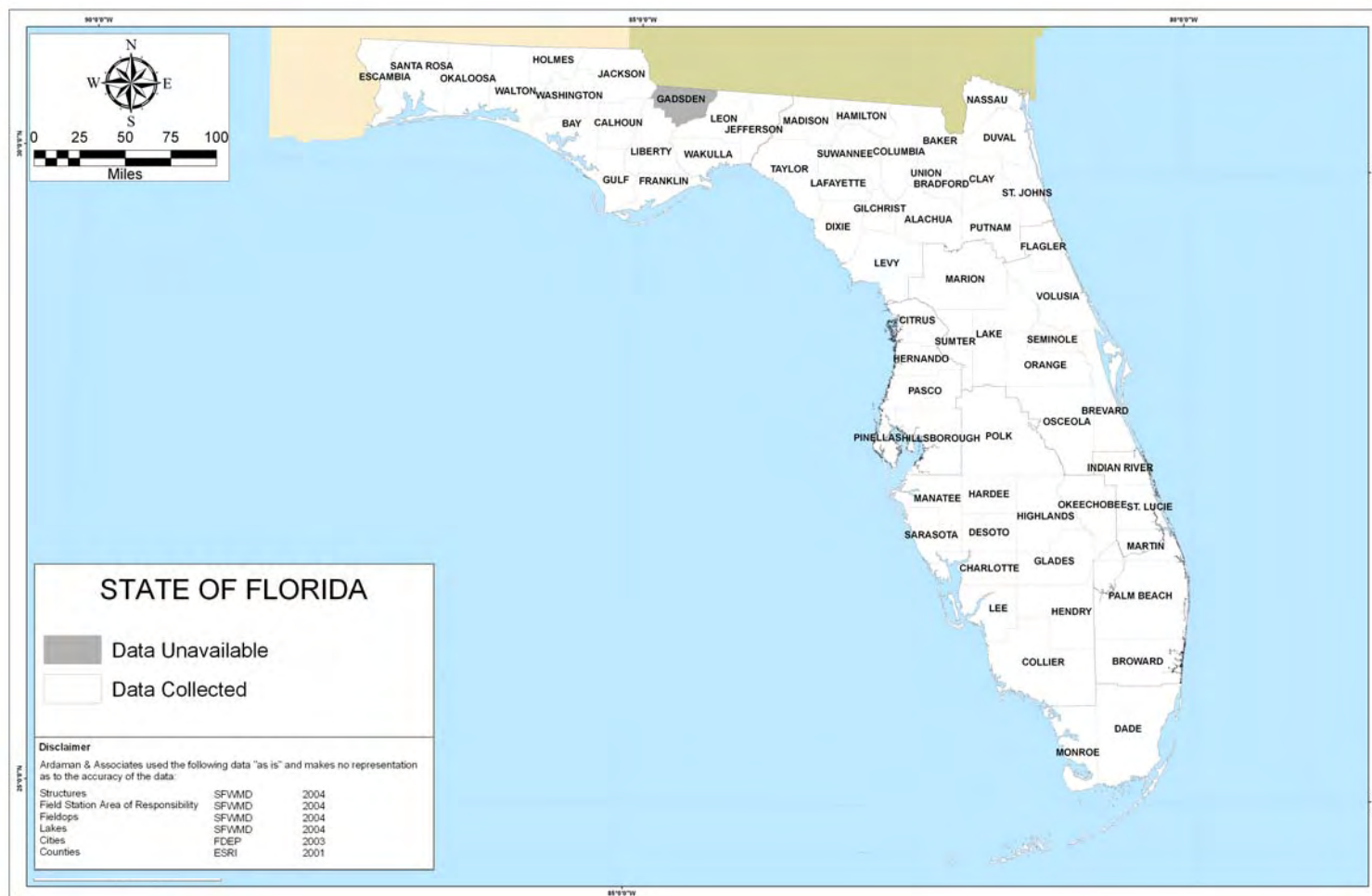
- Anderson, N. and Cardimona, S., 2000, Evaluating the utility of geophysical surveying methods, First International Conference on the application of geophysical methodologies & NDT to transportation facilities and infrastructure, December 11-15, 2000, St. Louis, Missouri.
- Auken, E. and Sørensen, K., 1999, Laterally constrained inversion of densely measured profile oriented EM data in "soft" 3D sedimentary environments: Salt Lake City, Utah, 232-236.
- Benson, R. C., 2000, An overview of methods and strategies assessing subsurface geologic conditions and structural testing of roads and bridges, First International Conference on the application of geophysical methodologies & NDT to transportation facilities and infrastructure, December 11-15, 2000, St. Louis, Missouri.
- Benson, R.C., 1993, Geophysical techniques for subsurface site characterization, chapter 14, in: Geotechnical practice for waste disposal, David Daniel, Ed., Chapman and Hall, 311-357.
- Berge, P.A., et al., 1999. "Comparing Geophysical Measurements to Theoretical Estimates for Soil Mixtures at Low Pressures", Proceedings of the Symposium on the application of Geophysics to Engineering & Environmental Problems (SAGEEP), March 14-18, 1999, Oakland, California, Environmental and Engineering Geophysical Society, Wheat Ridge, Colorado, 425-472.
- Bernstone, C., and Dahlin, T., 1999, Assessment of two automated electrical resistivity data acquisition systems for landfill location surveys: two case studies, Journal of environmental and engineering geophysics, V. 4, 113-121.
- Dahlin, T. and Bernstone, C., 1997, A roll-along technique for 3-D resistivity data acquisition with multi-electrode arrays, proceedings of the symposium on the application of geophysics to environmental and engineering problems, SAGEEP '97, Reno, Nevada, March 23-26, 1997, Vol. 2, 927-935.
- Doll, W. E., et al., 2001, Evaluation of new geophysical tools for investigation of a landfill, Camp Roberts, California, Proceedings of SAGEEP, Denver, Colorado, March 2001.
- Loke, M.H. and Barker, R.D., 1996, Rapid least-squares inversion of apparent resistivity pseudo-sections by a Quasi-Newton method, geophysical prospecting, Vol. 44, 131-152.

- Møller, I., 2001, OhmMapper field tests at sandy and clay till sites in Denmark, proceedings of the Symposium on the application of geophysics to environmental and engineering problems, SAGEEP '01, Birmingham, England, pp., 869-874.
- Park, C.B., Miller, R.D., and Xia, J., 1999, Multi-channel analysis of surface waves, geophysics, Vol. **64**, 800-808.
- Møller, I., Sørensen, K. I., and Christensen, N. B., 1998, DC-Resistivity multi-electrode profiling in hydrogeological investigations: A comparative study of the pulled array continuous electrical sounding method and a multi-electrode method with fixed electrodes: Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems, Chicago, USA, EEGS, 869-873.
- Møller, I., 2001, Ohmmapper field tests at sandy and clay till sites in Denmark: Proceedings - Electrical and Electromagnetic Methods Session, Birmingham, England, EEGS, 100-101.
- Park, C.B., Miller, R.D., and Xia, J., 1999, Multi-channel analysis of surface waves, geophysics, Vol. **64**, 800-808.
- Shin, S.F. and Doolittle, J.A., 1984, Using Radar to Investigate Organic Soil Thickness in the Florida Everglades, Soil Science Society of America Journal, Vol. 48, p. 651-656.

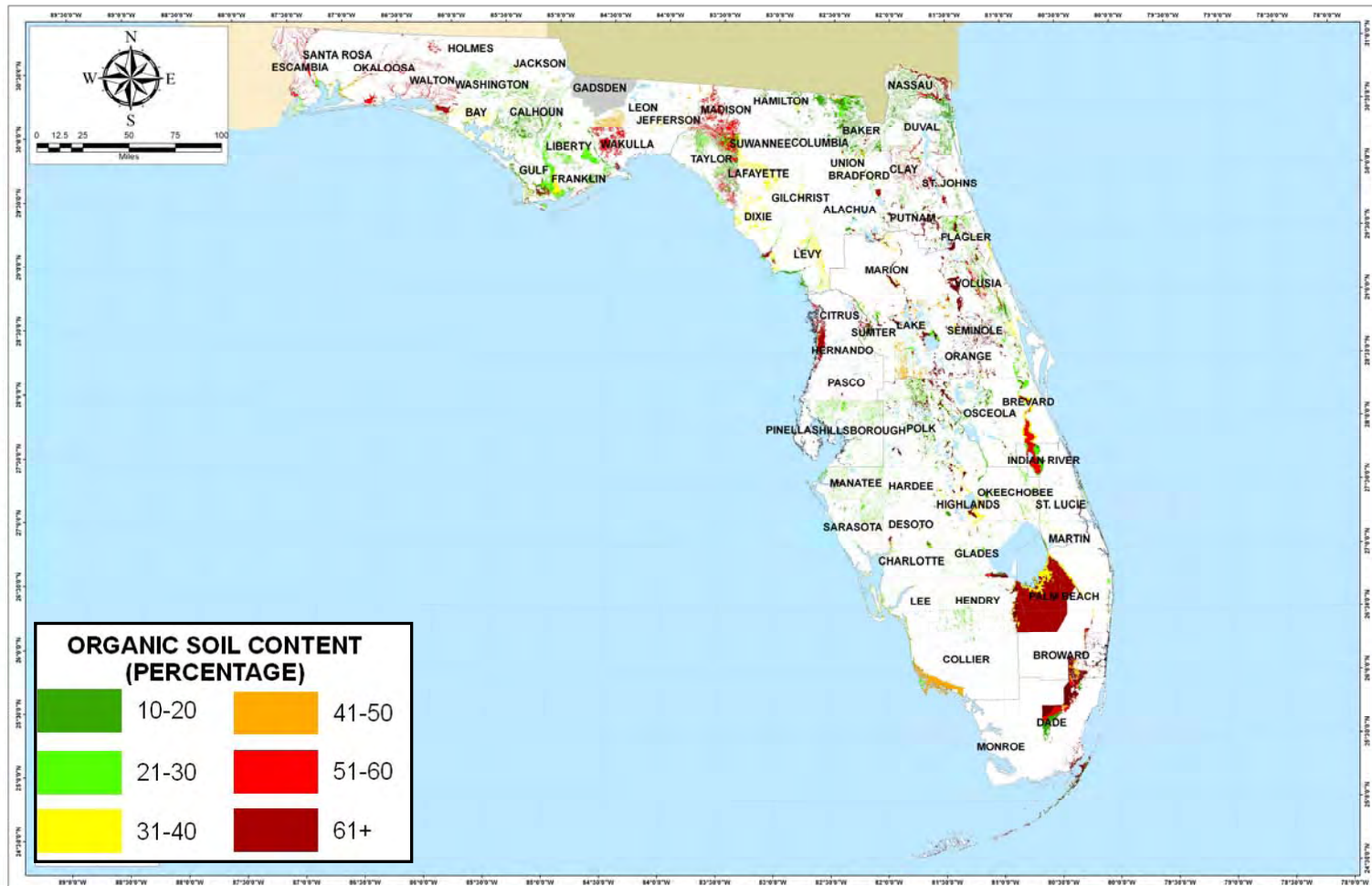


## **APPENDIX A**

### **MAPS**

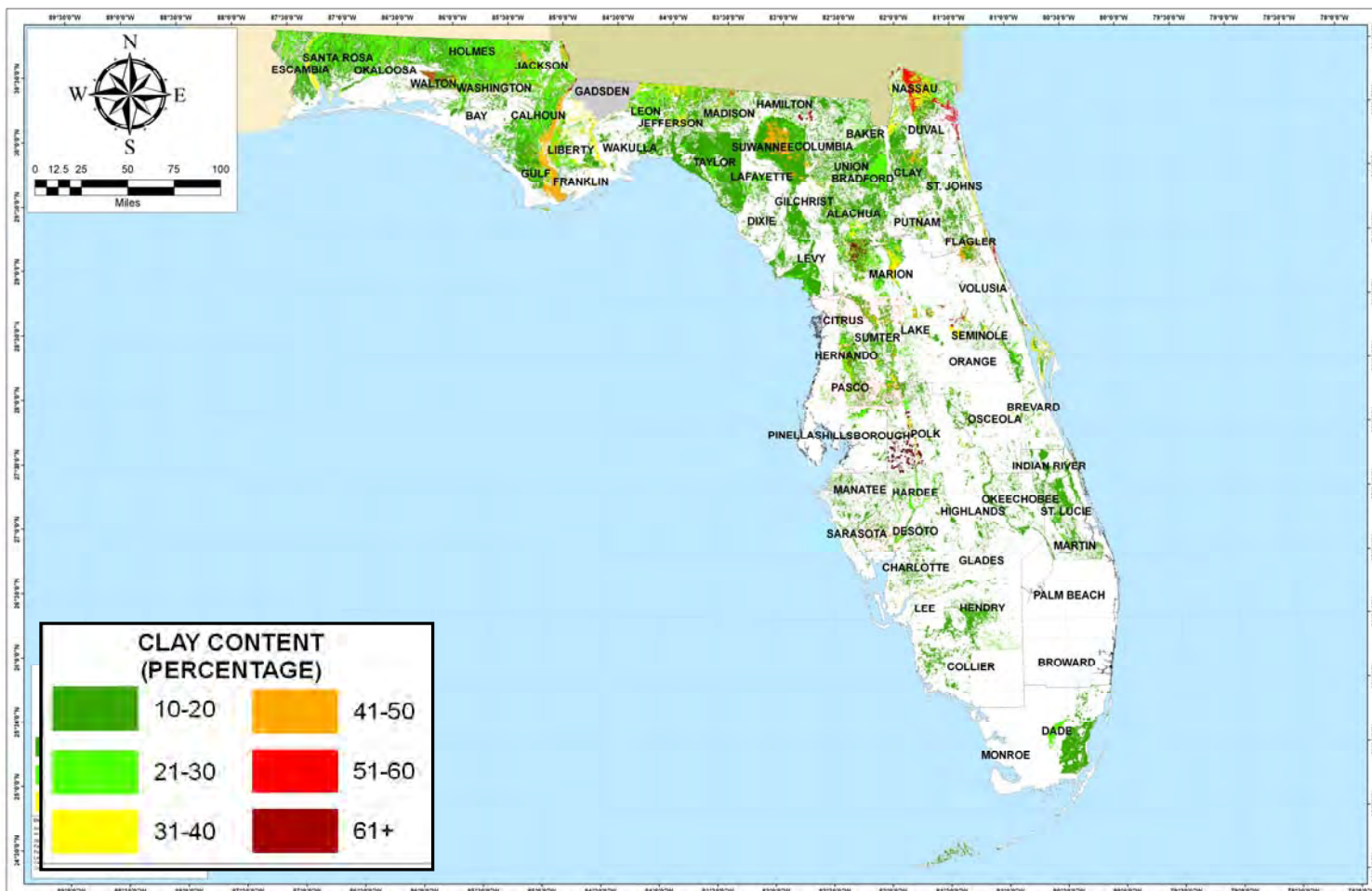


STATE OF FLORIDA REFERENCE MAP

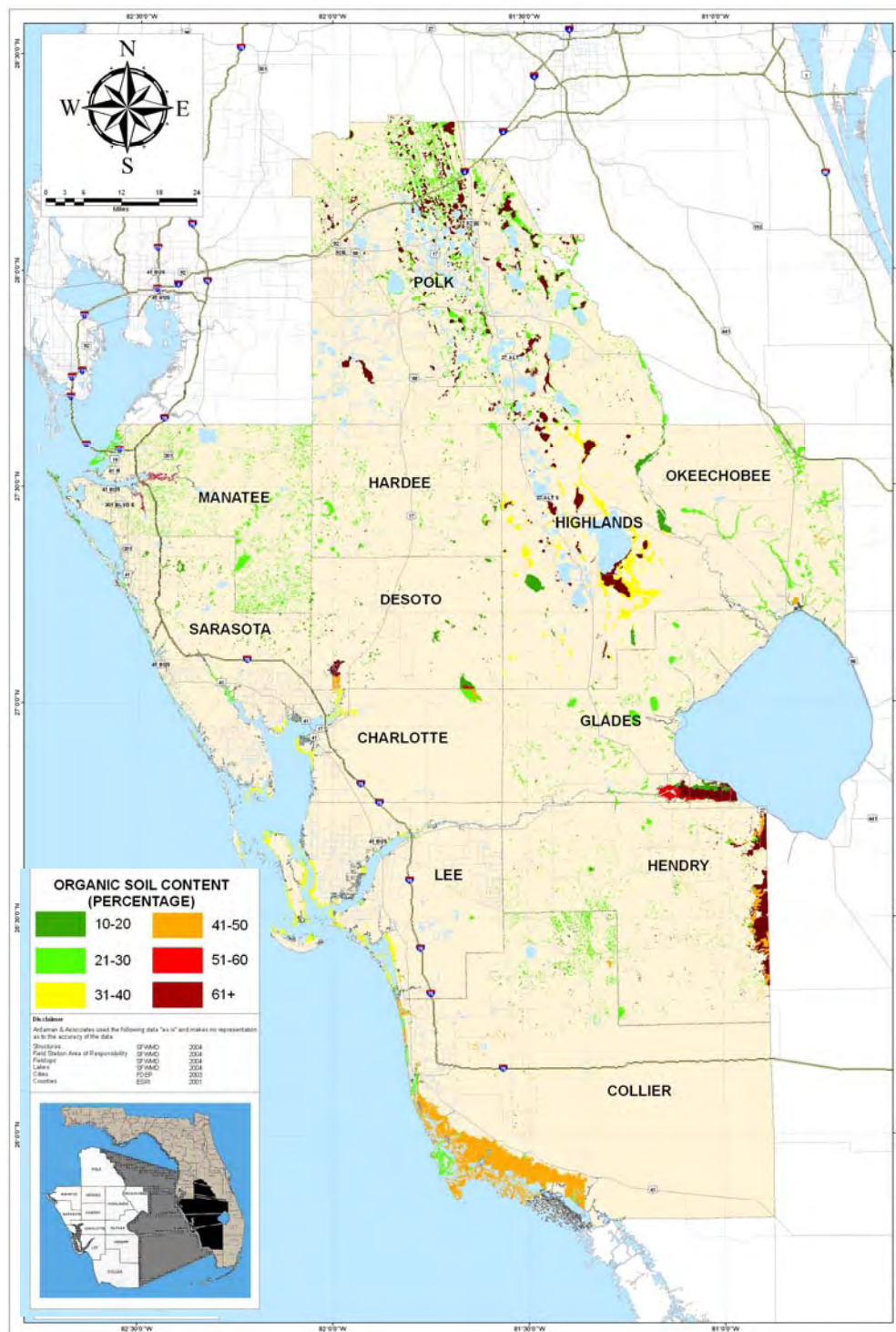


STATE OF FLORIDA – ORGANIC SOILS (NRCS)



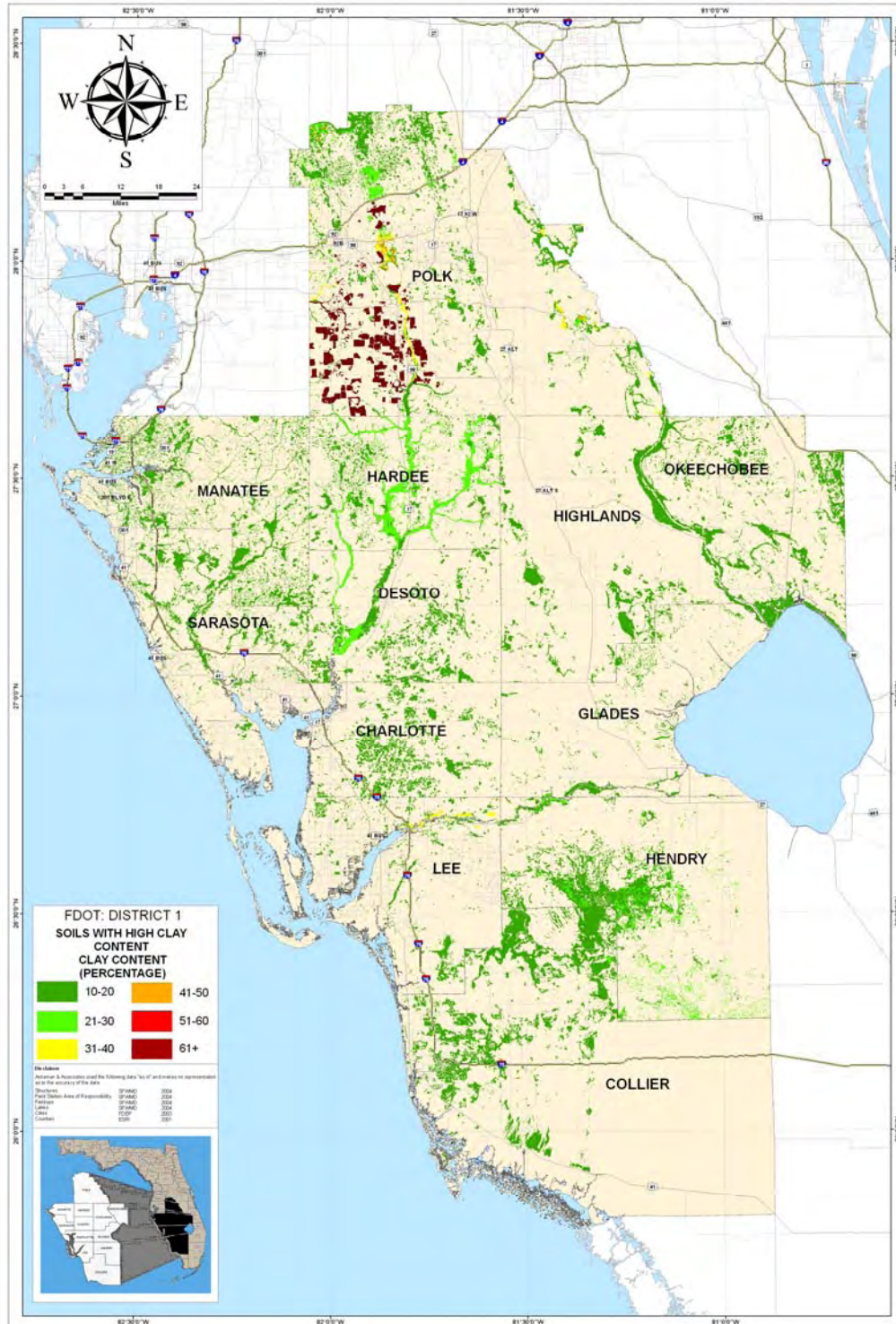


STATE OF FLORIDA – CLAYEY SOILS (NRCS)

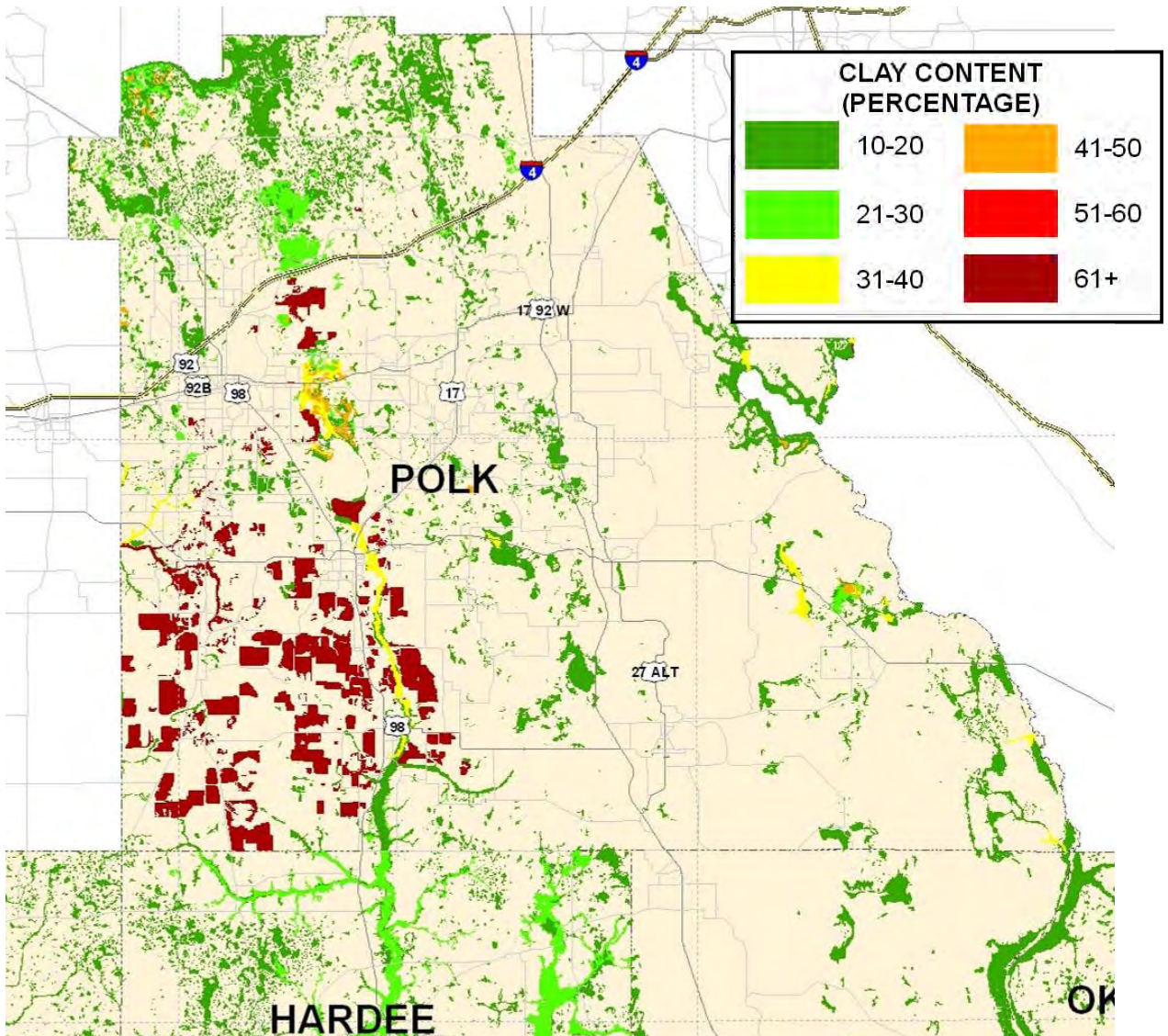


**FDOT DISTRICT 1 – ORGANIC SOILS (NRCS)**



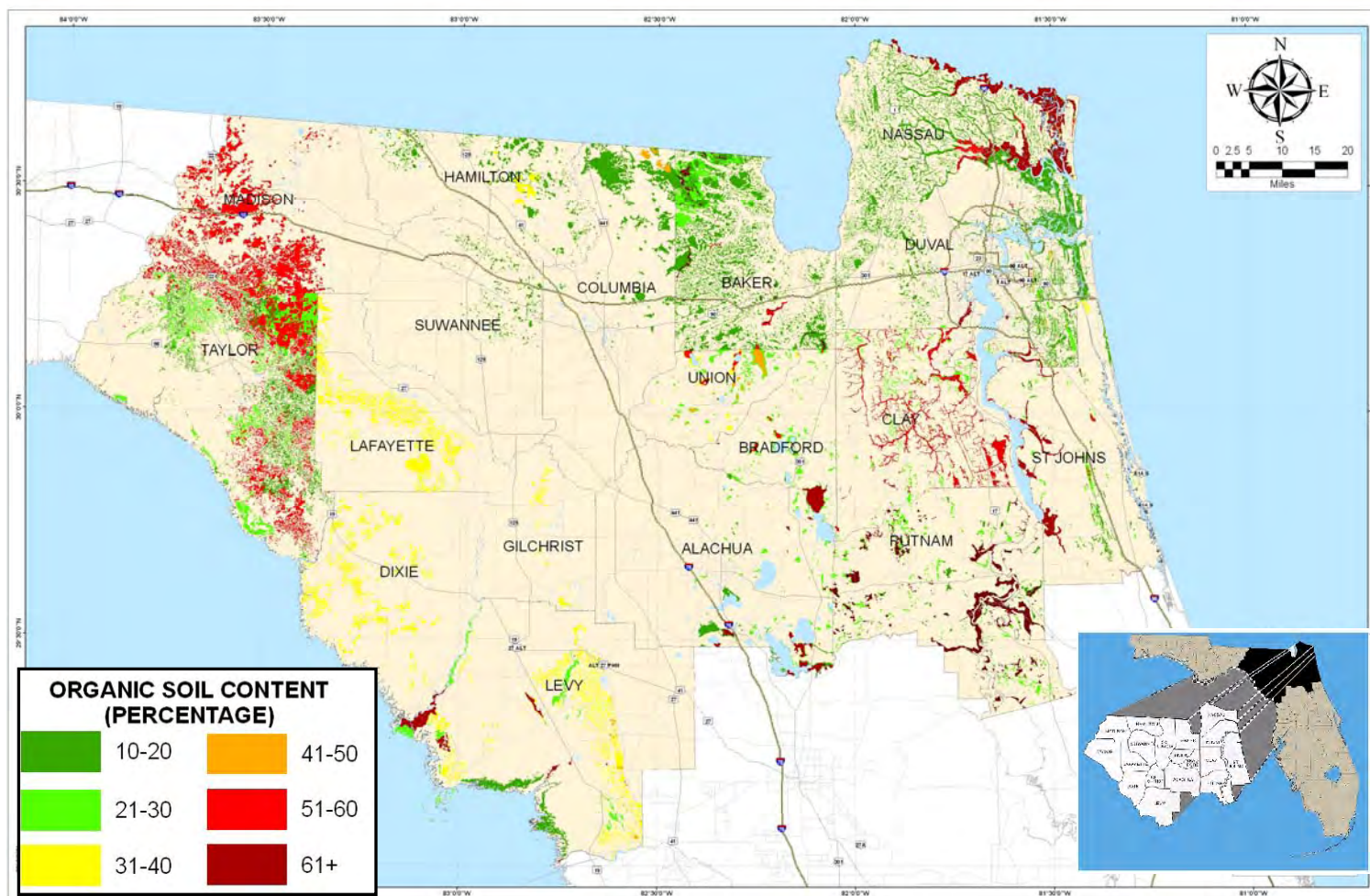


**FDOT DISTRICT 1 – CLAYEY SOILS (NRCS)**

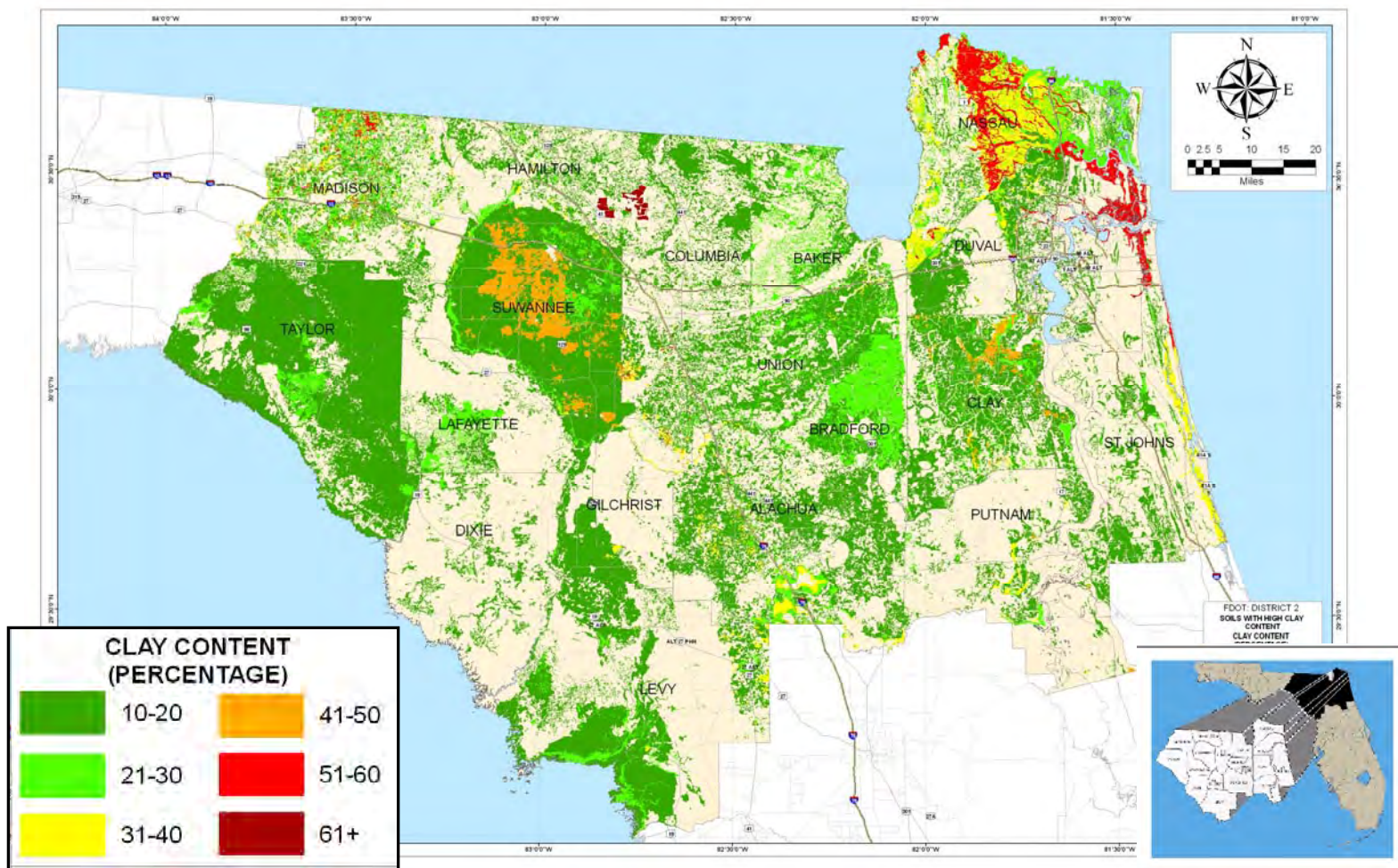


**POLK COUNTY – CLAYEY SOILS (NRCS)**



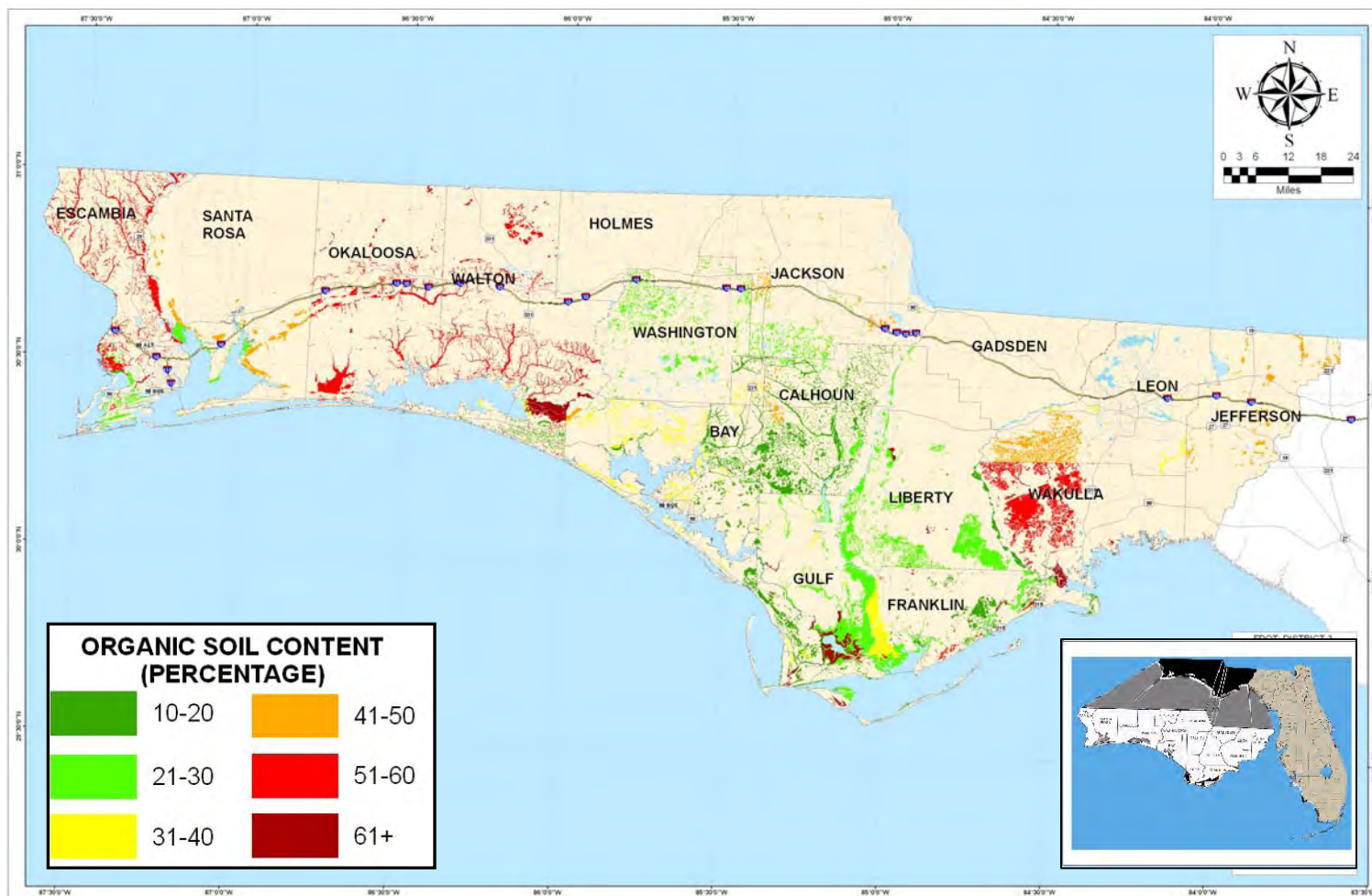


**FDOT DISTRICT 2 – ORGANIC SOILS (NRCS)**



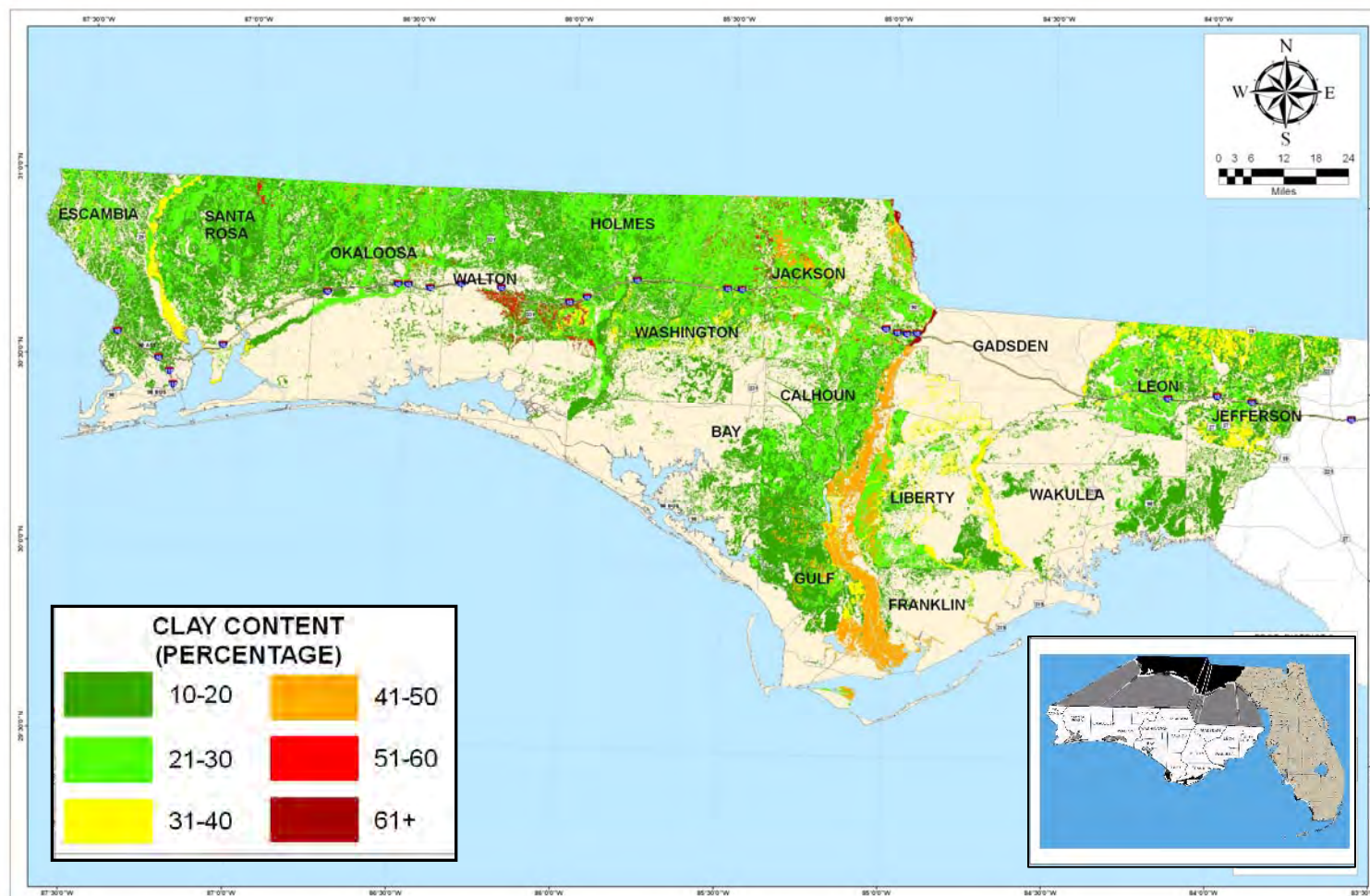
FDOT DISTRICT 2 – CLAYEY SOILS (NRCS)





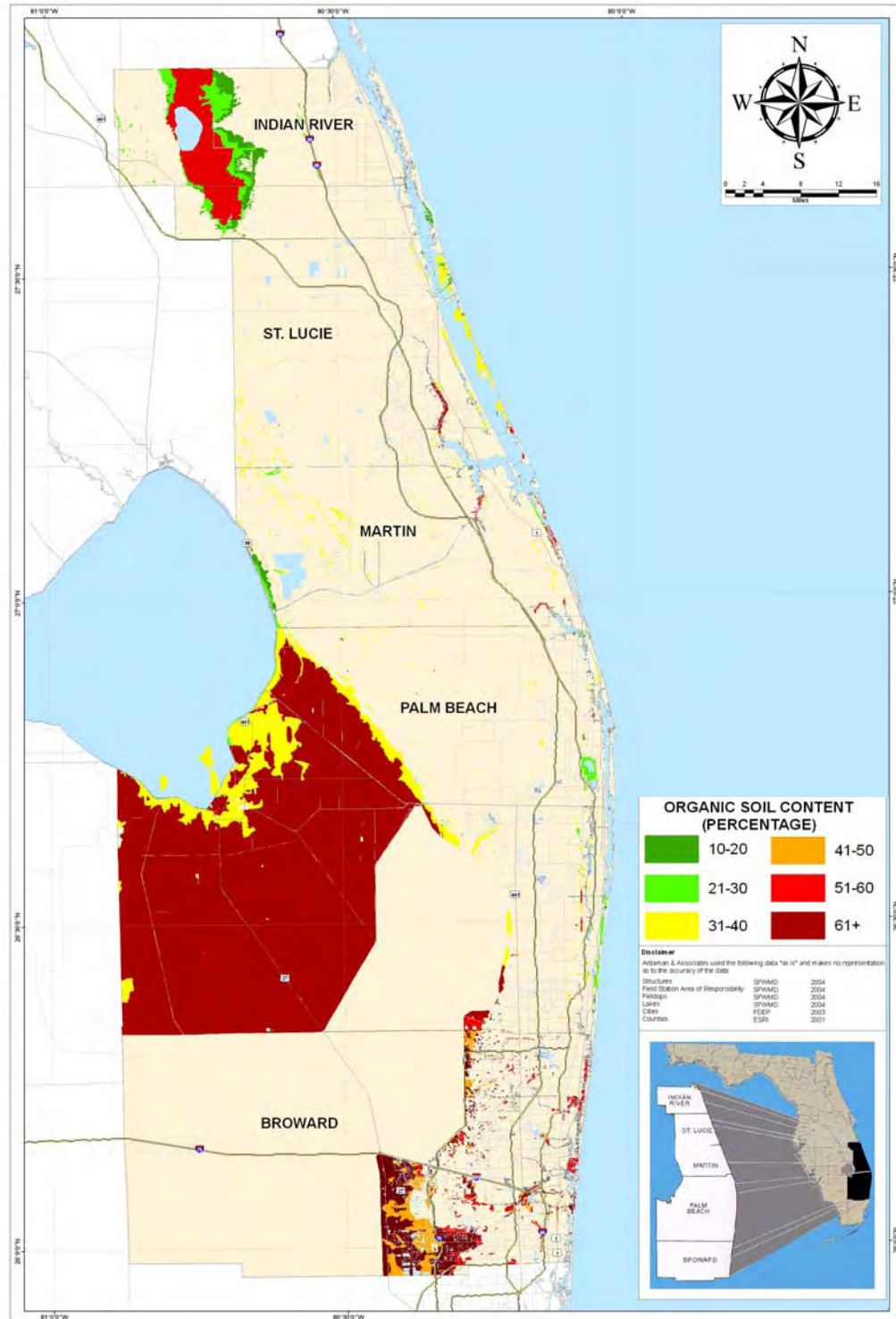
**FDOT DISTRICT 3 – ORGANIC SOILS (NRCS)**

MAPS

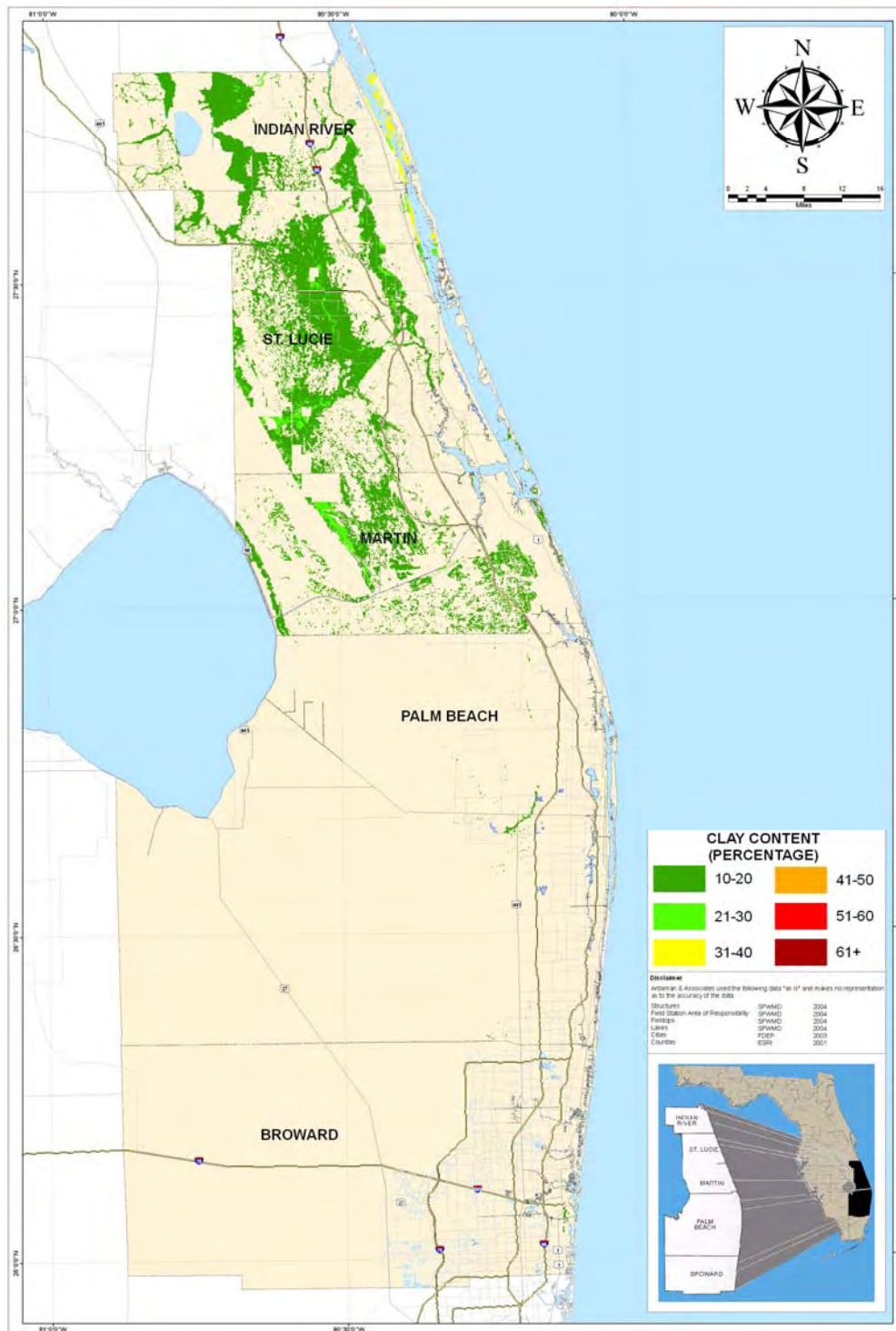


FDOT DISTRICT 3 – CLAYEY SOILS (NRCS)

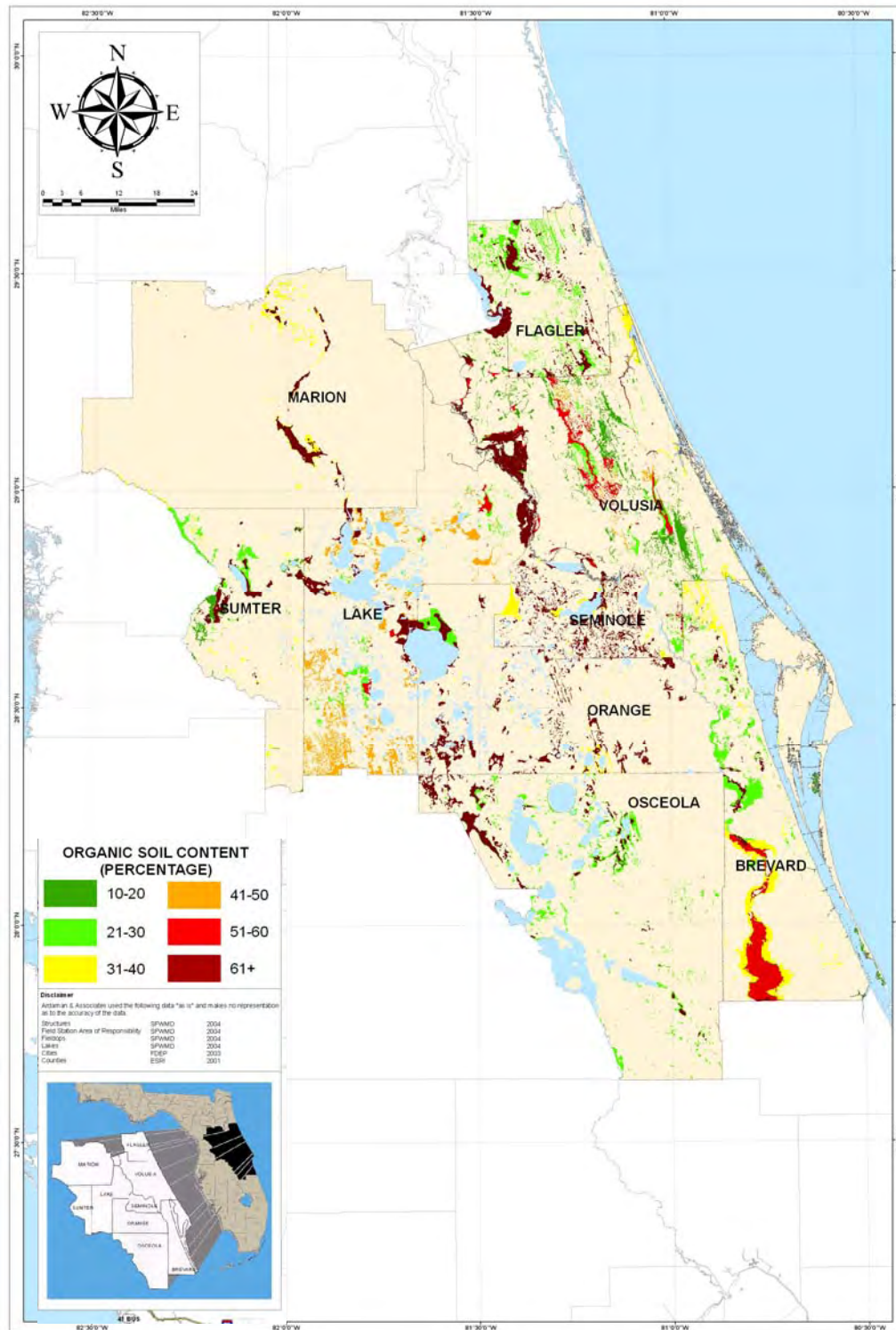




**FDOT DISTRICT 4 – ORGANIC SOILS (NRCS)**

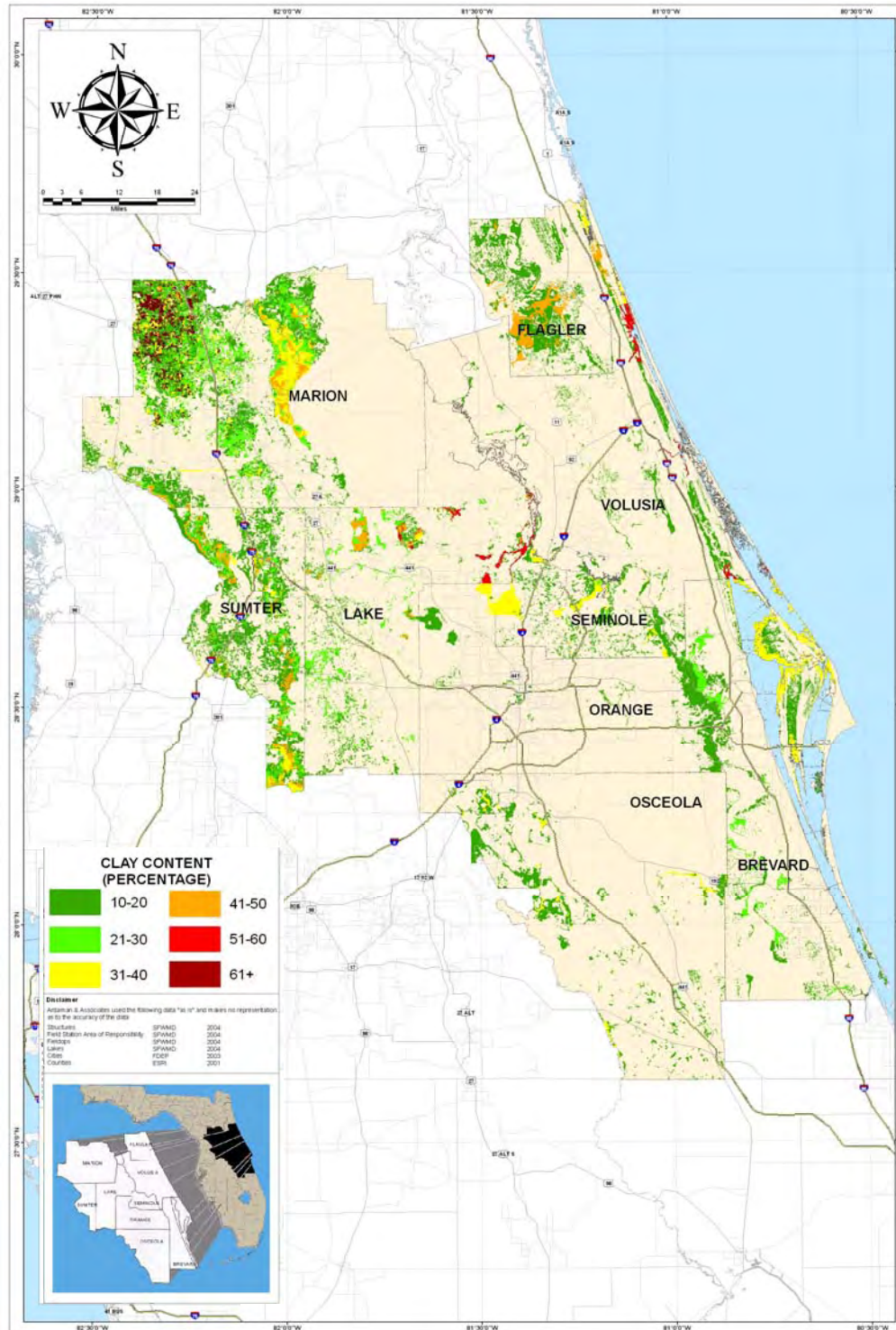


**FDOT DISTRICT 4 – CLAYEY SOILS (NRCS)**

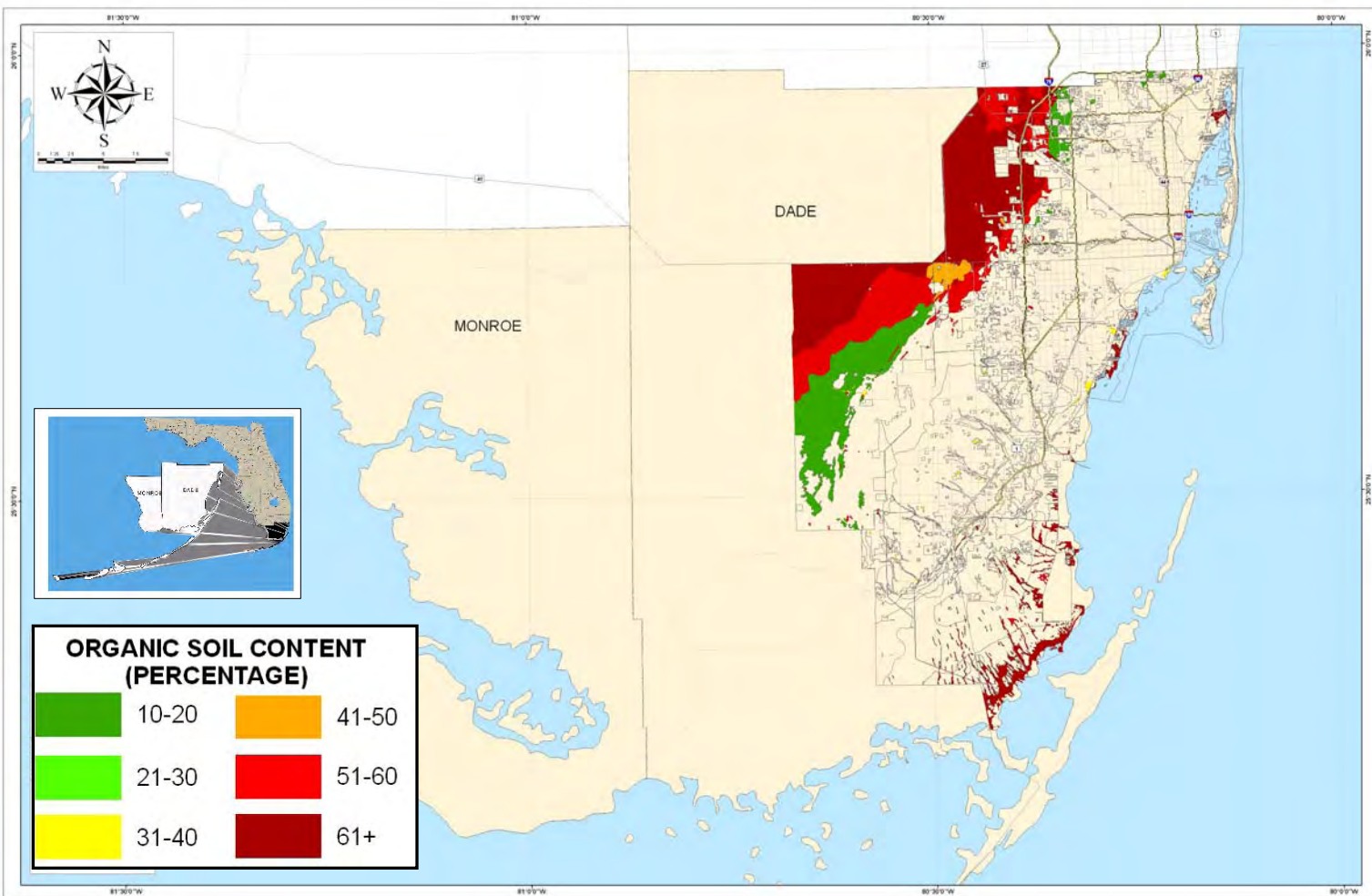


**FDOT DISTRICT 5 – ORGANIC SOILS (NRCS)**

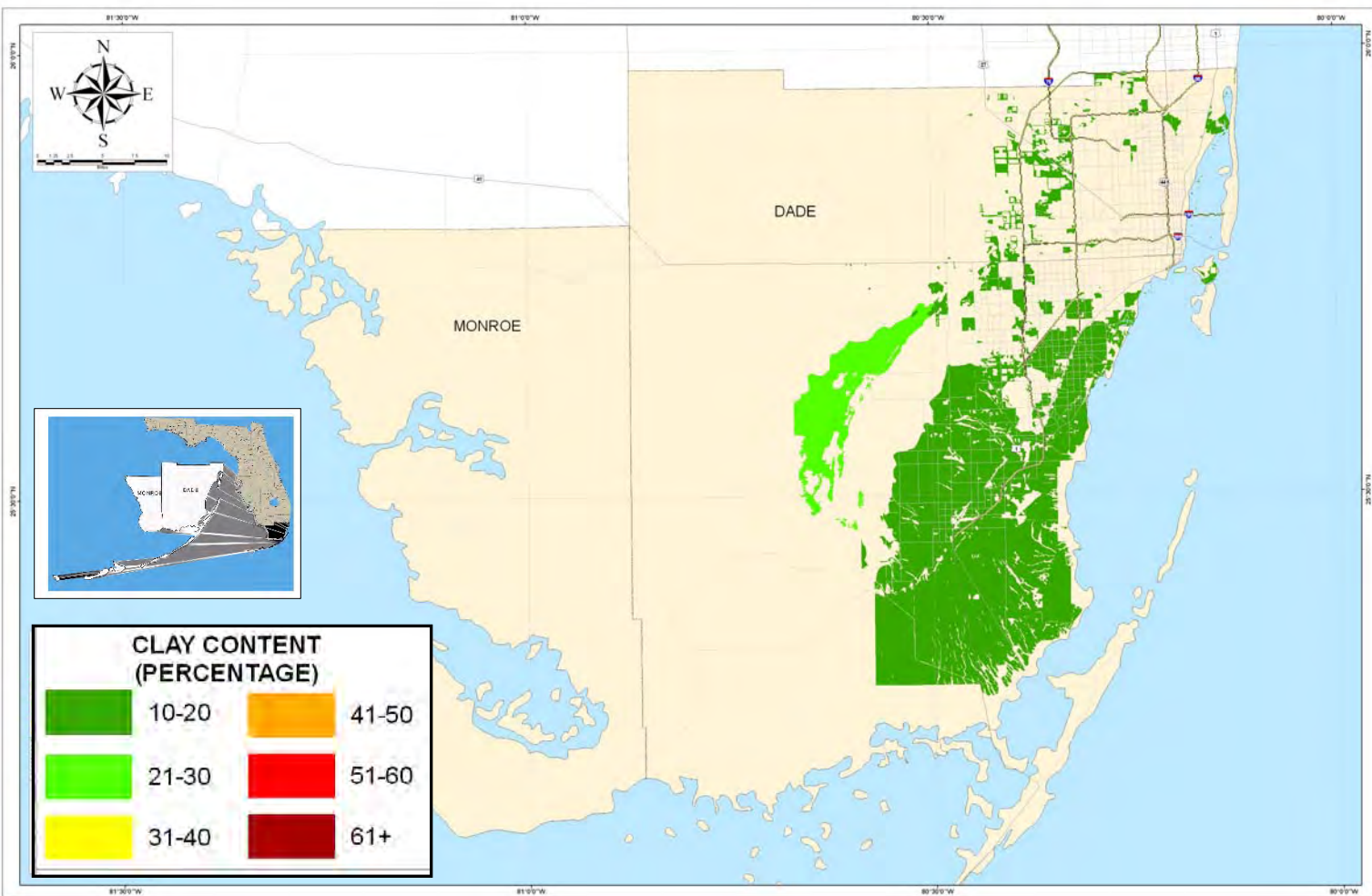




**FDOT DISTRICT 5 – CLAYEY SOILS (NRCS)**



**FDOT DISTRICT 6 – ORGANIC SOILS (NRCS)**



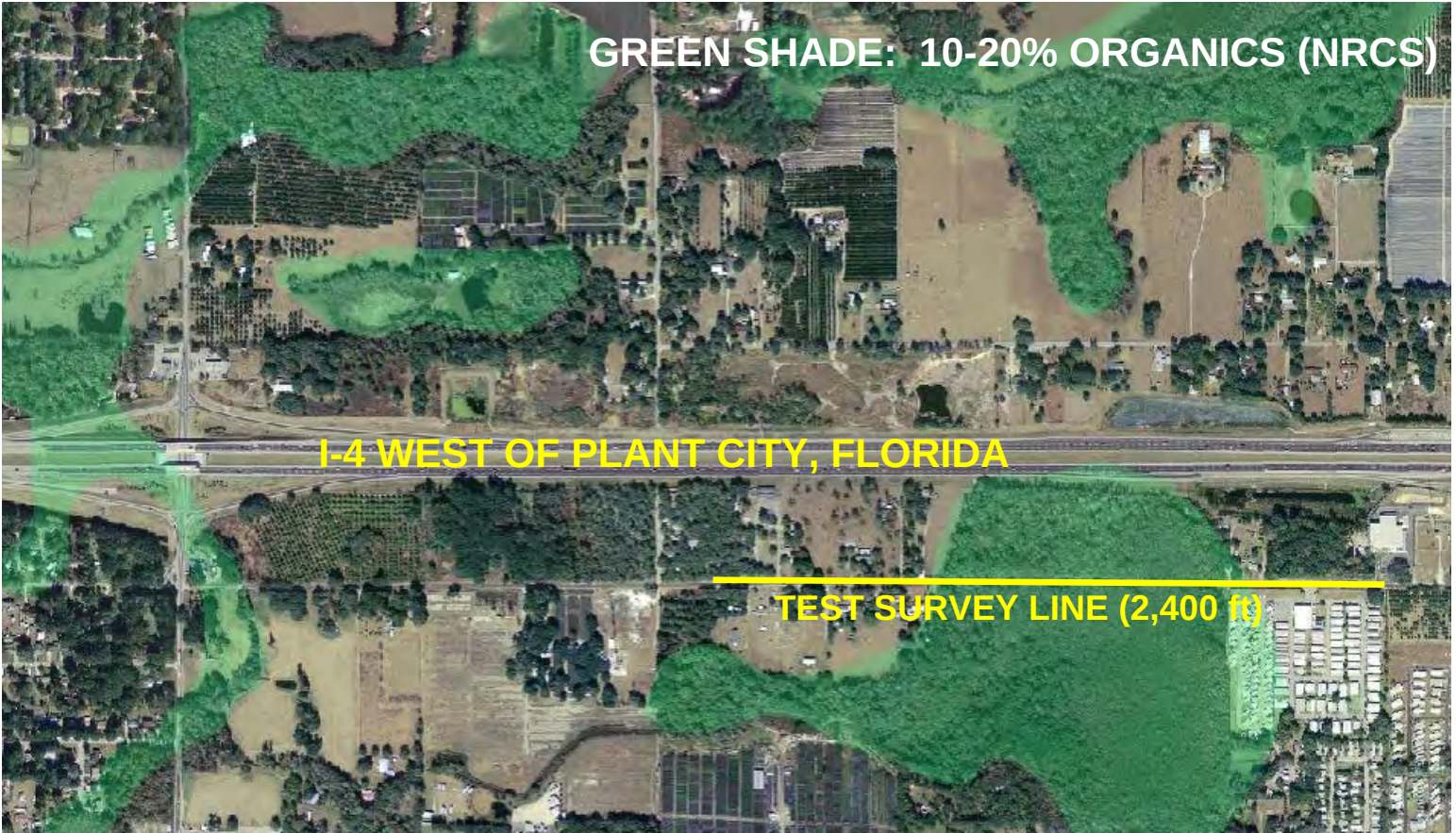
FDOT DISTRICT 6 – CLAYEY SOILS (NRCS)





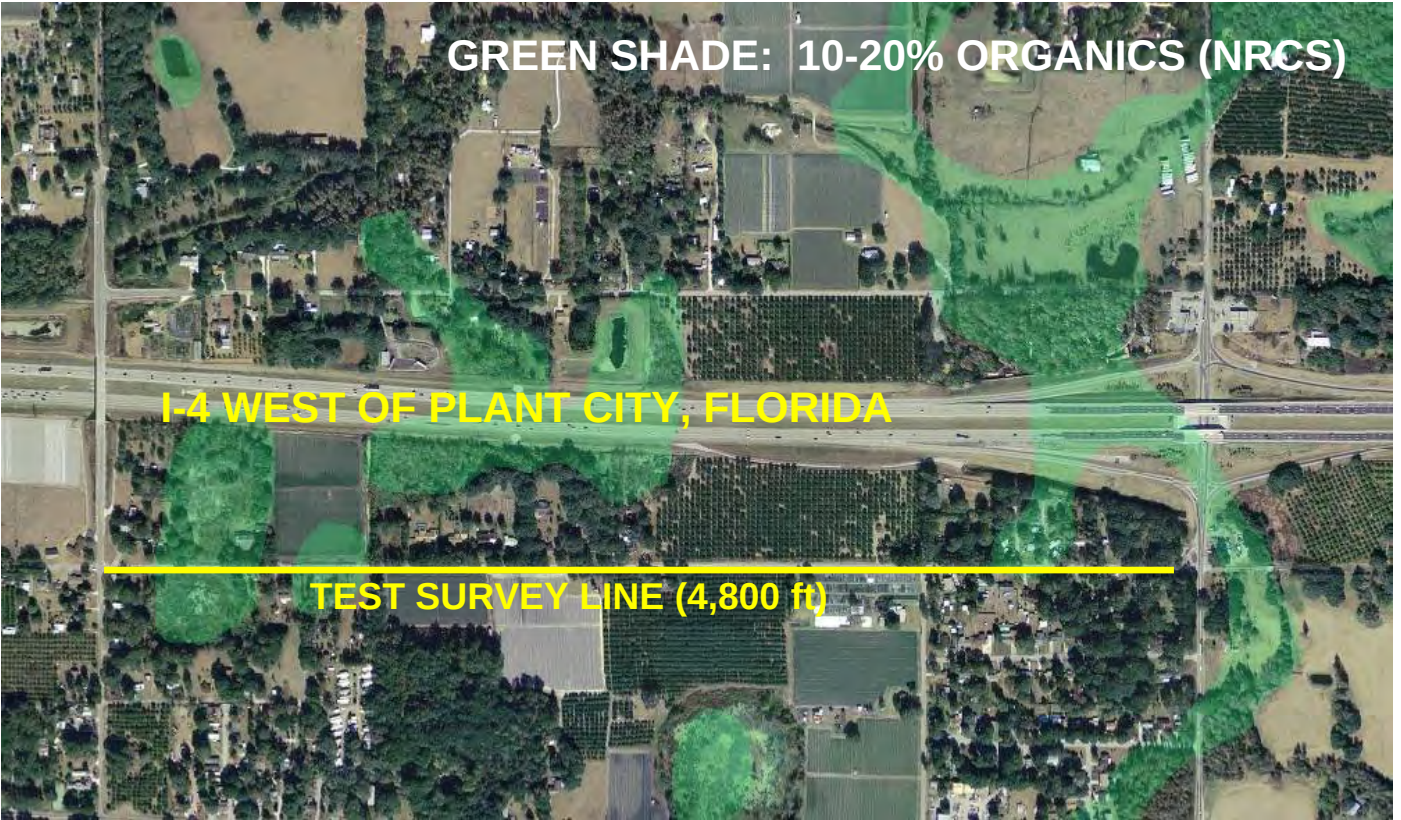






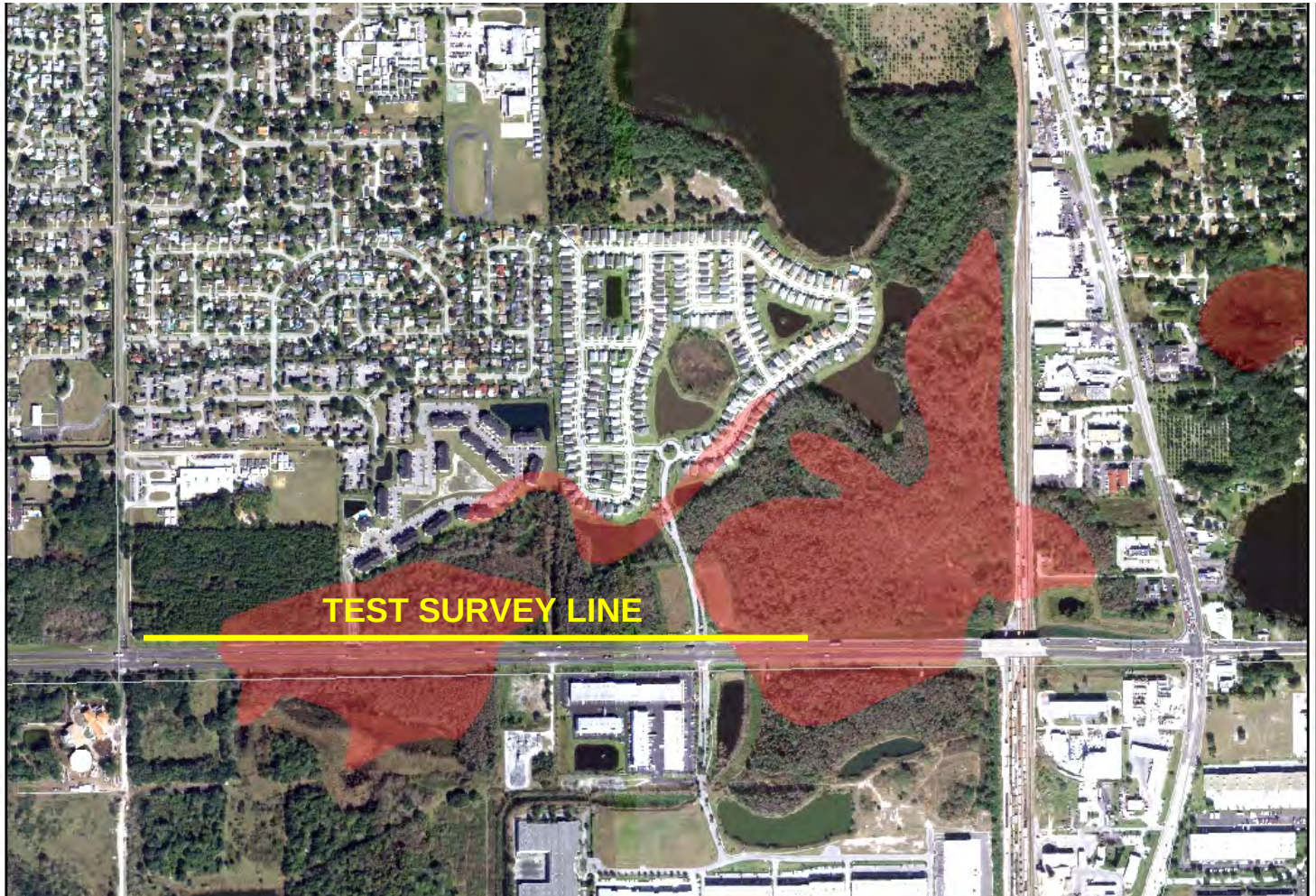
**BEAUCHAMP ROAD TEST SITE**





**GLEN HARWELL ROAD TEST SITE**





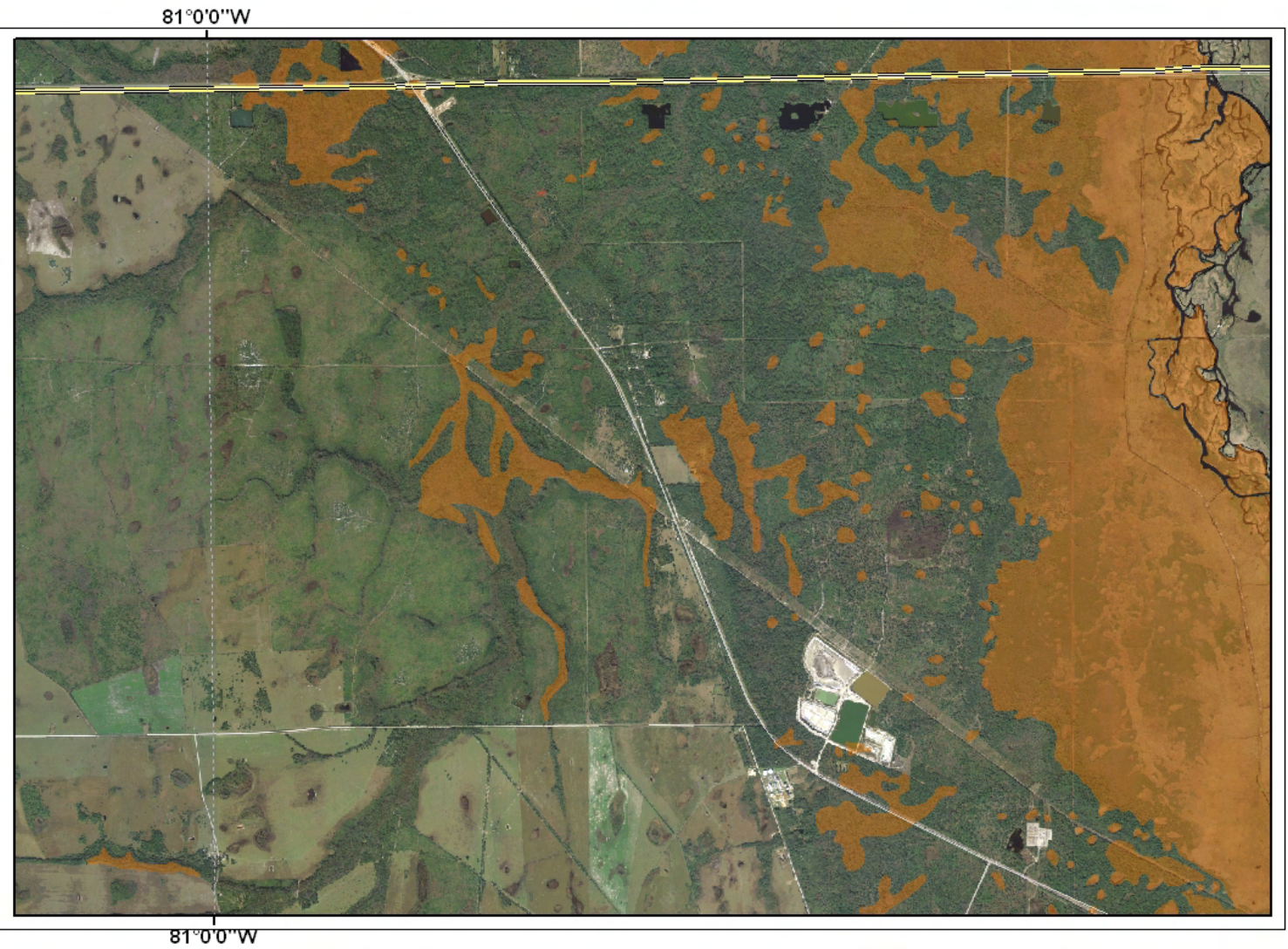
**SANDLAKE ROAD TEST SITE**





S.R. 520 TEST SITE



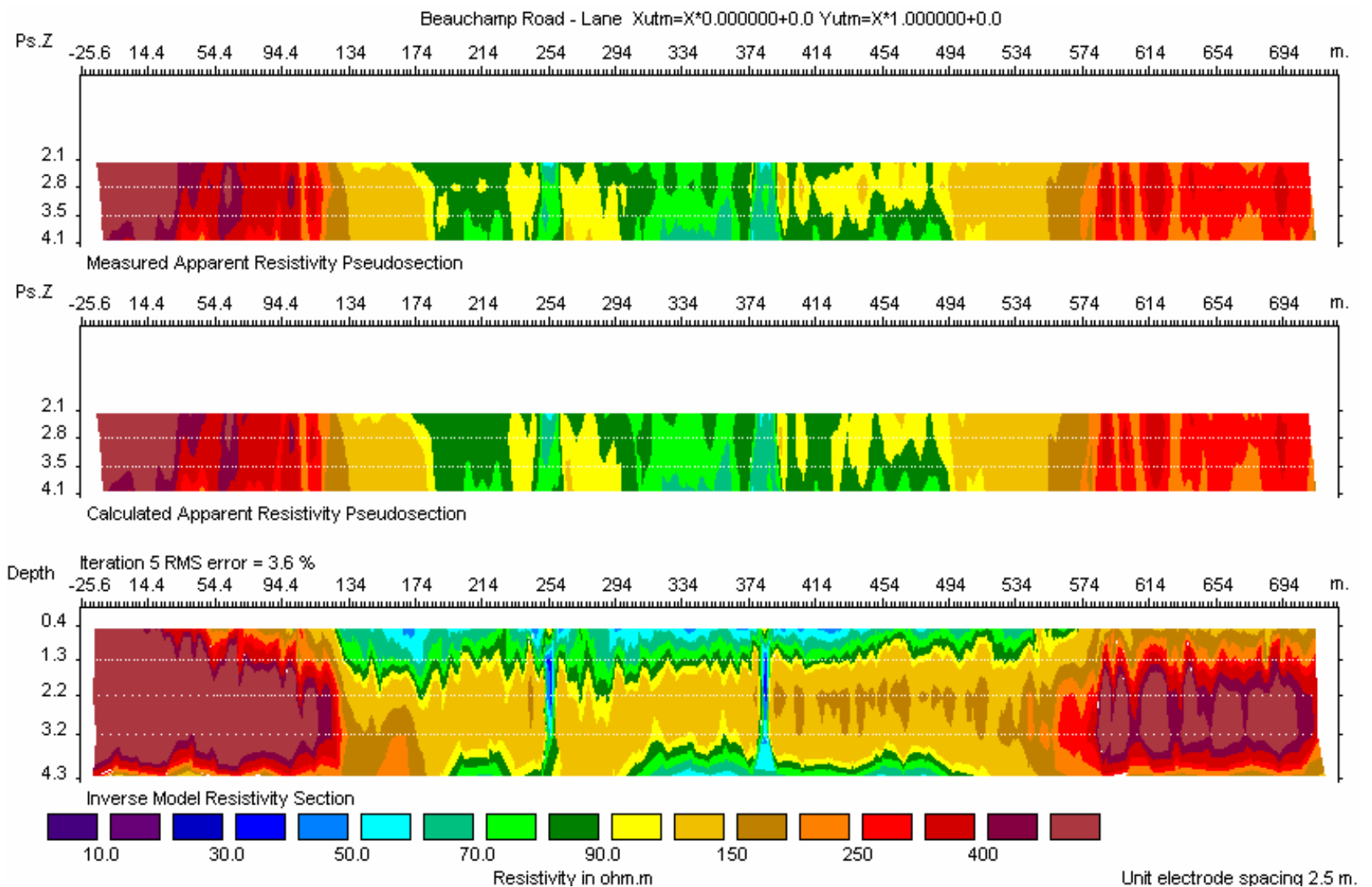


**S.R. 520 TEST SITE – CLAYEY SOILS (NRCS)**

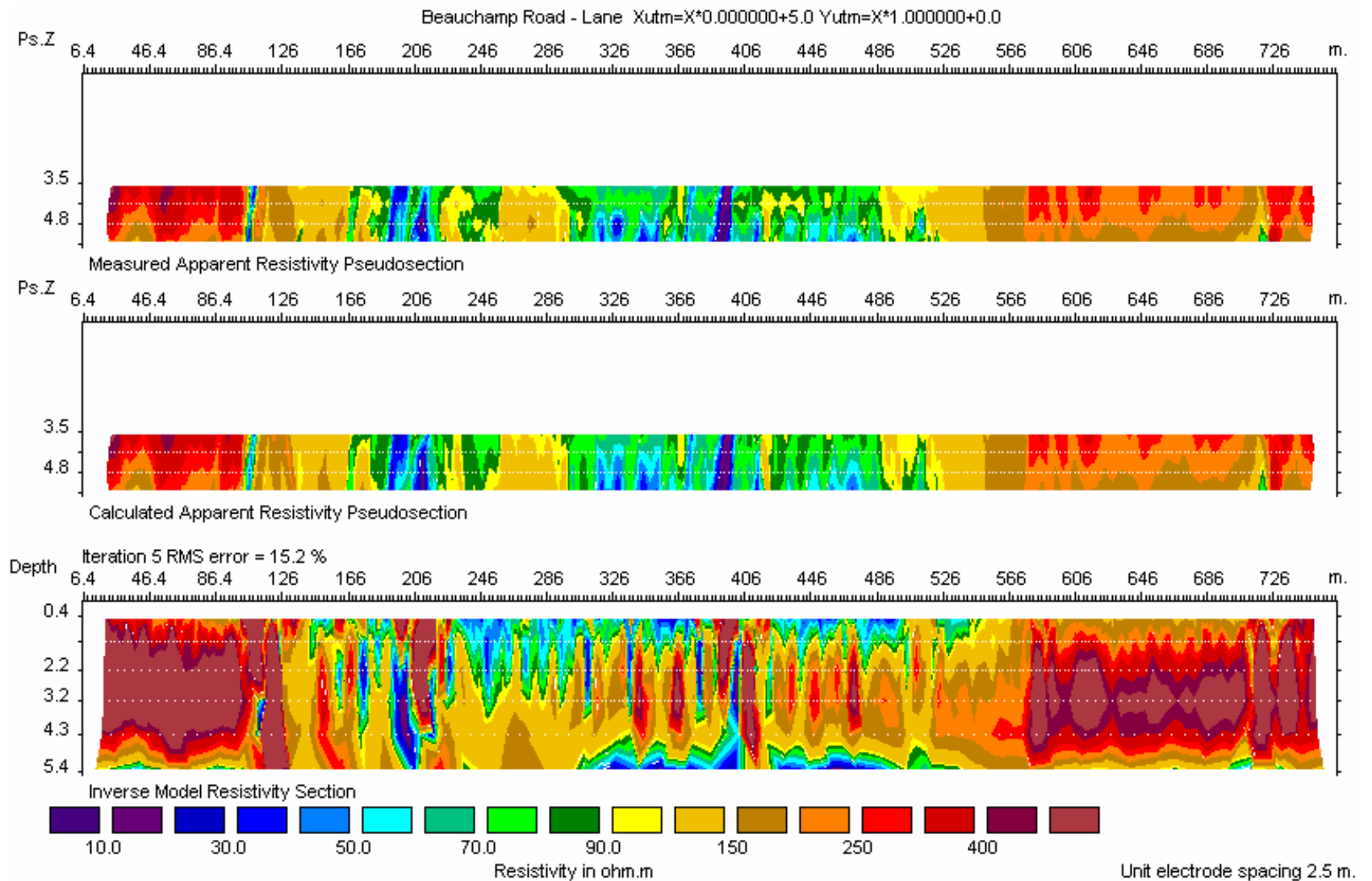


## **APPENDIX B**

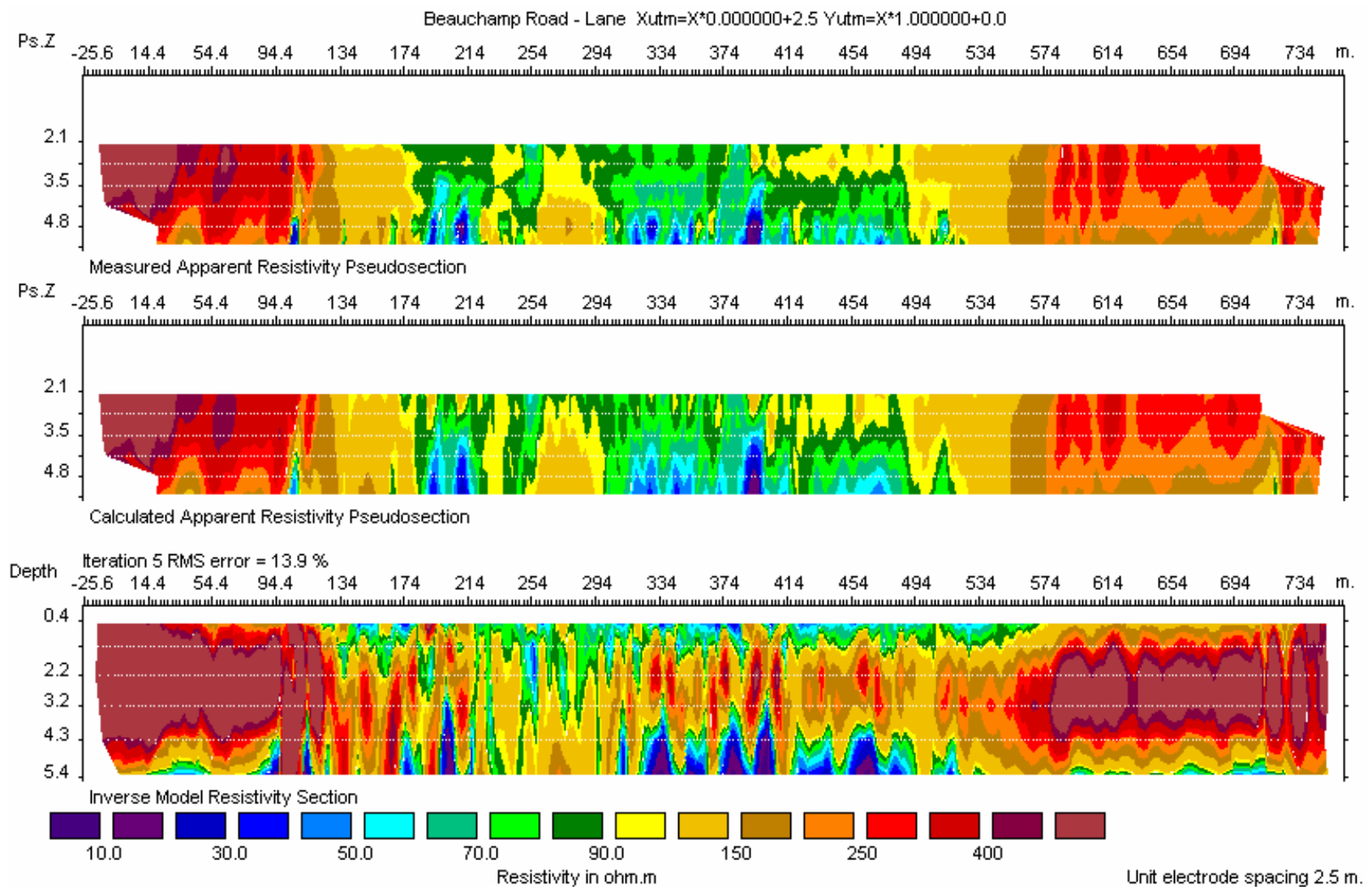
### **BEAUCHAMP ROAD TEST DATA**



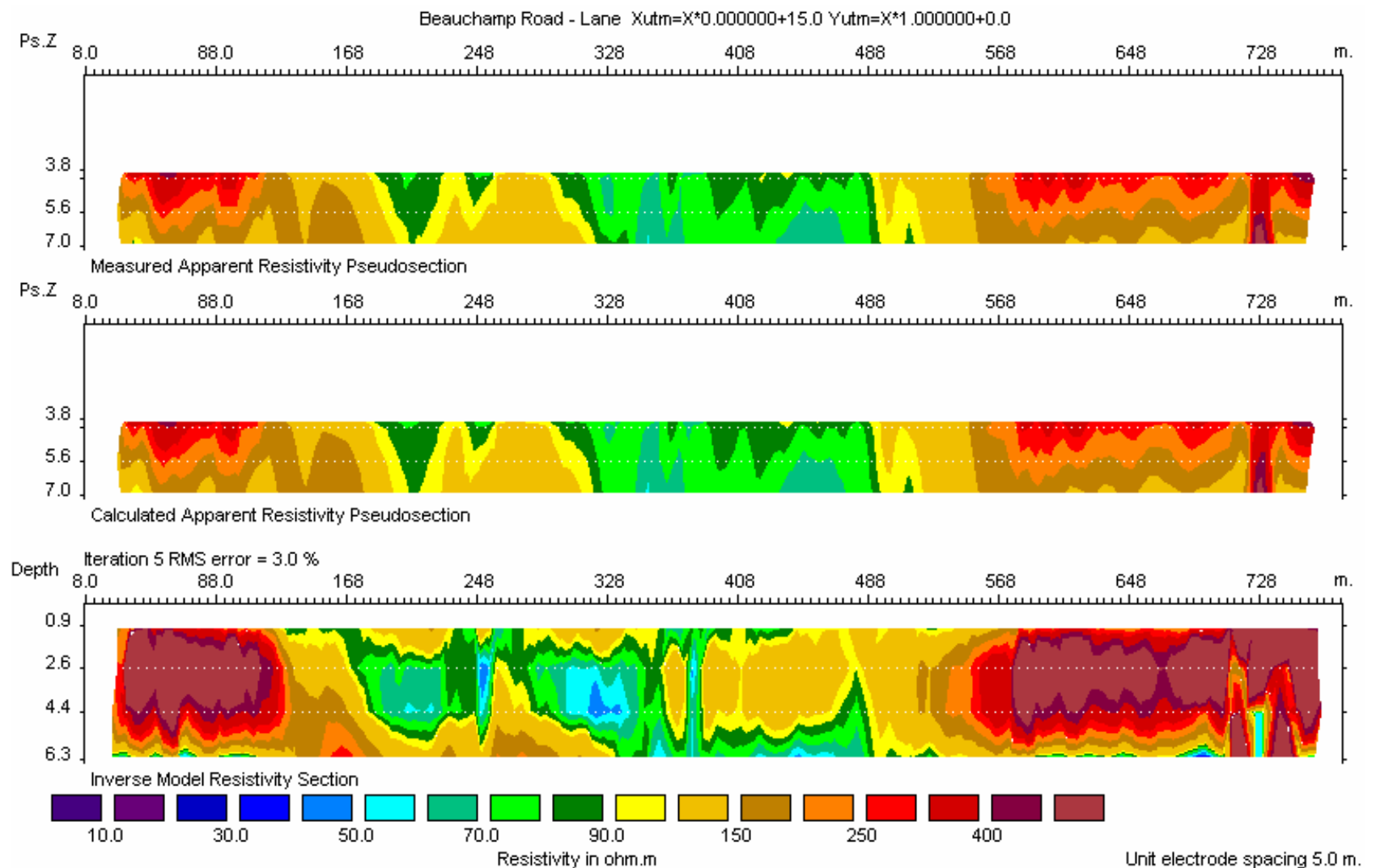
Pavement Pass 1 - 5m Dipole with 5m Rope



Pavement Pass 2 - 5m Dipole with 10m Rope

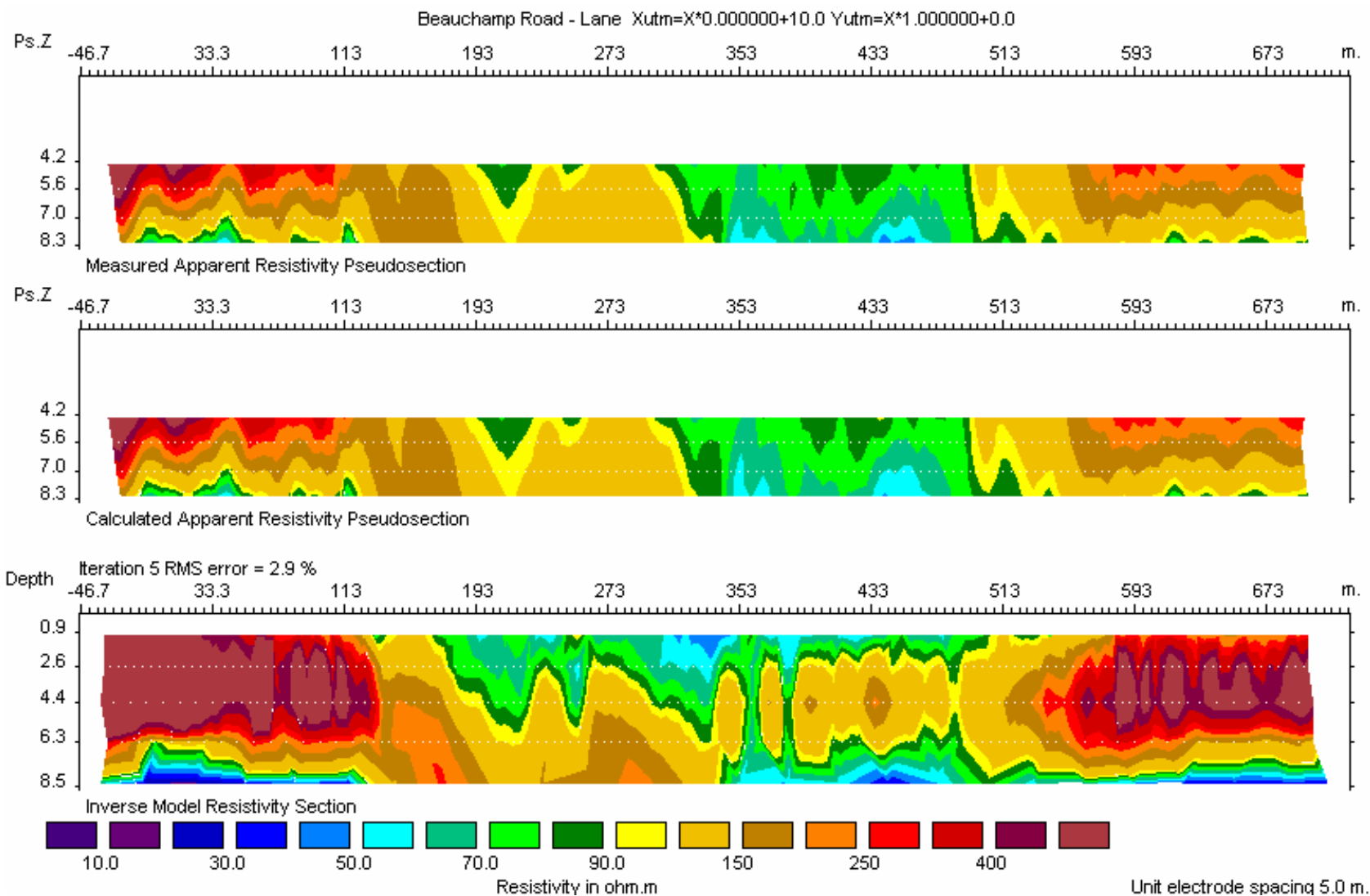


Combined Pavement Passes 1 and 2 (5m Dipoles)

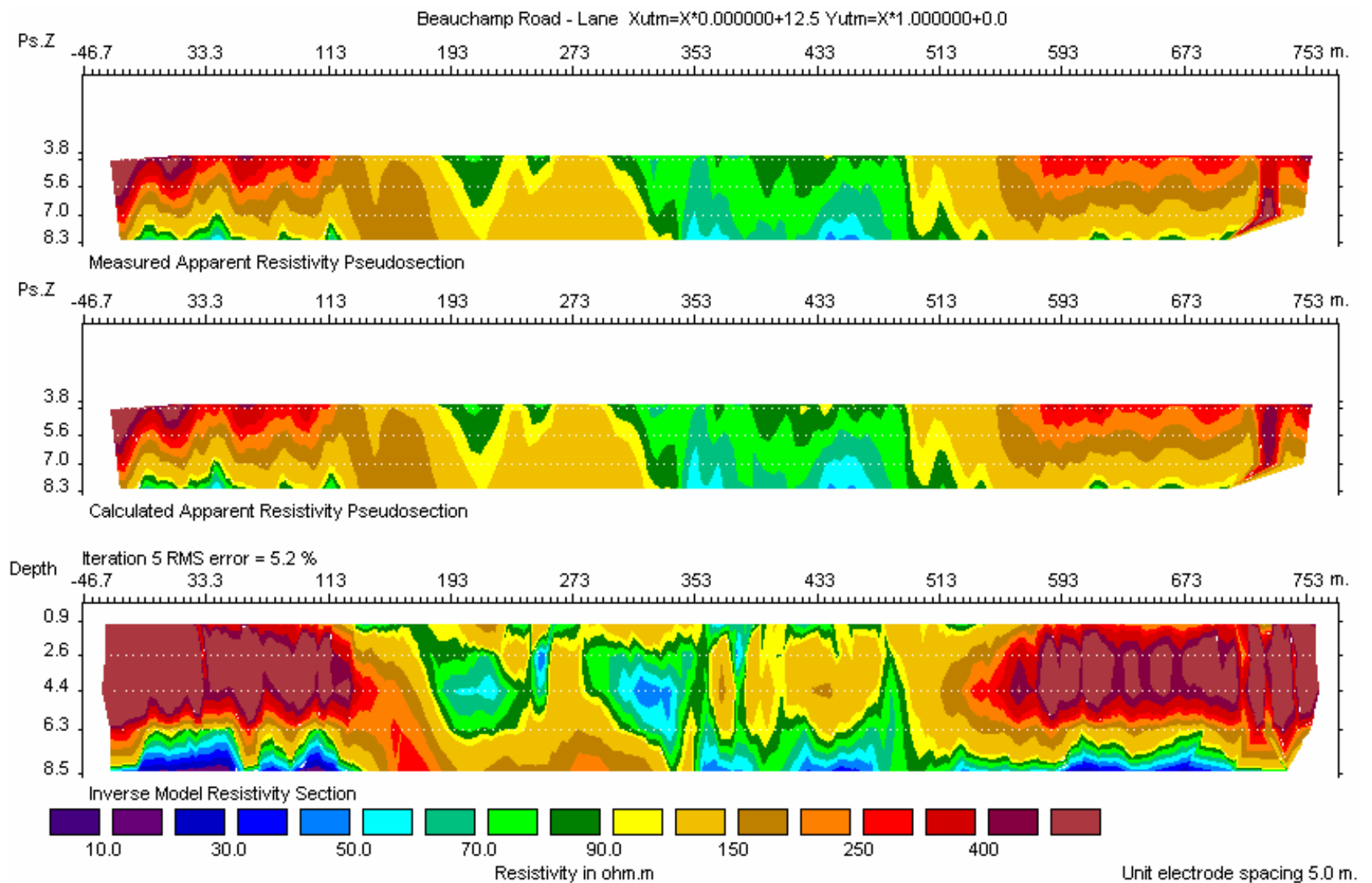


**Pavement Pass 3 - 10m Dipole with 5m Rope**

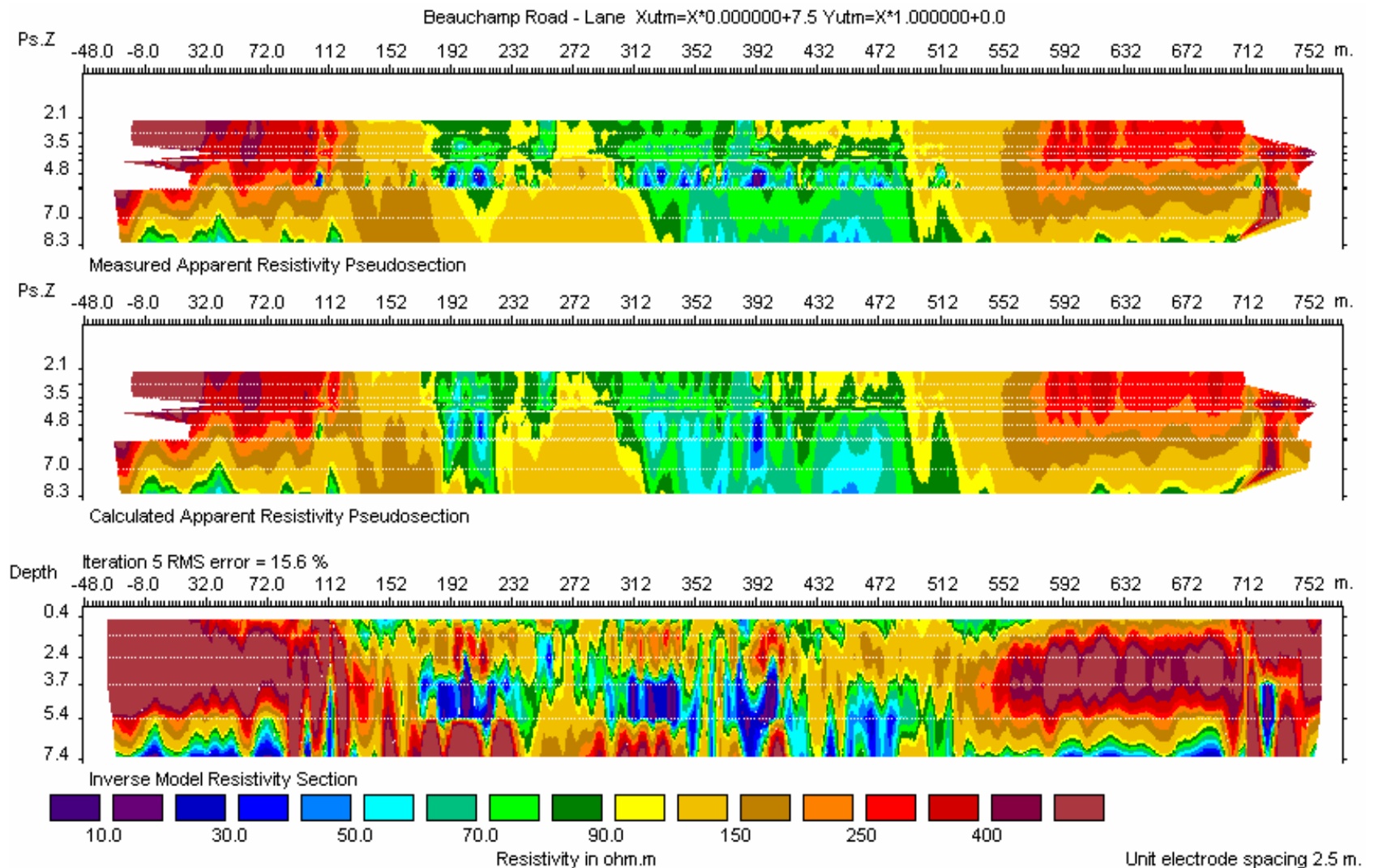




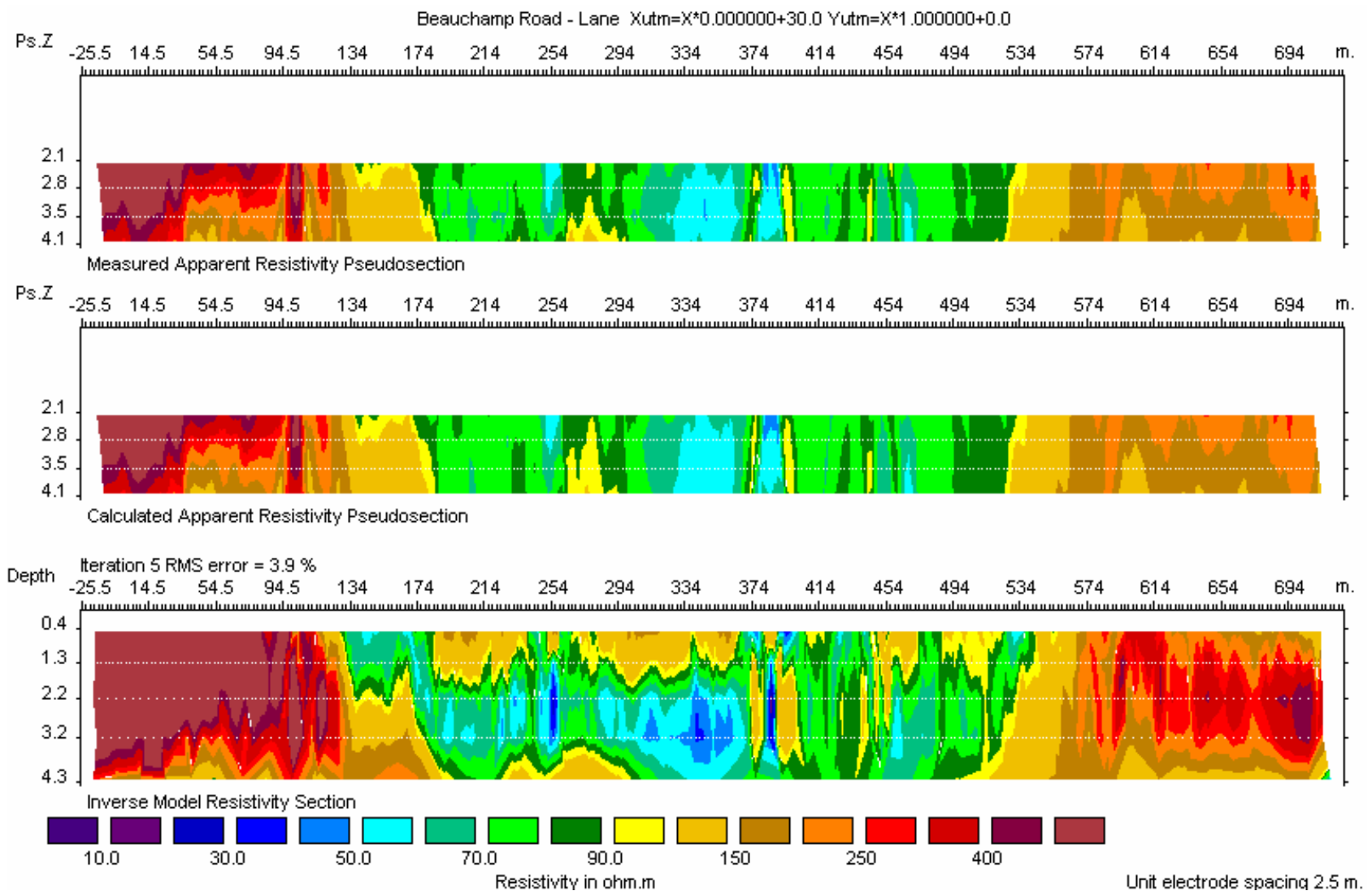
Pavement Pass 4 - 10m Dipole with 10m Rope



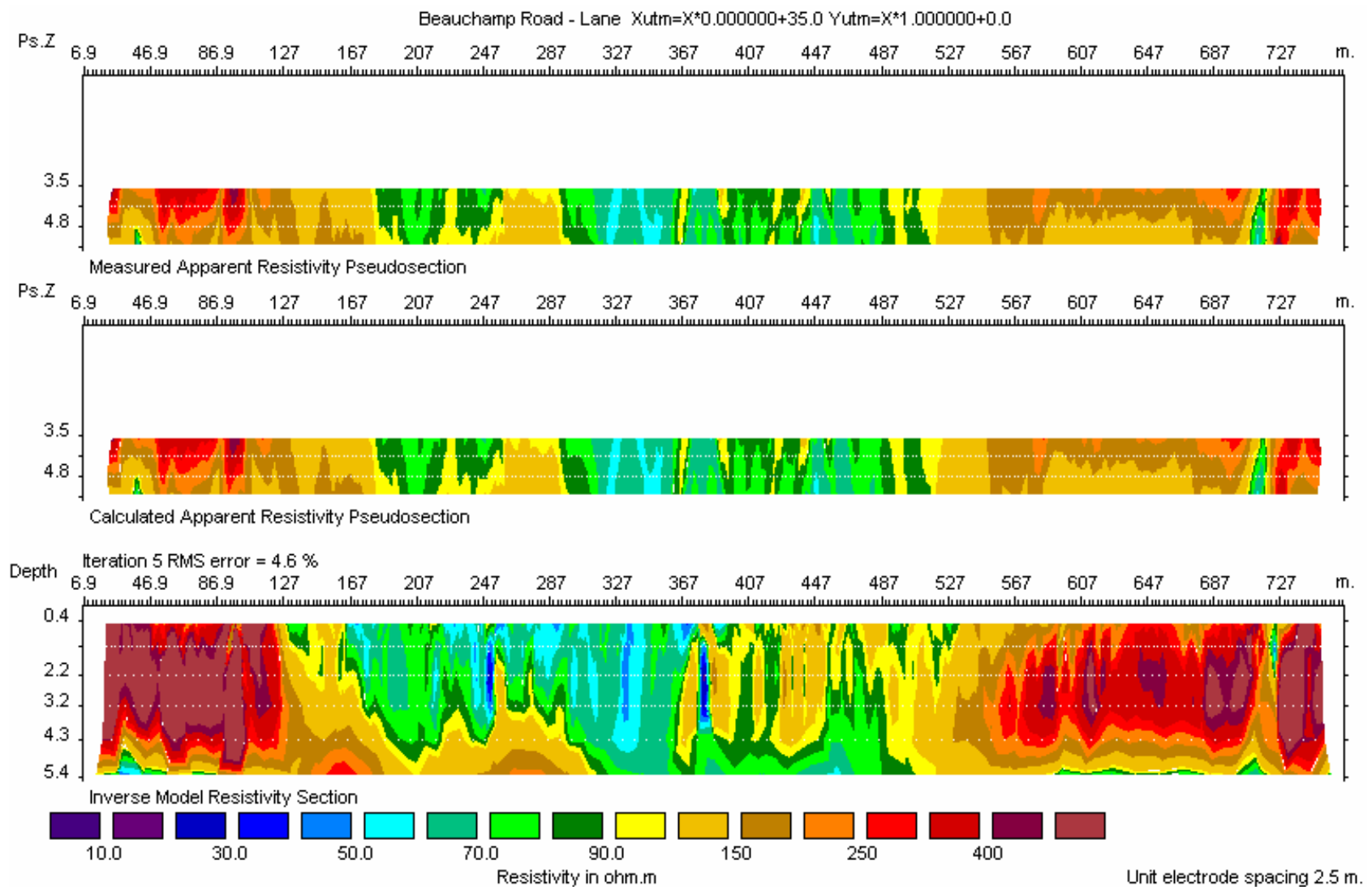
Combined Pavement Passes 3 and 4 (10m Dipoles)



Combined Pavement Passes 1 Through 4

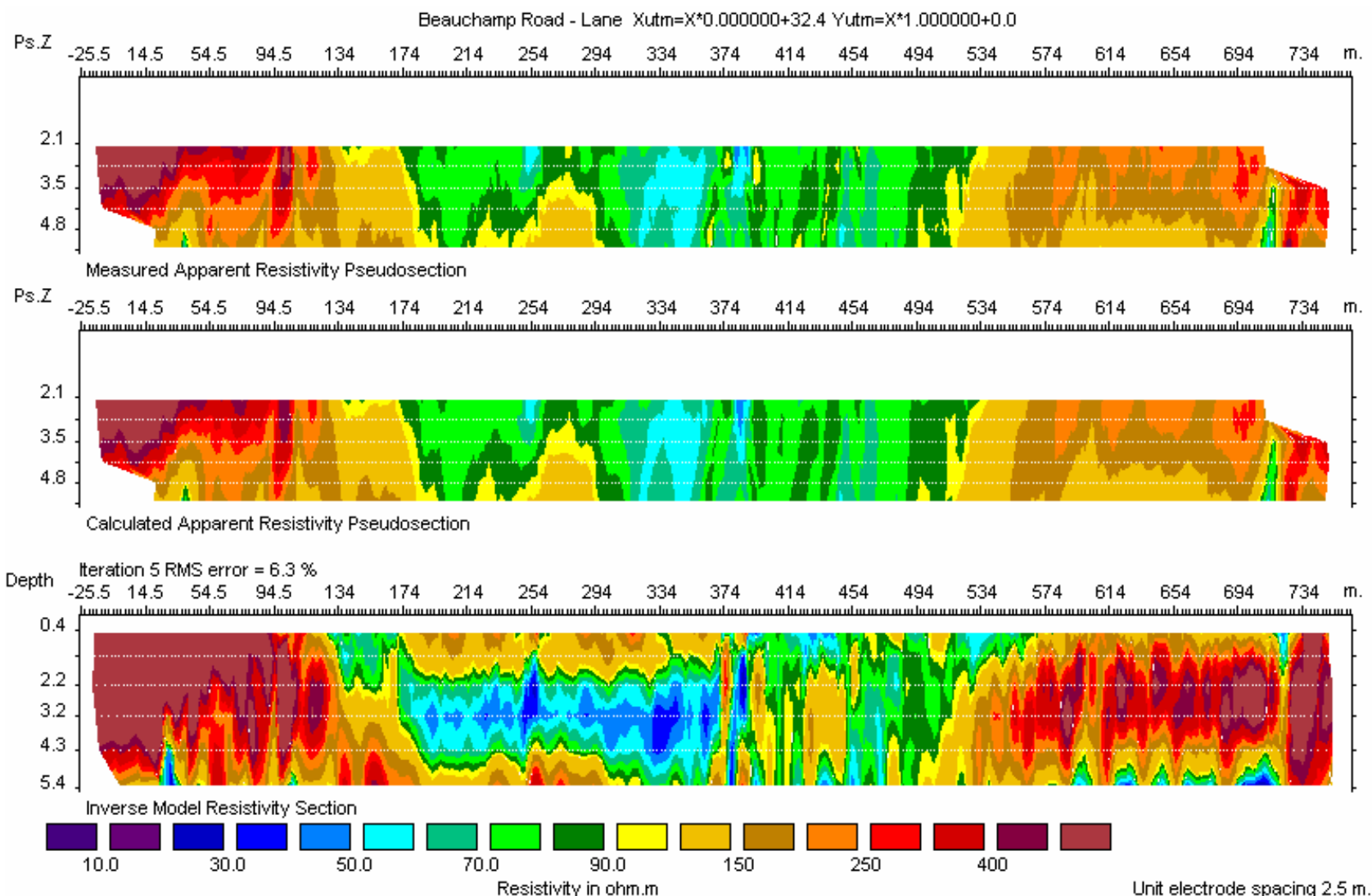


Shoulder Pass 1 - 5m Dipole with 5m Rope

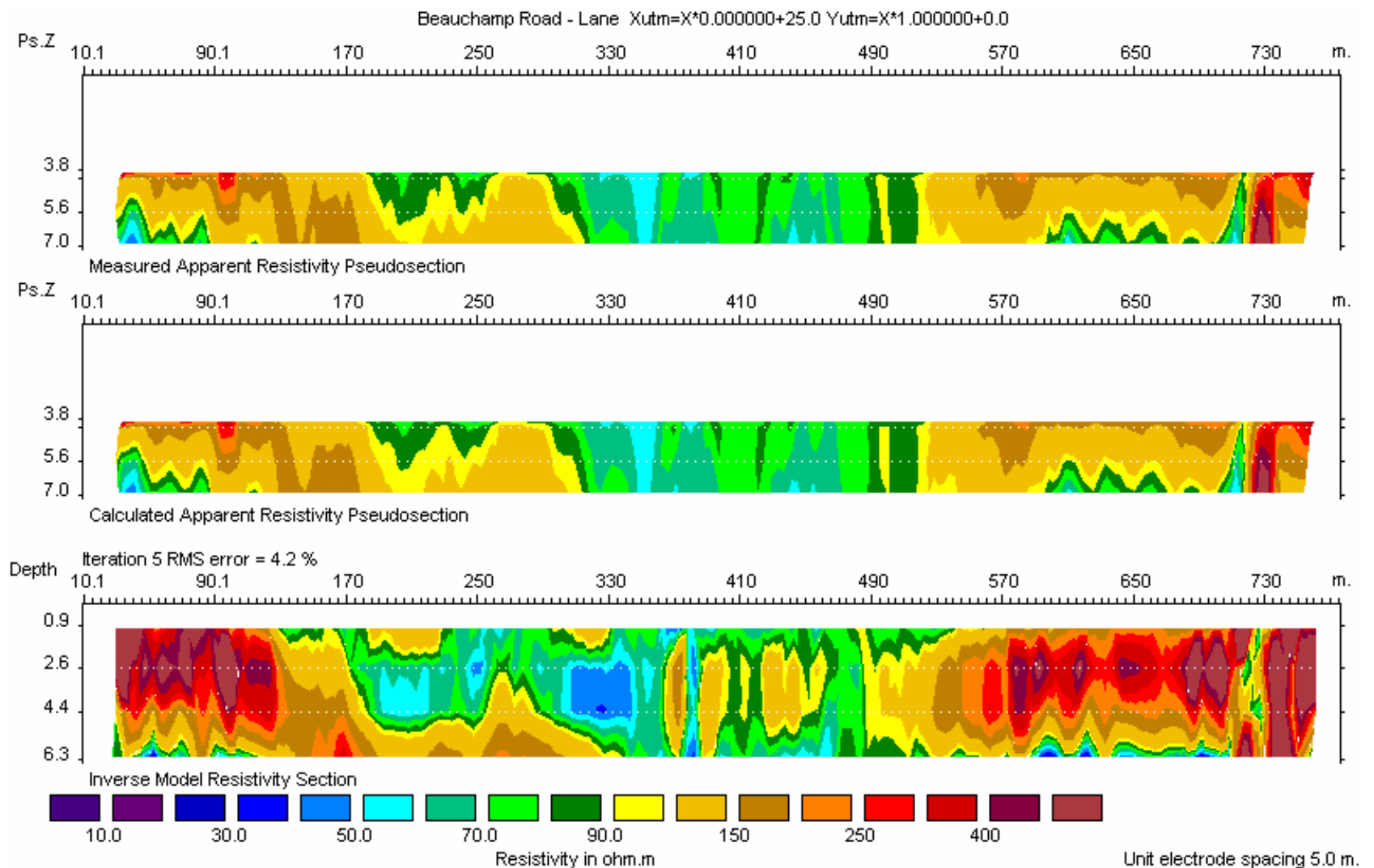


Shoulder Pass 2 - 5m Dipole with 10m Rope

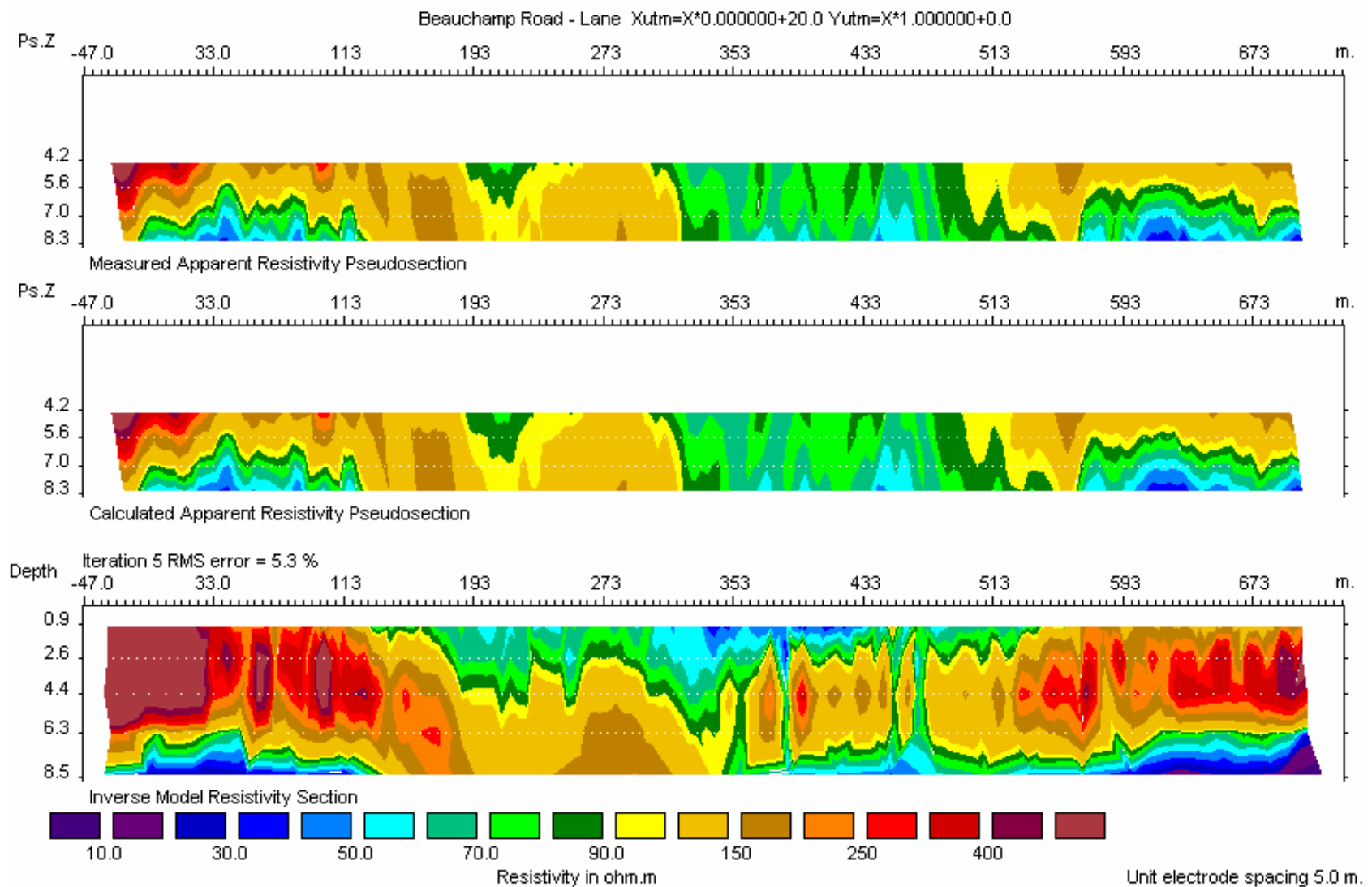




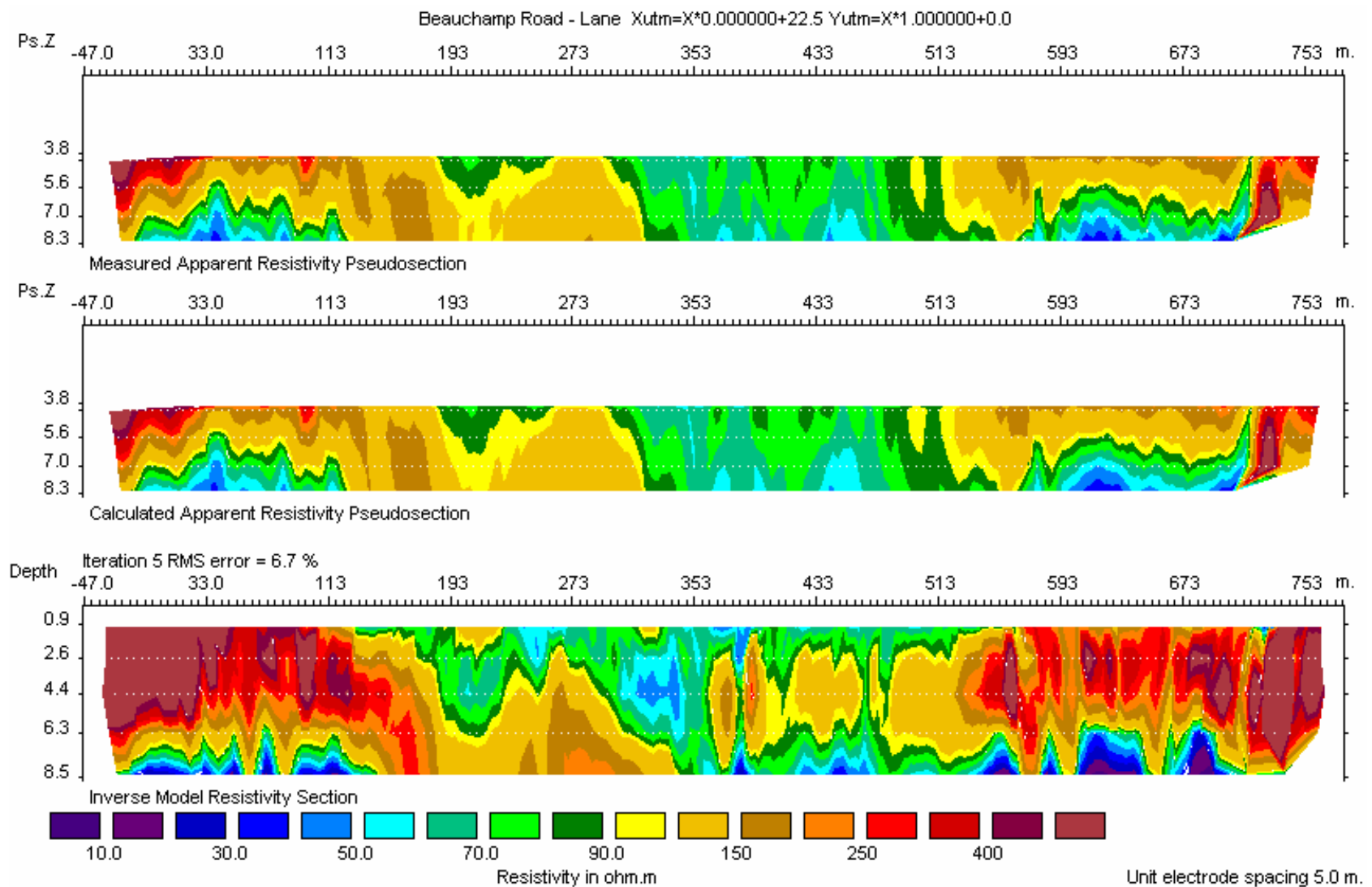
Combined Shoulder Passes 1 and 2 (5m Dipoles)



Shoulder Pass 3 - 10m Dipole with 5m Rope

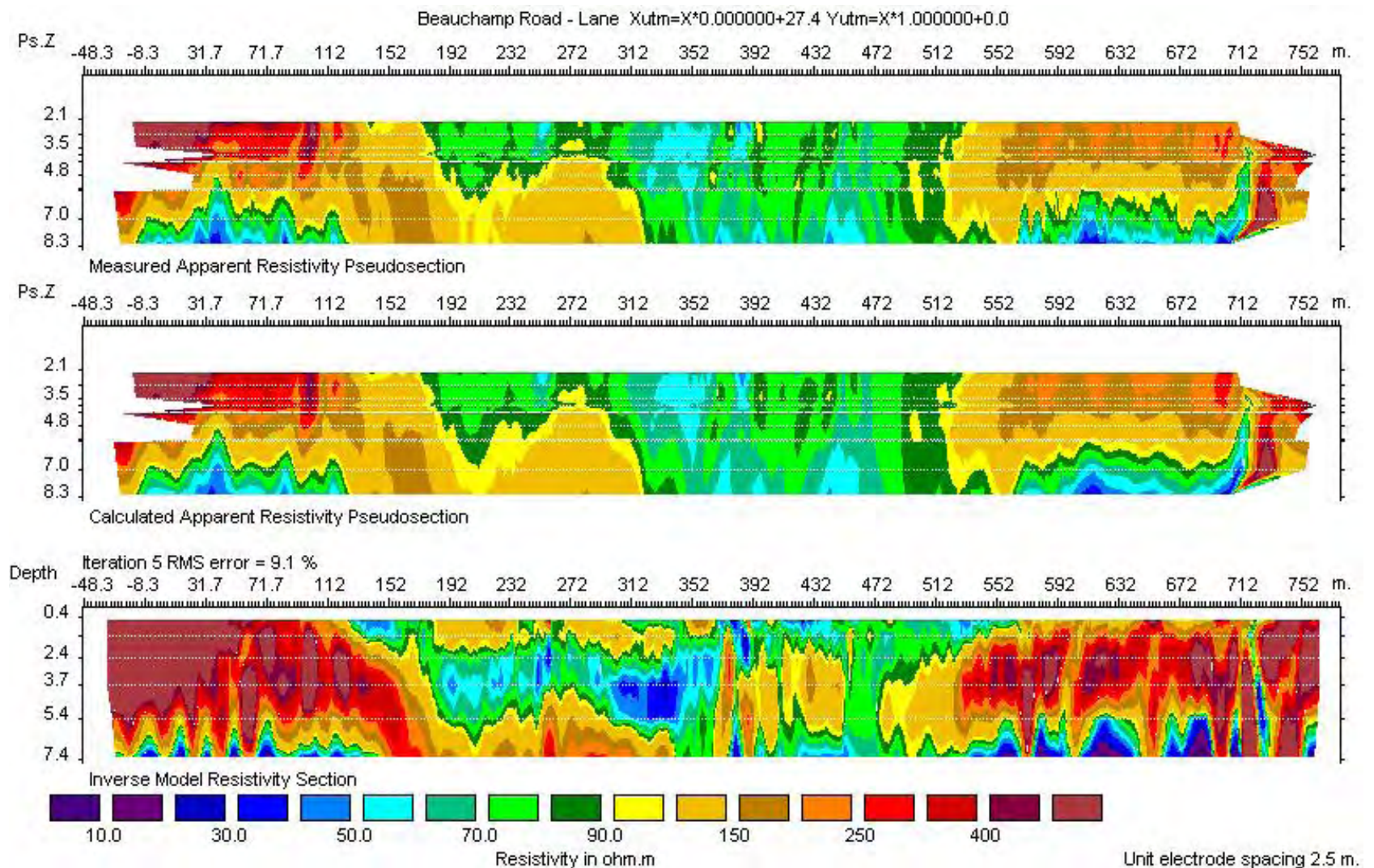


Shoulder Pass 4 - 10m Dipole with 10m Rope



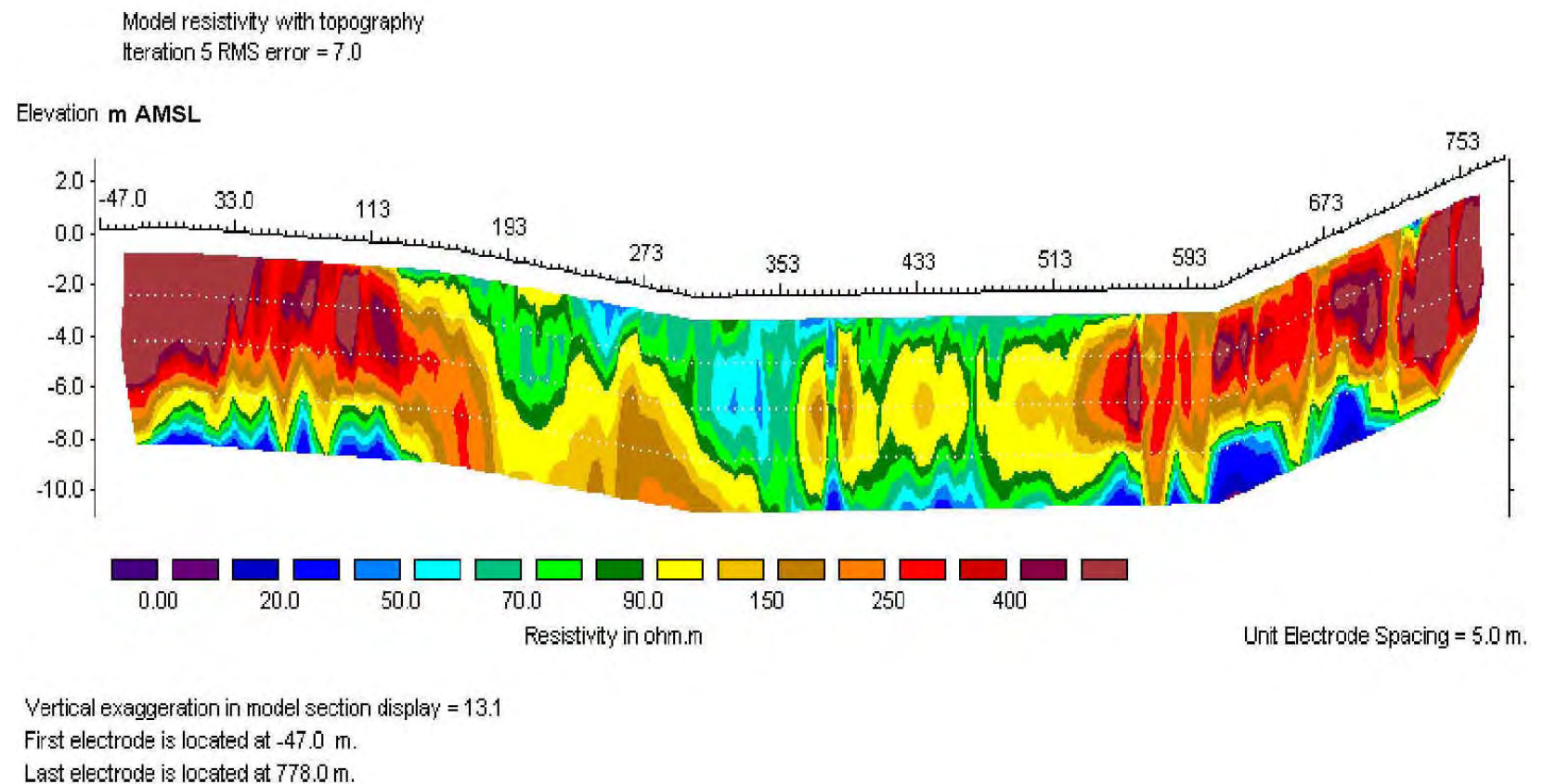
Combined Shoulder Passes 3 and 4 (10m Dipoles)





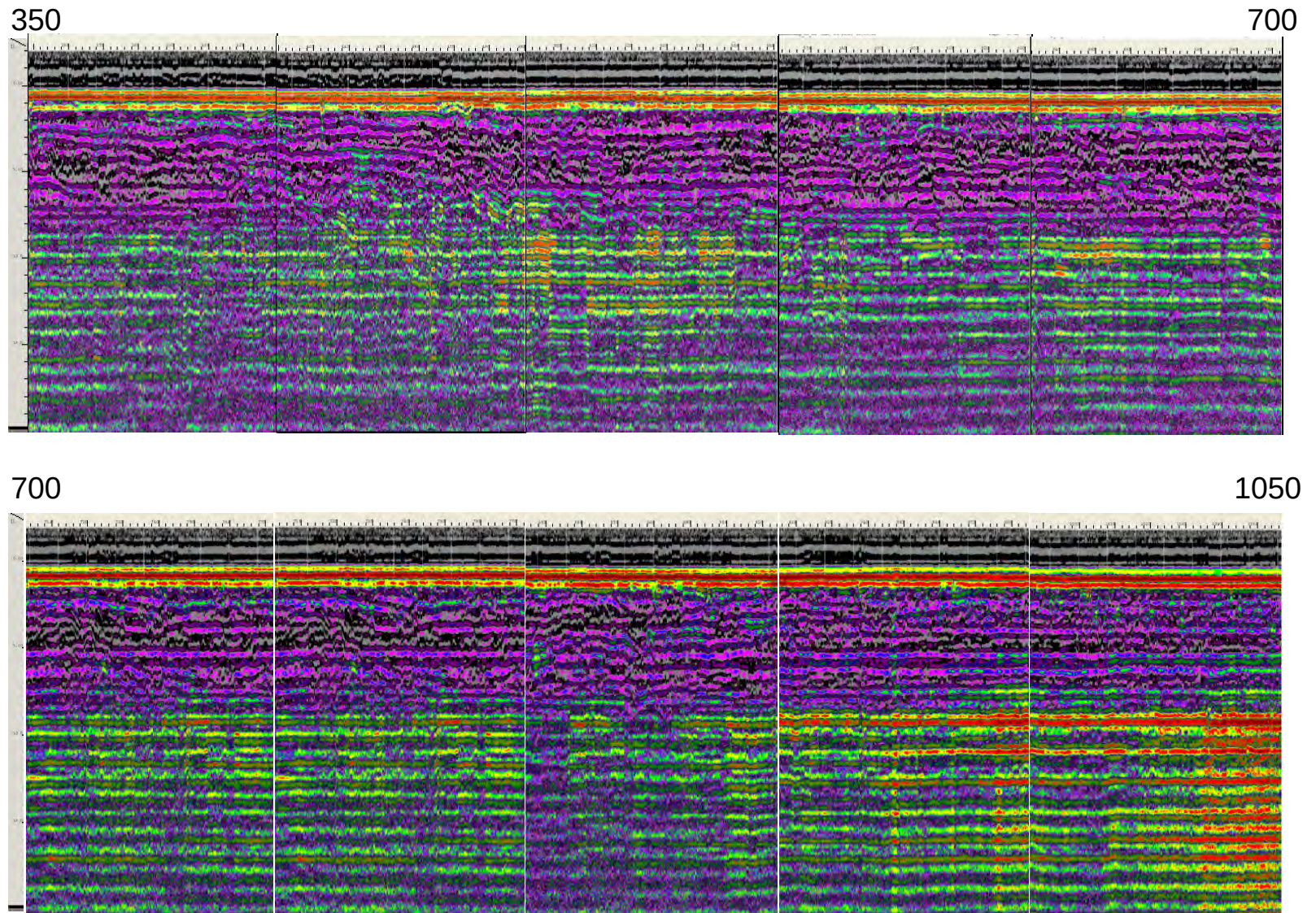
Combined Shoulder Passes 1 Through 4





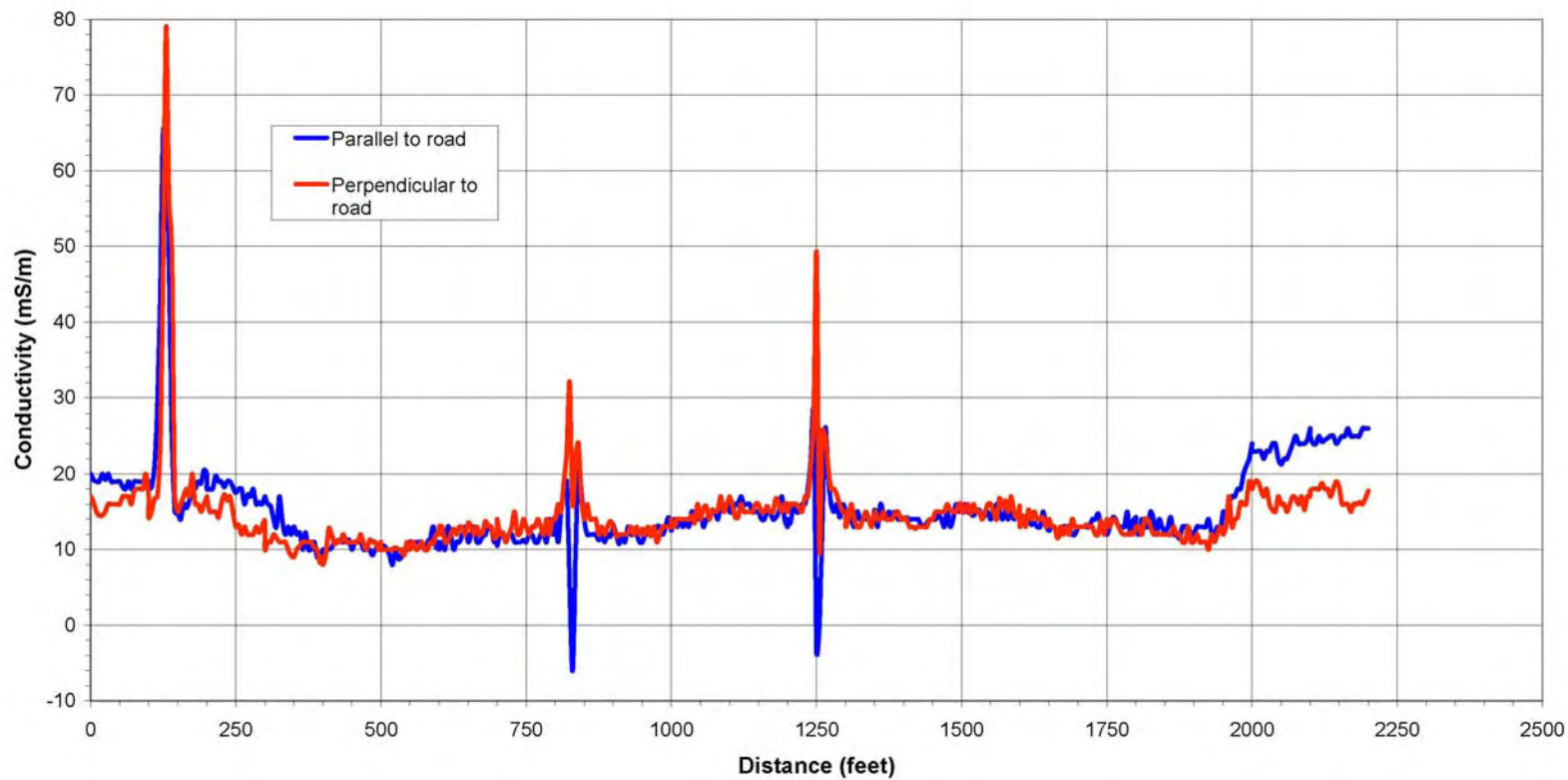
**Pavement Pass 3 – Approximate Elevation Profile Using  
USGS Quadrangle Map Topography**



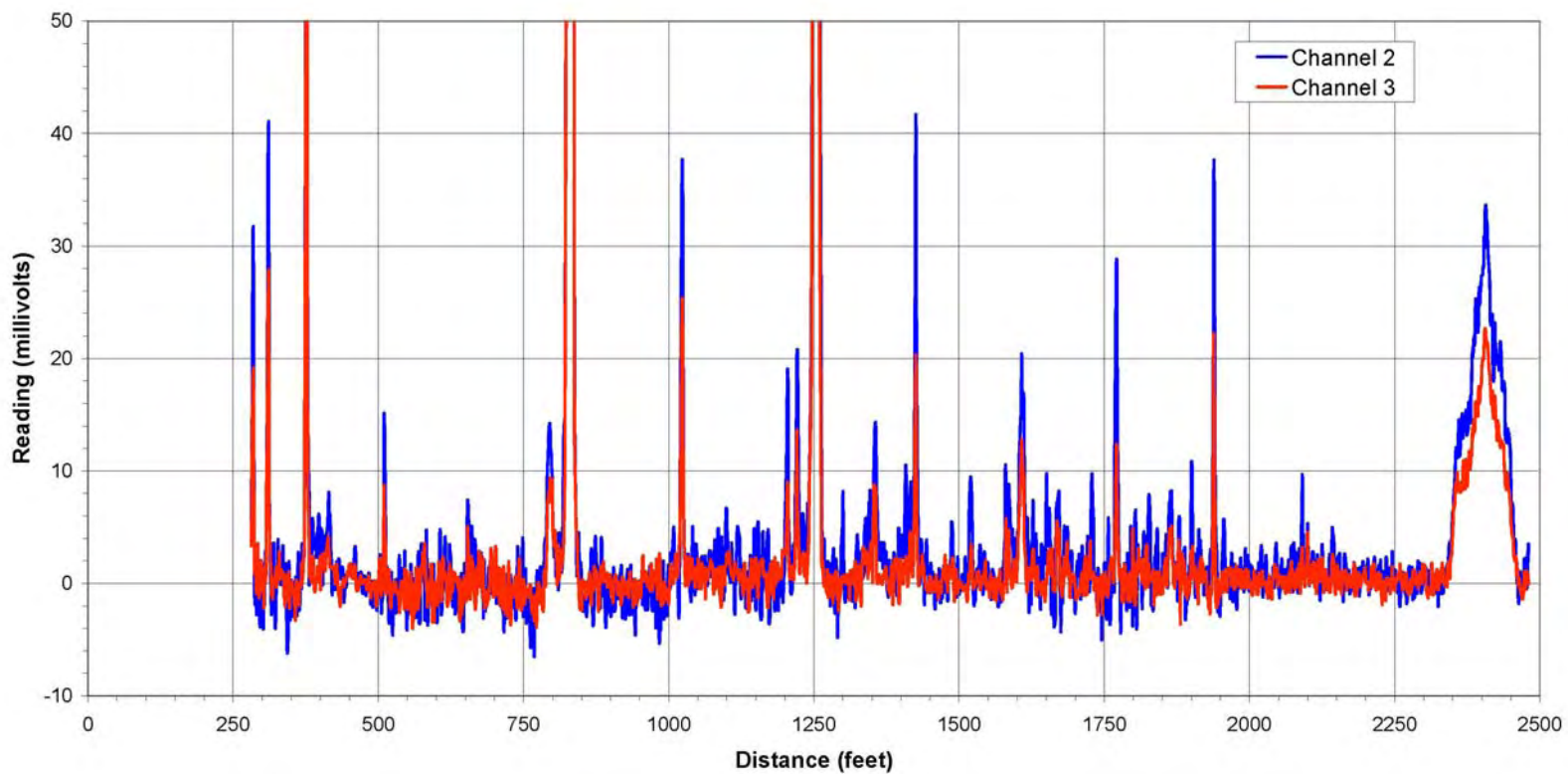


GPR Results (350- 1050 Feet)

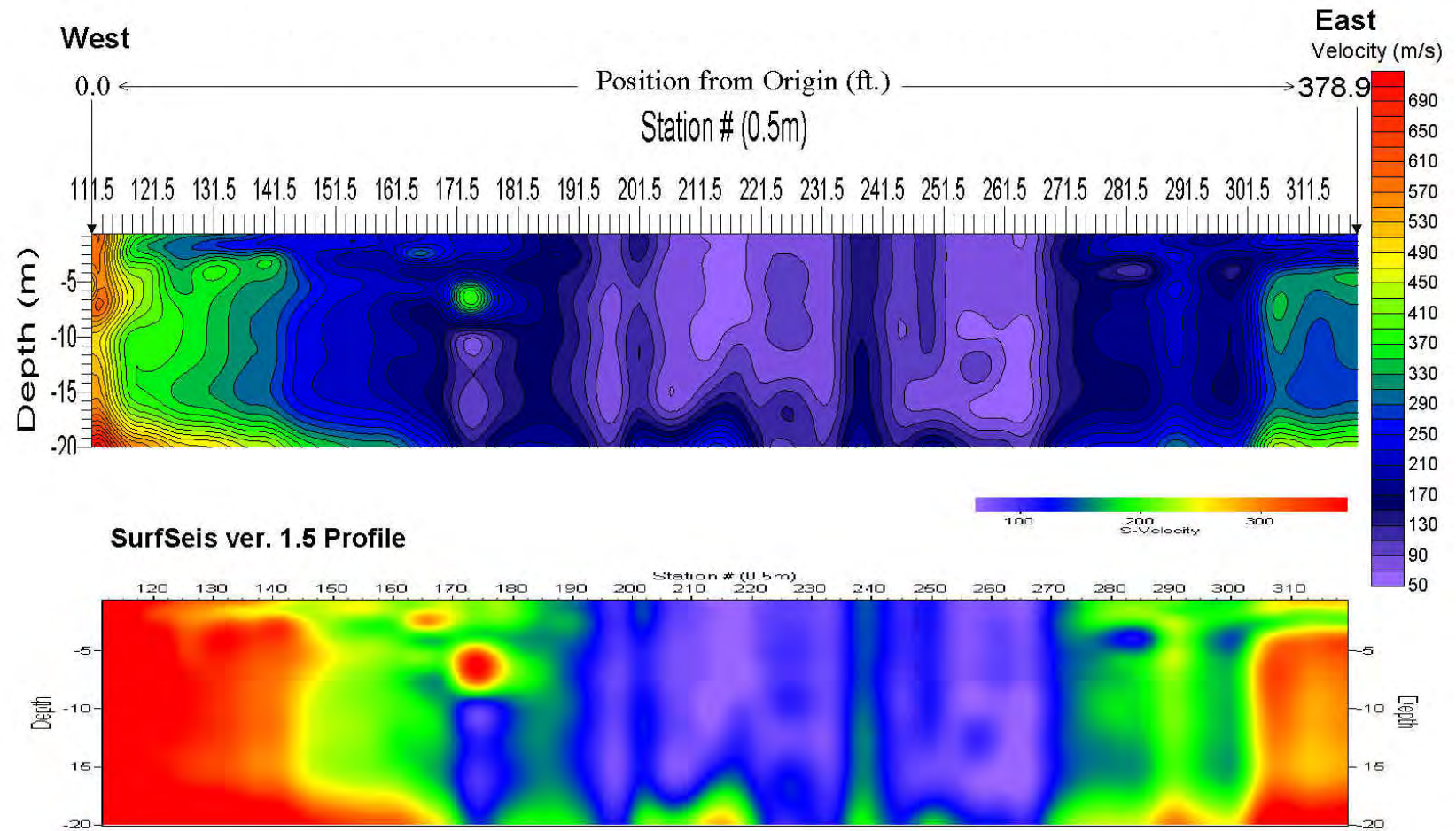




Geonics EM-31 Terrain Conductivity Survey



**Geonics EM-61 Terrain Conductivity Survey**

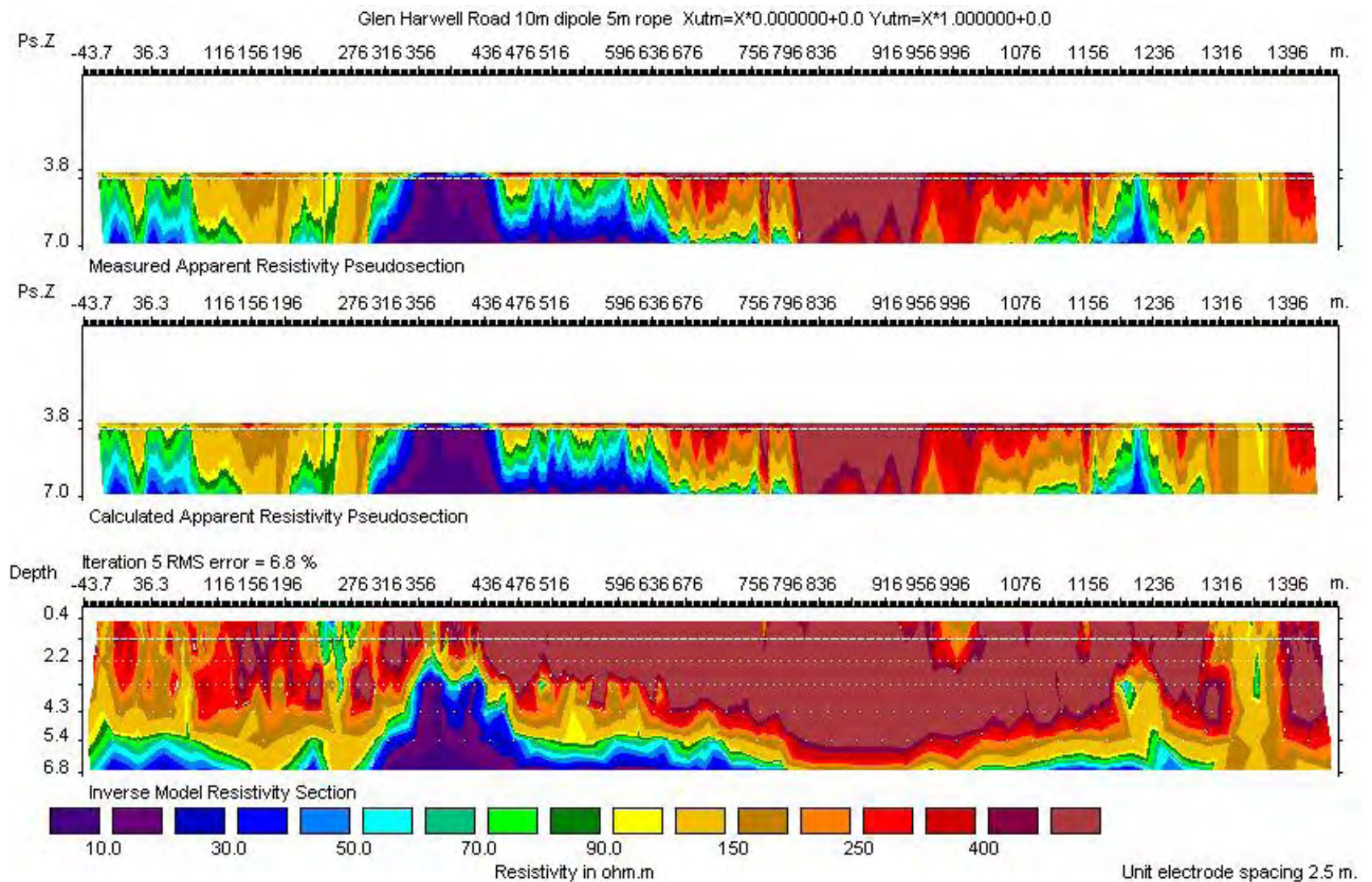


Shear Velocity Profile From MASW Survey

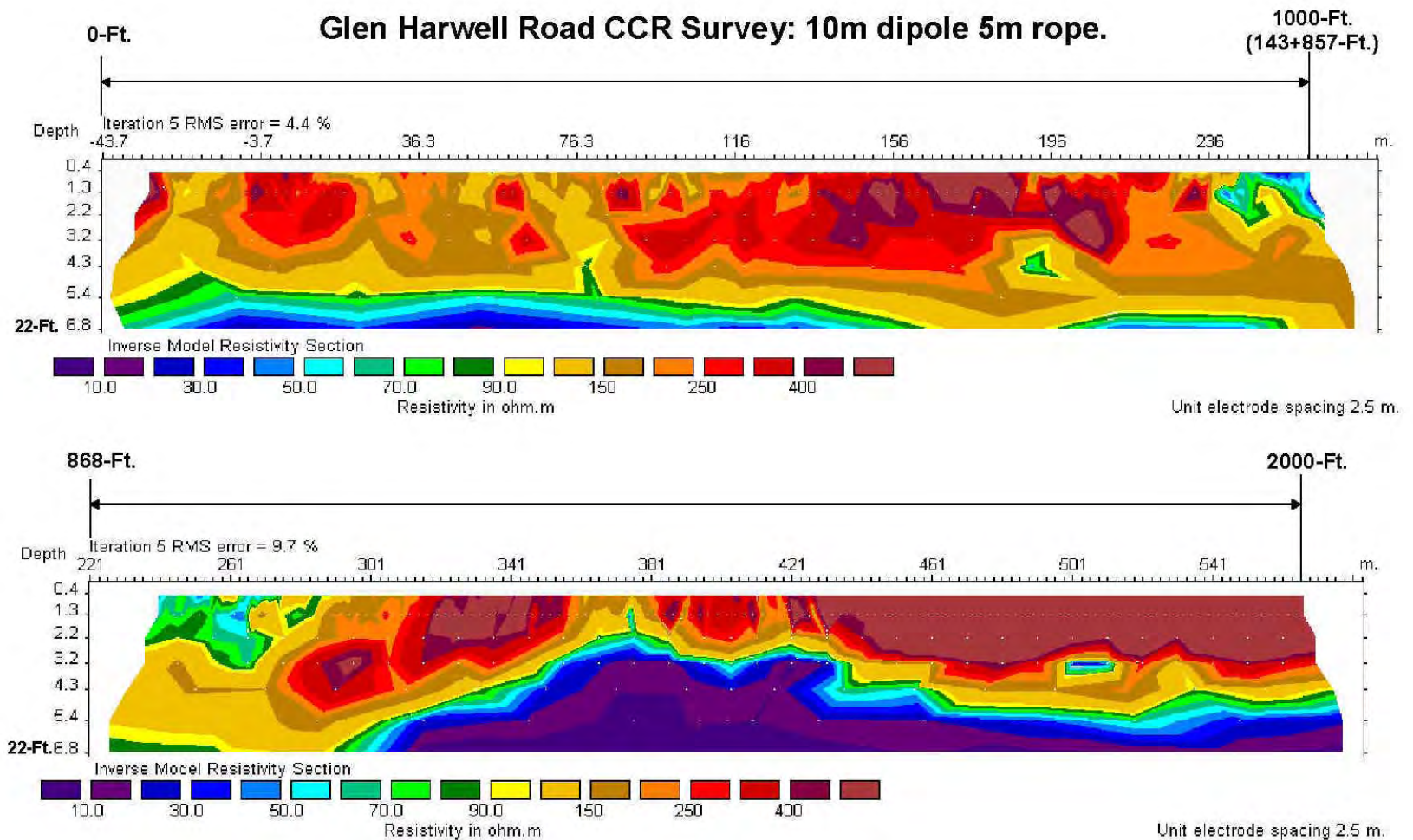


## **APPENDIX C**

### **GLEN HARWELL ROAD TEST DATA**

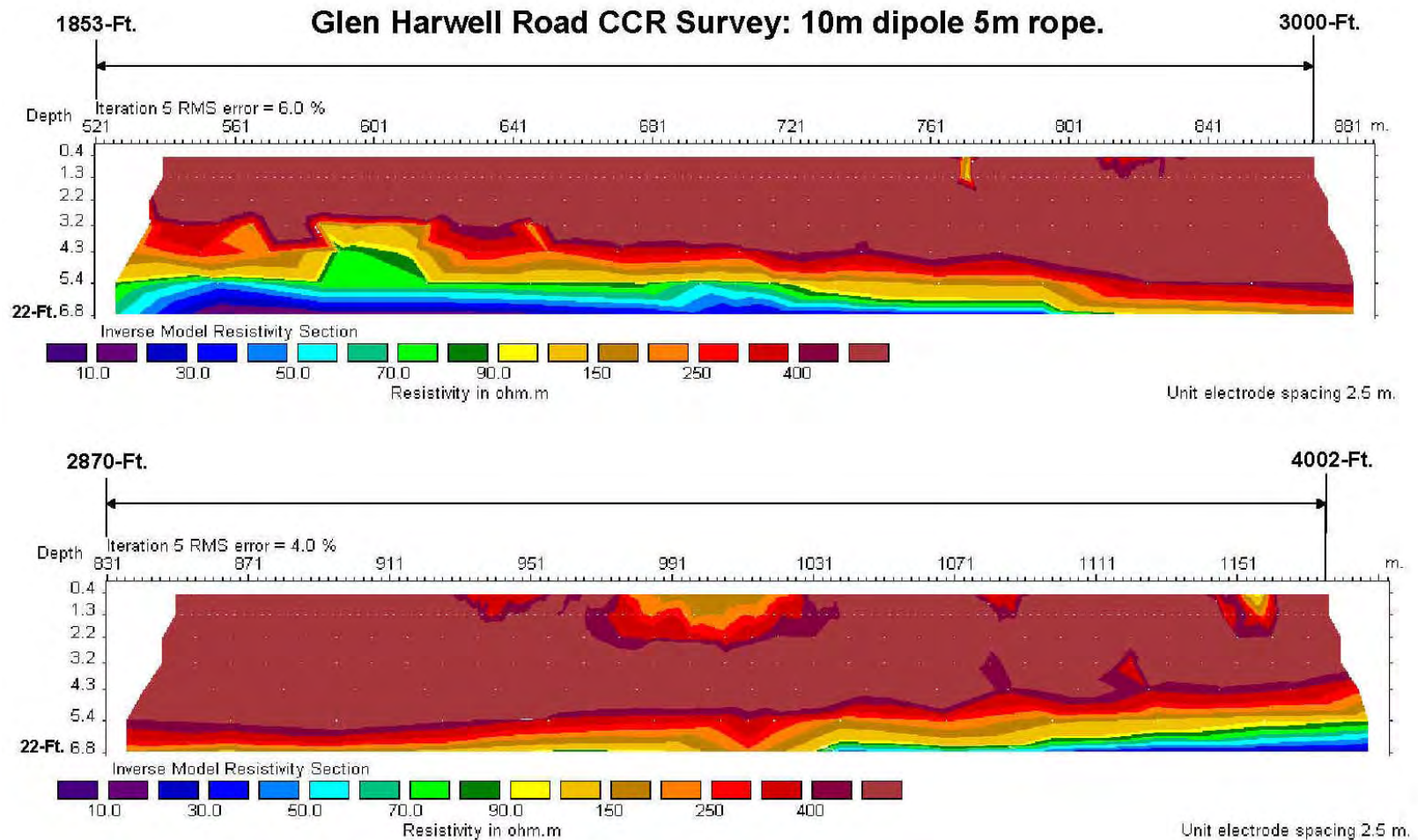


Pass 1 - 10m Dipole with 5m Rope

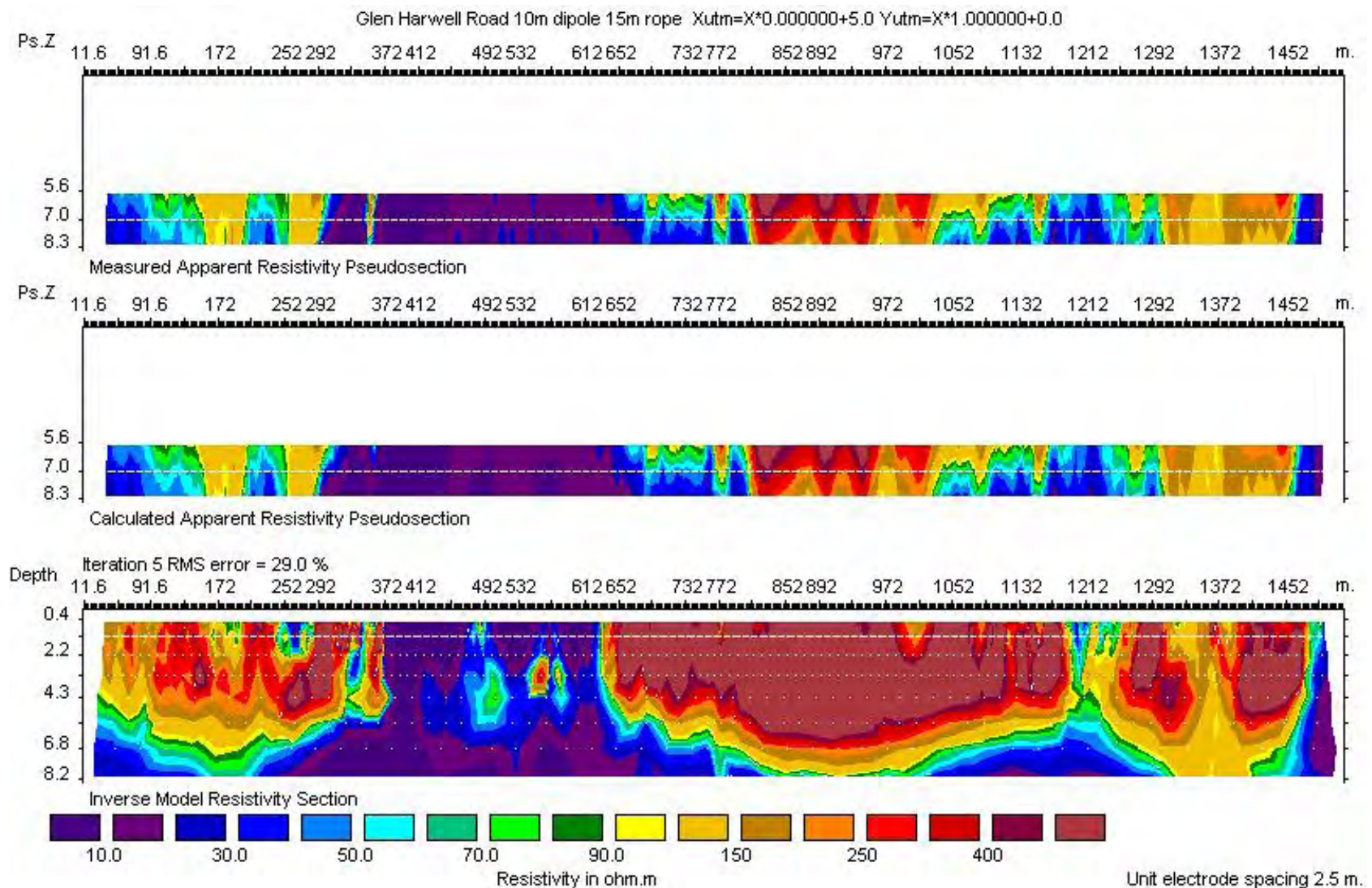


**Pass 1 – Extended Scale Plots (0-2000 feet)**



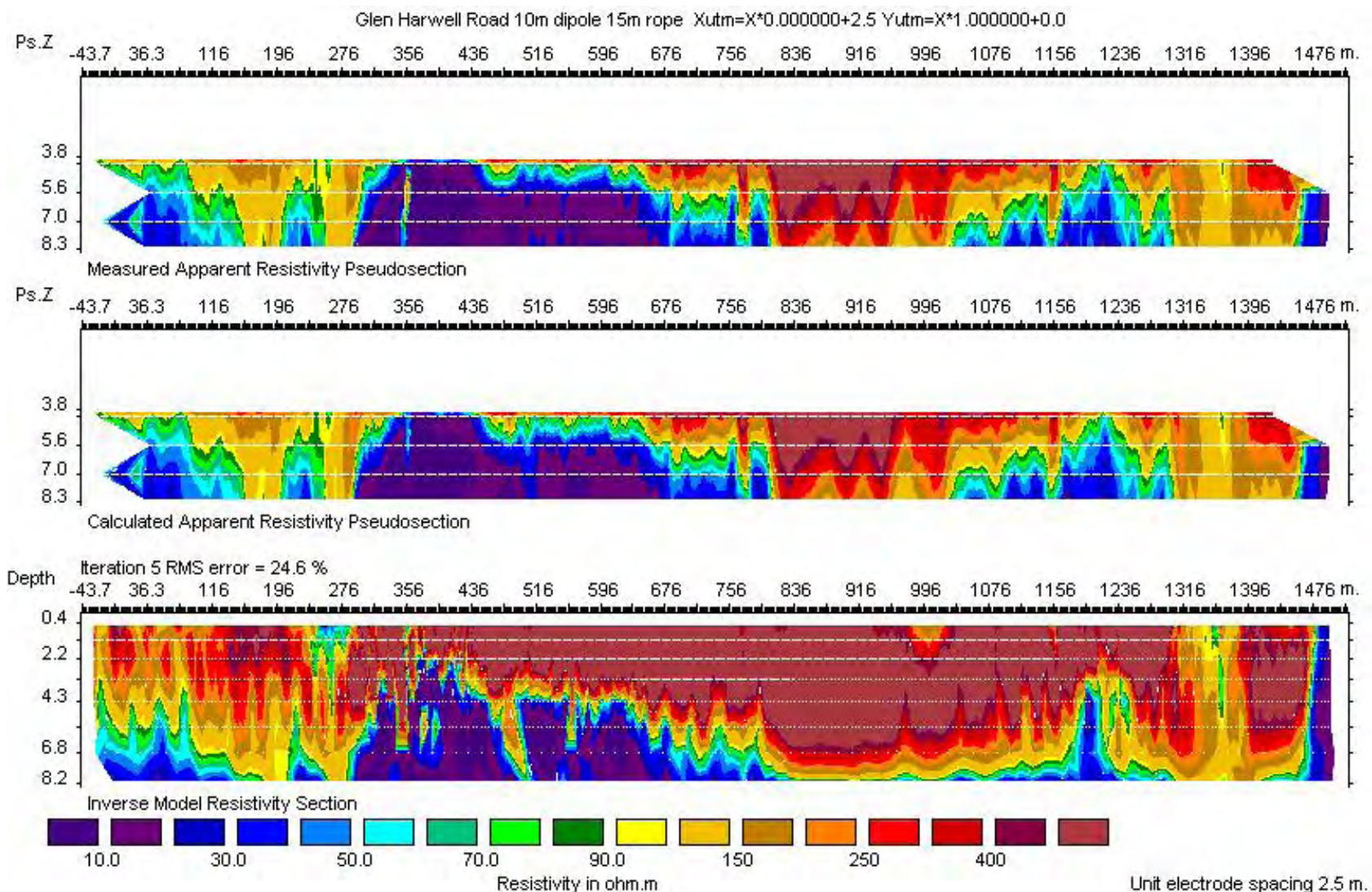


**Pass 1 – Extended Scale Plots (2000-4000 feet)**

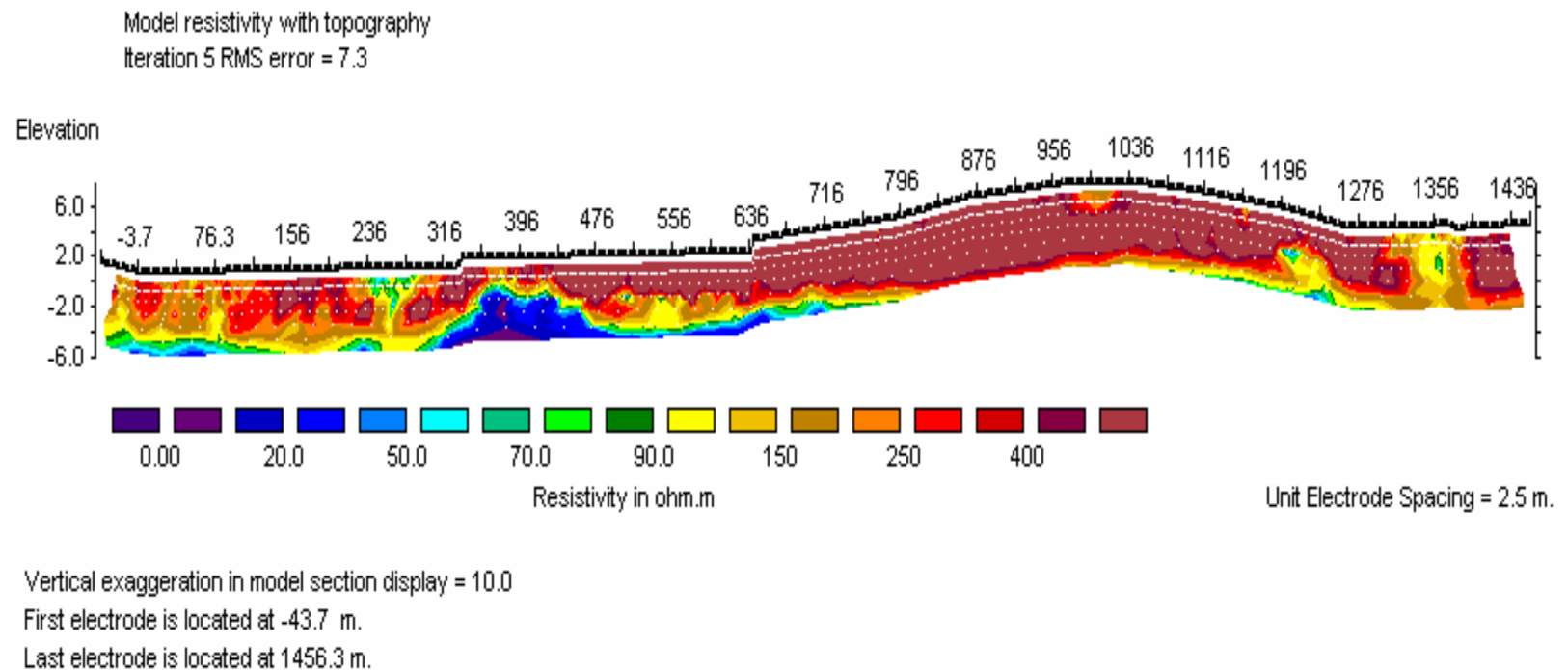


Pass 2 - 10m Dipole with 15m Rope



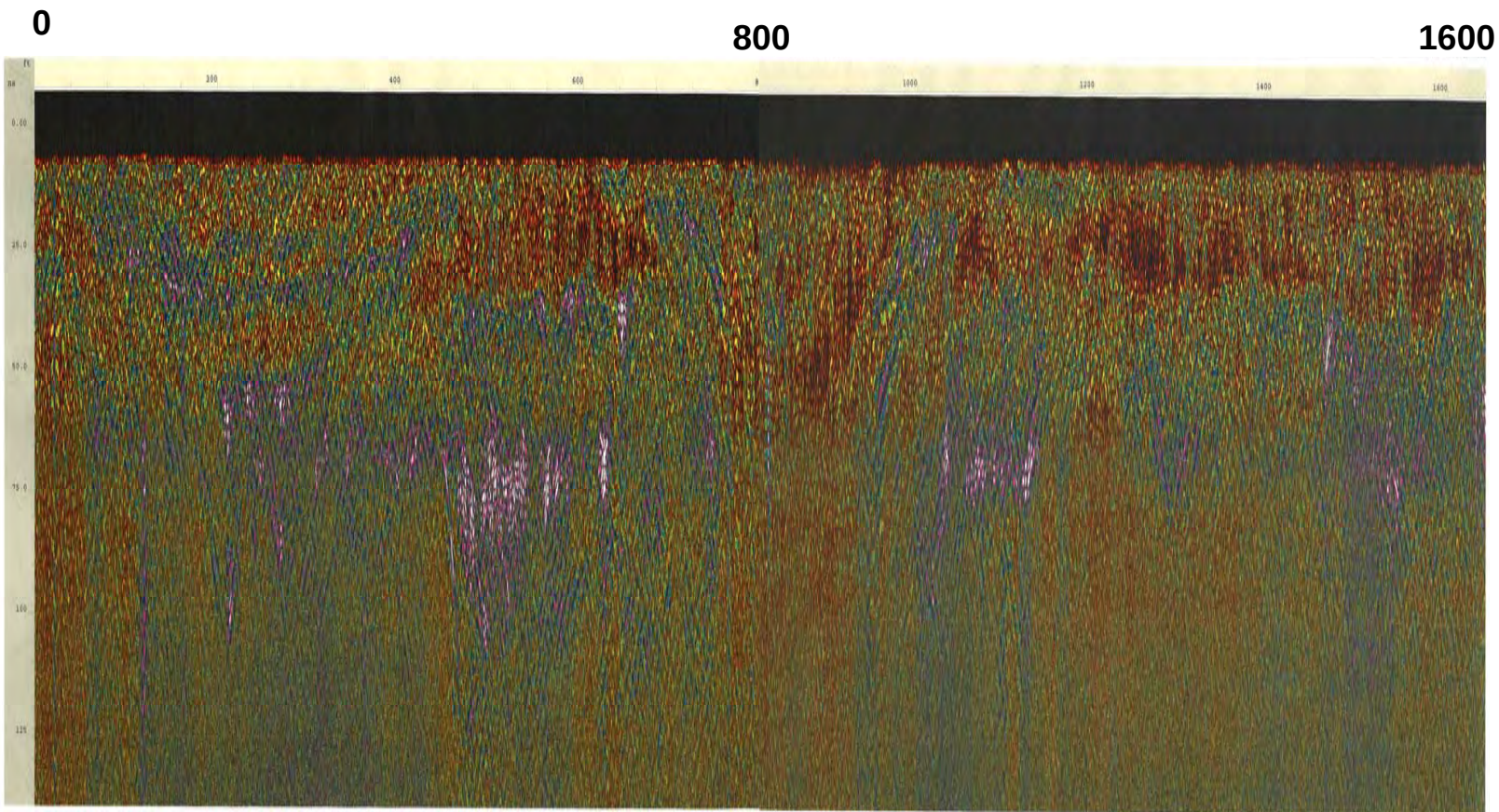


Combined Passes 1 and 2 (10m Dipoles)



Resistivity Model With Preliminary USGS Topography





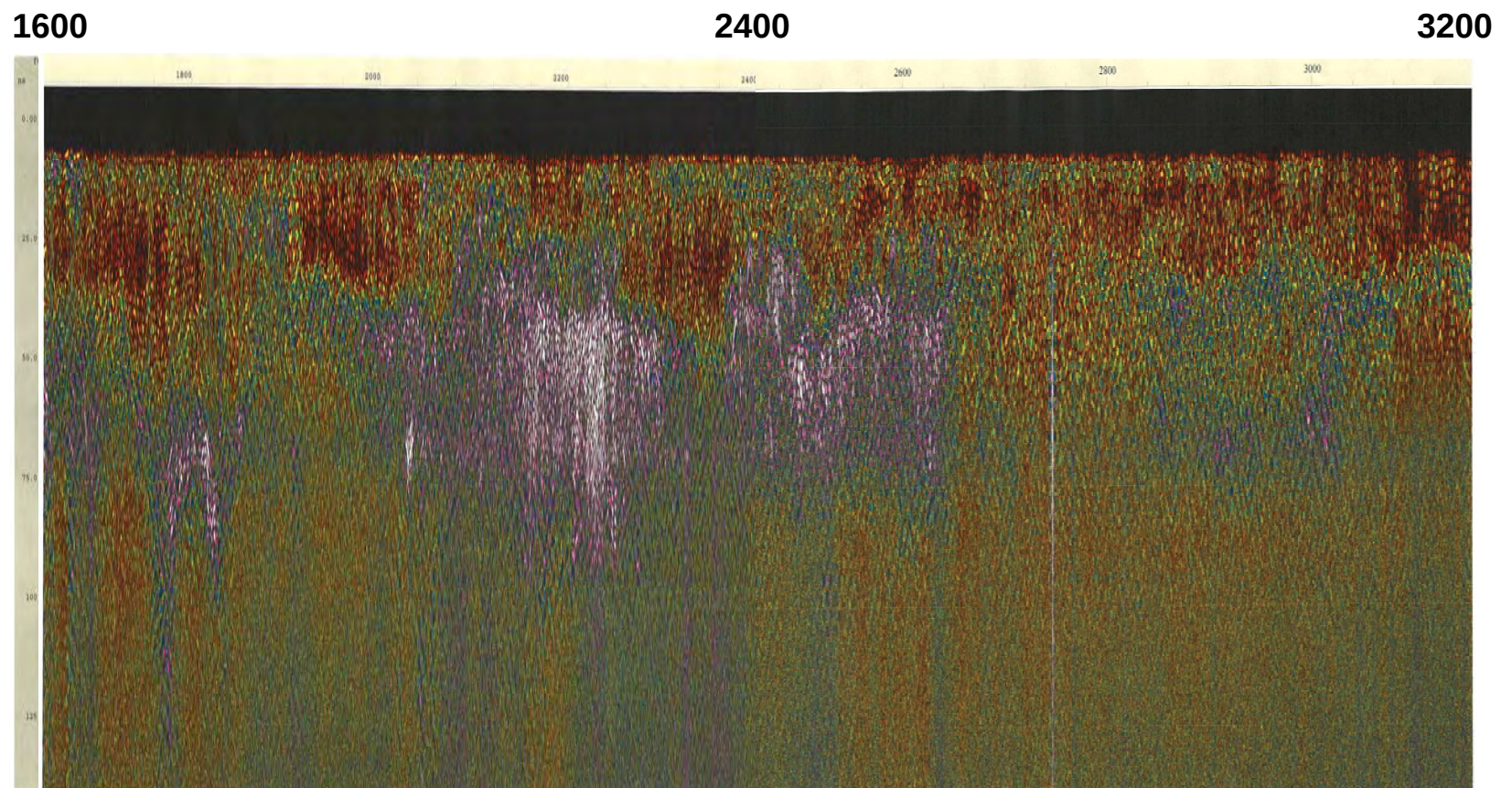
**GPR Along Shoulder (0 – 1600 feet)**

**Florida Department of Transportation  
Research Project No. BD-498  
Ardaman & Associates, Inc.**

**GLEN HARWELL ROAD TEST DATA  
GROUND PENETRATING RADAR RESULTS**

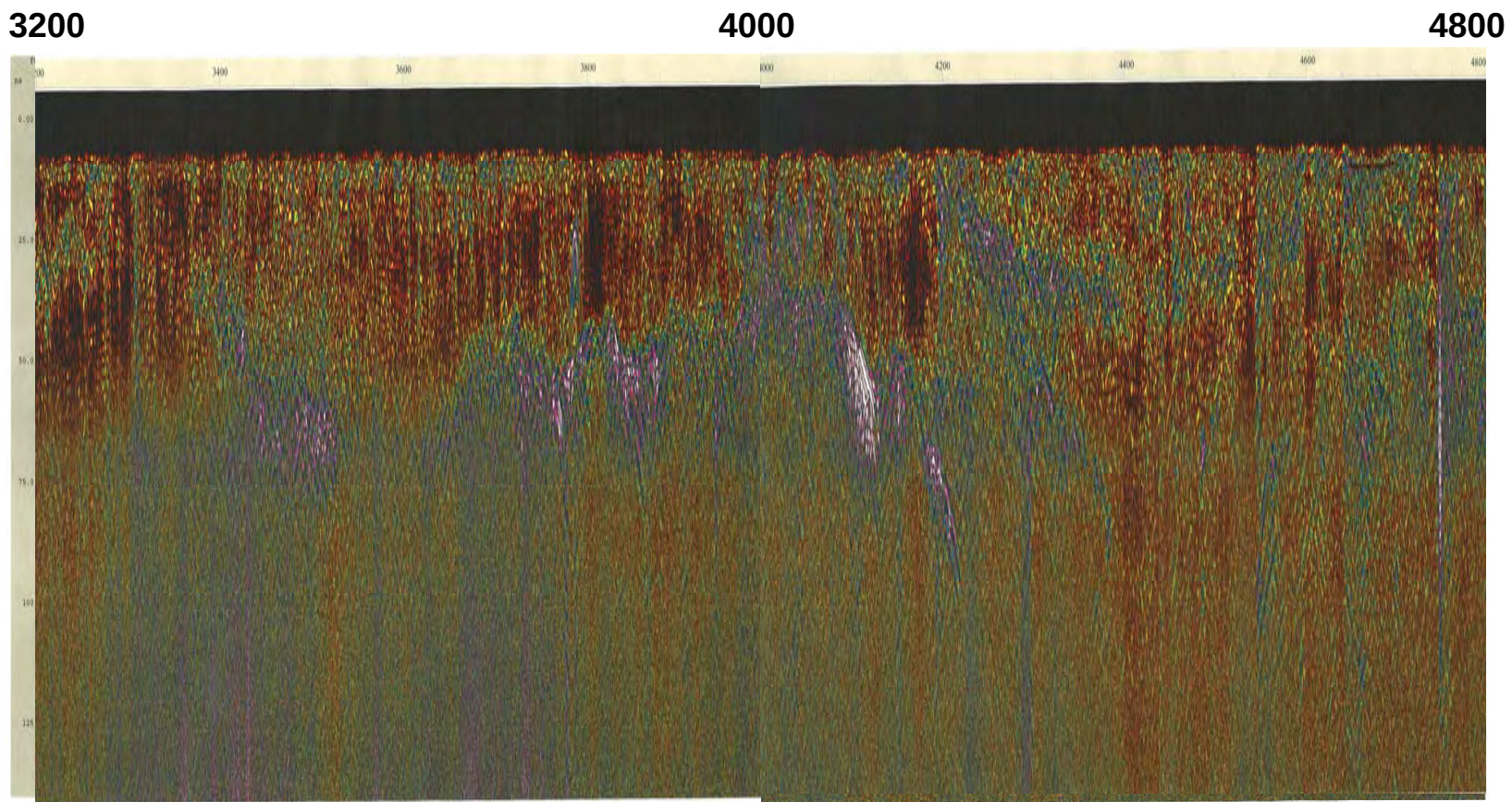
**FIGURE  
C7**





GPR Along Shoulder (1600 – 3200 feet)





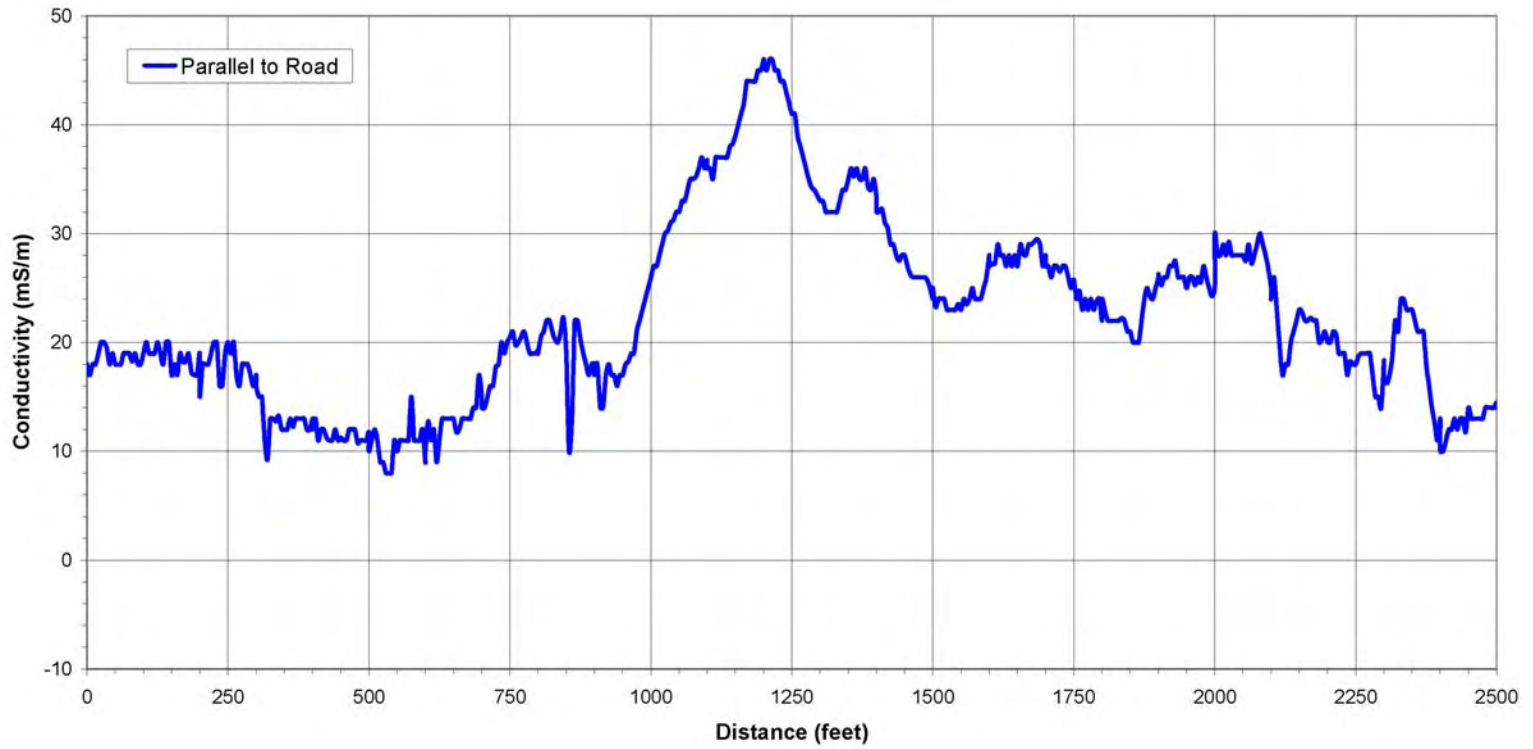
GPR Along Shoulder (3200 – 4800 feet)

Florida Department of Transportation  
Research Project No. BD-498  
Ardaman & Associates, Inc.

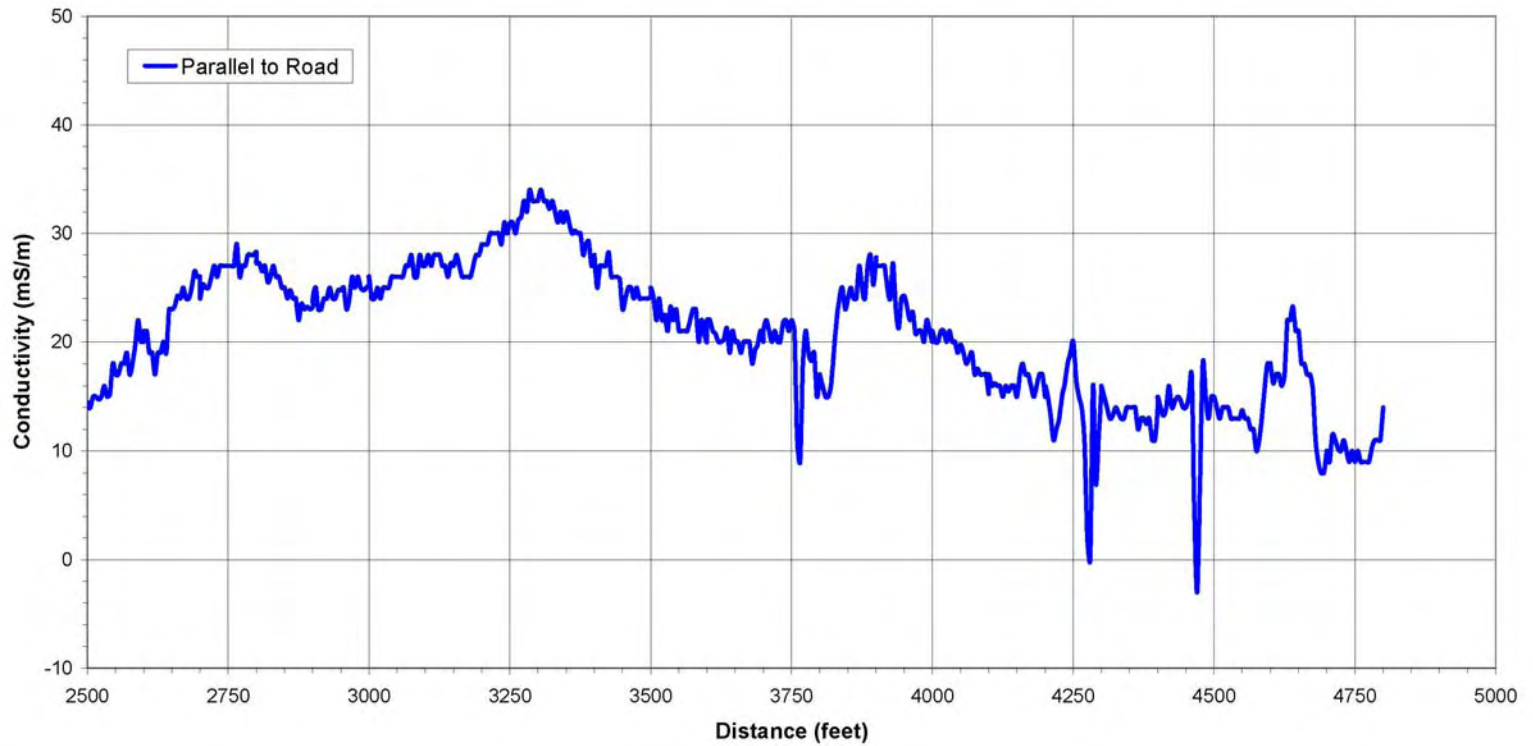
GLEN HARWELL ROAD TEST DATA  
GROUND PENETRATING RADAR RESULTS

FIGURE  
C9

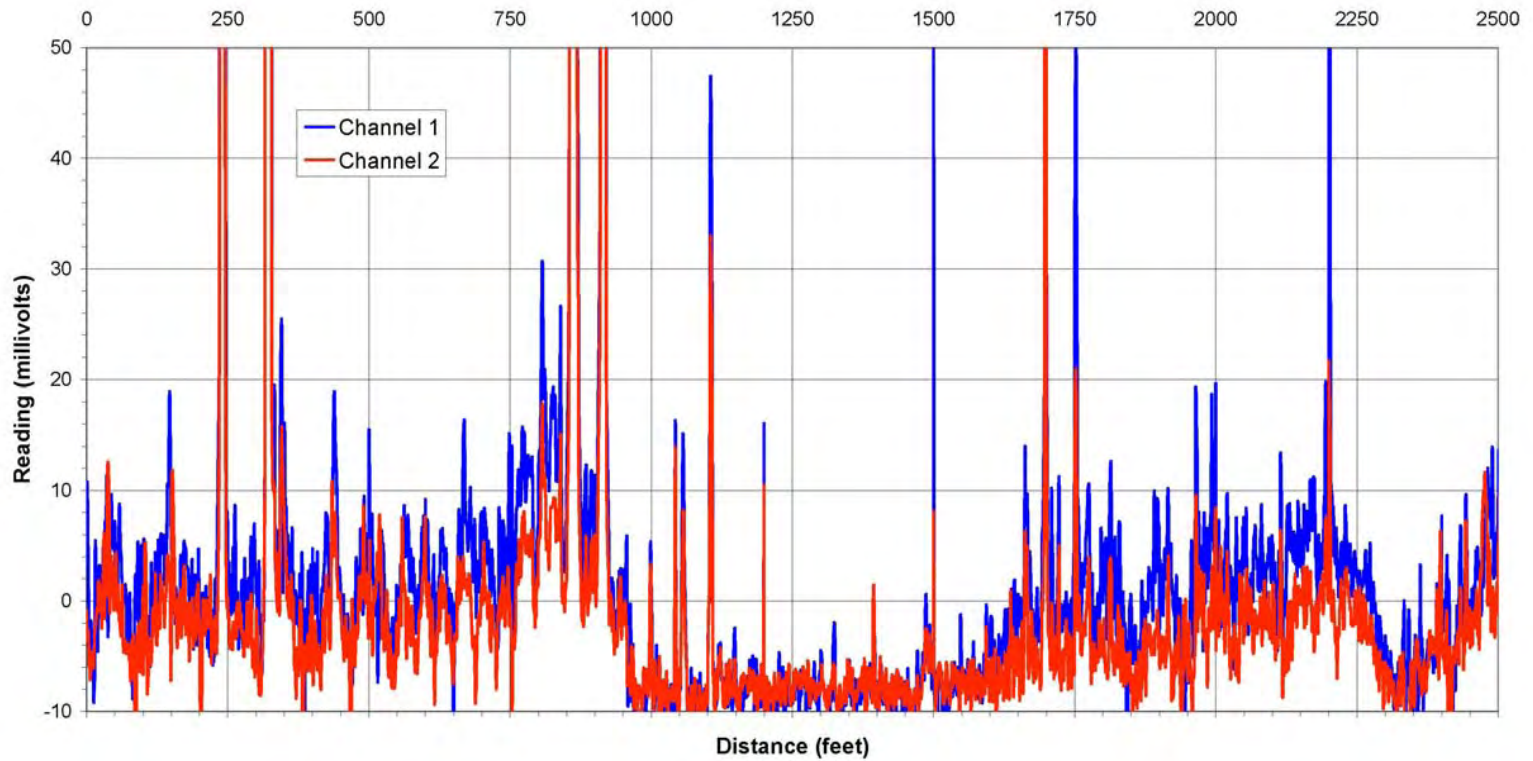




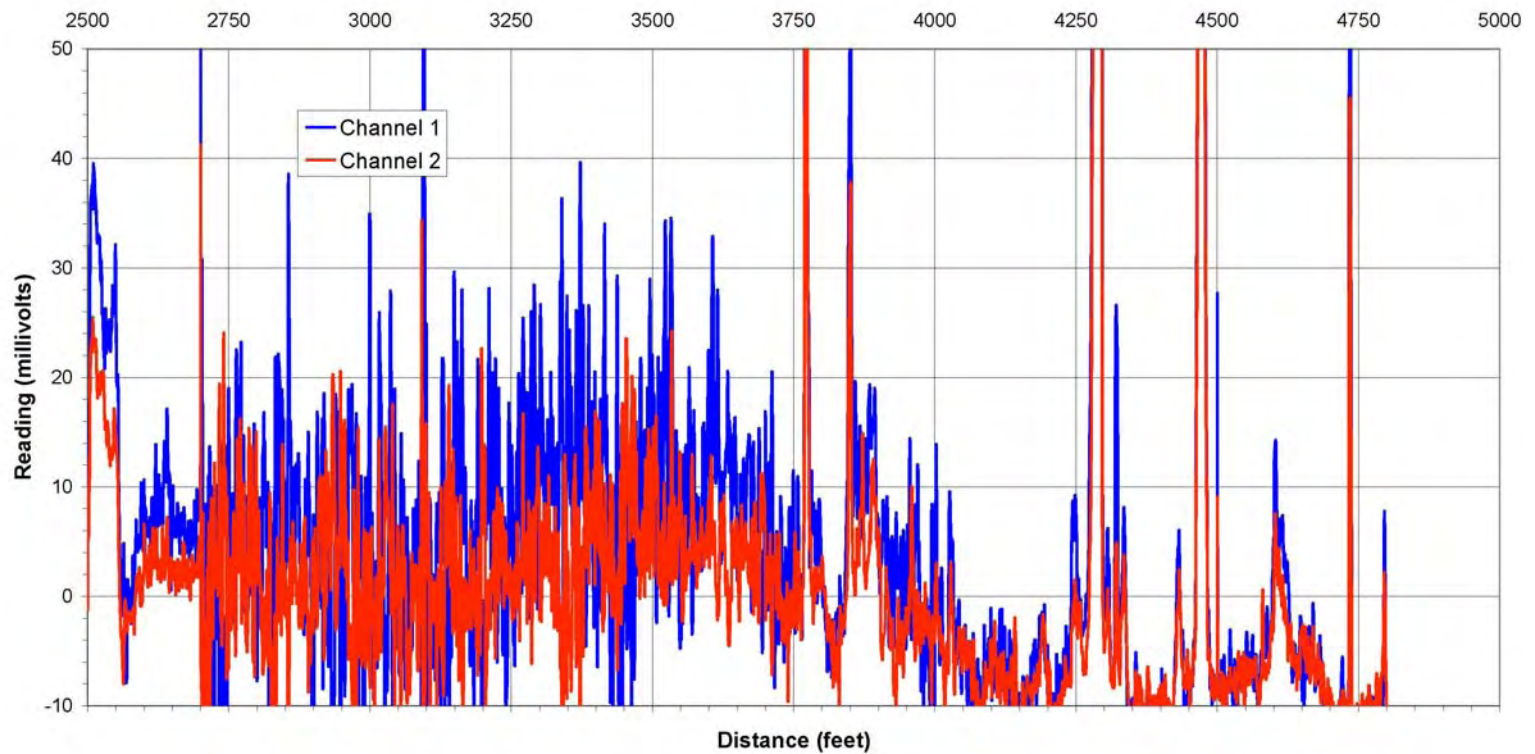
**Geonics EM-31 Terrain Conductivity Survey (0 – 2500 Feet)**



**Geonics EM-31 Terrain Conductivity Survey (2500 – 5000 Feet)**

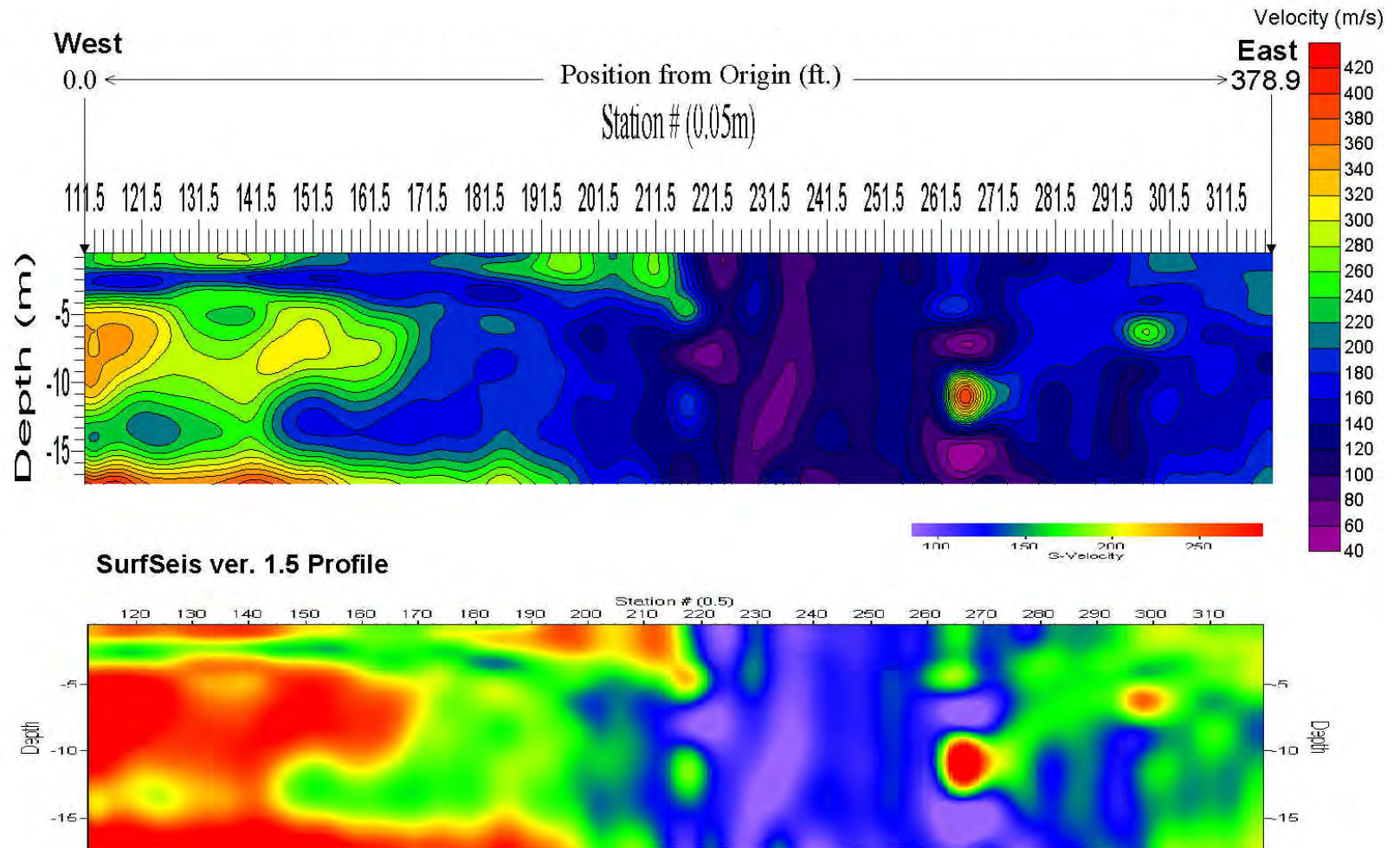


**Geonics EM-61 Terrain Conductivity Survey (0 – 2500 Feet)**



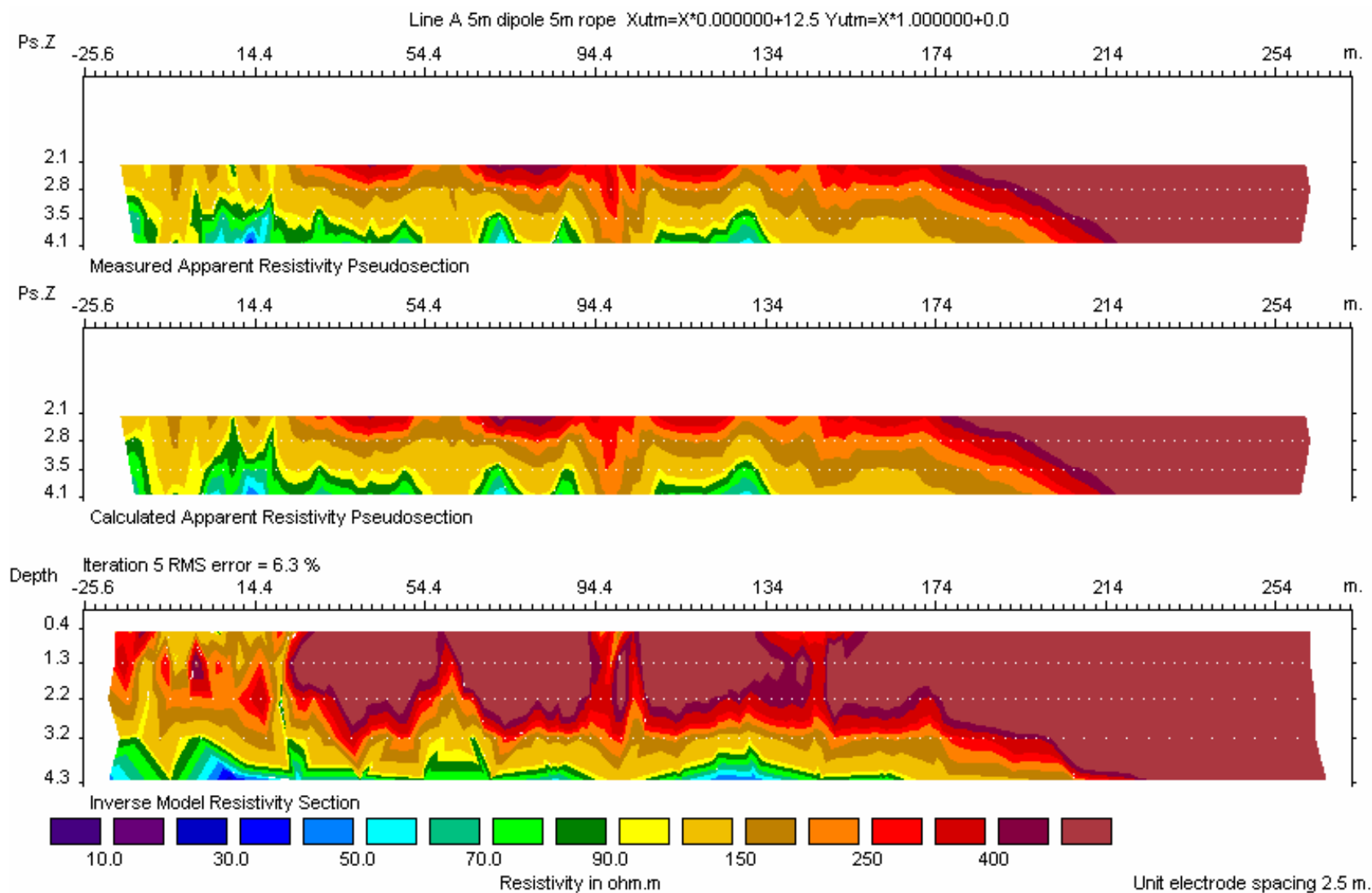
**Geonics EM-61 Terrain Conductivity Survey (2500 – 5000 Feet)**



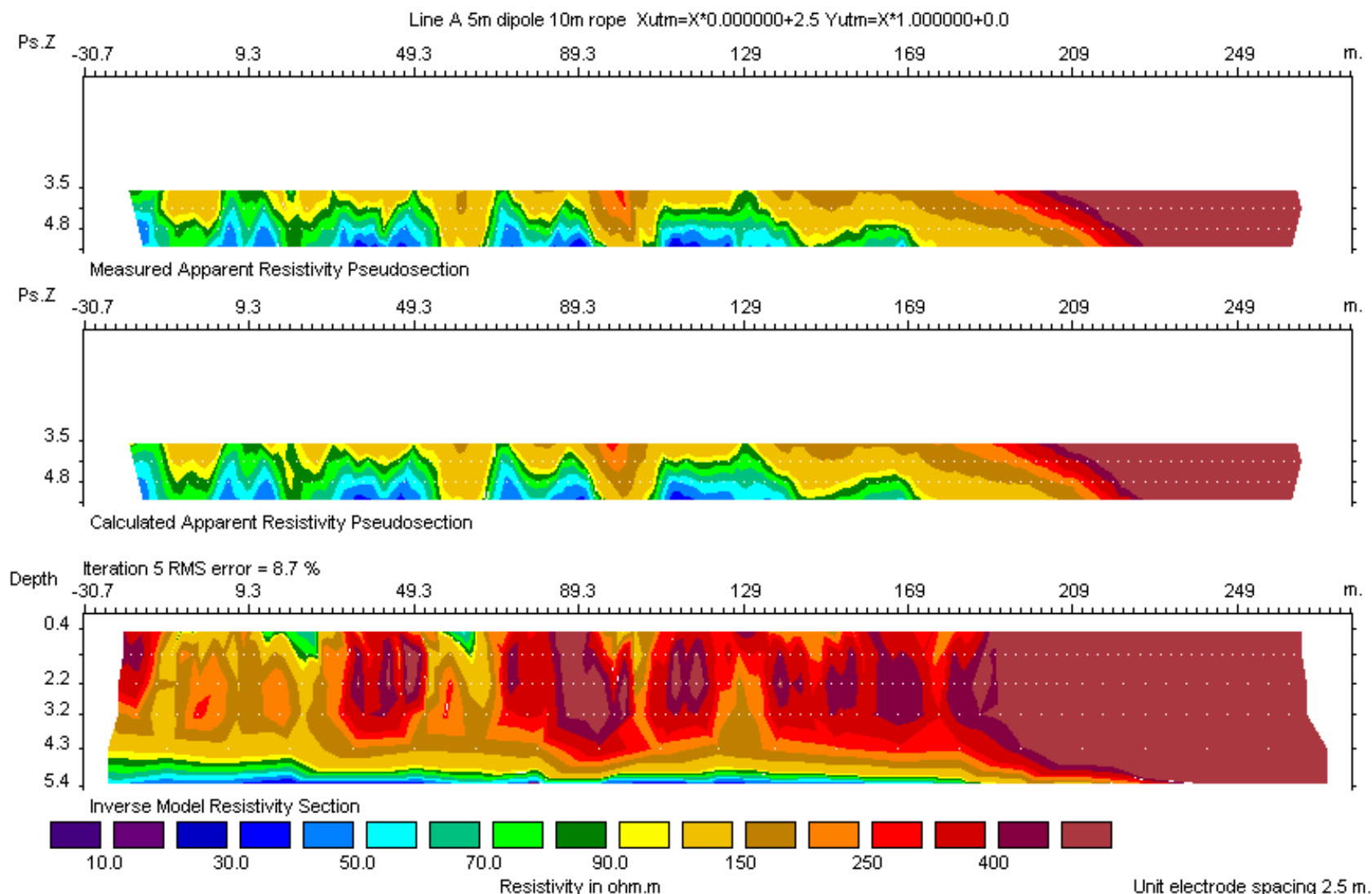


## **APPENDIX D**

### **PHOSPHATE MINE TEST SITE**

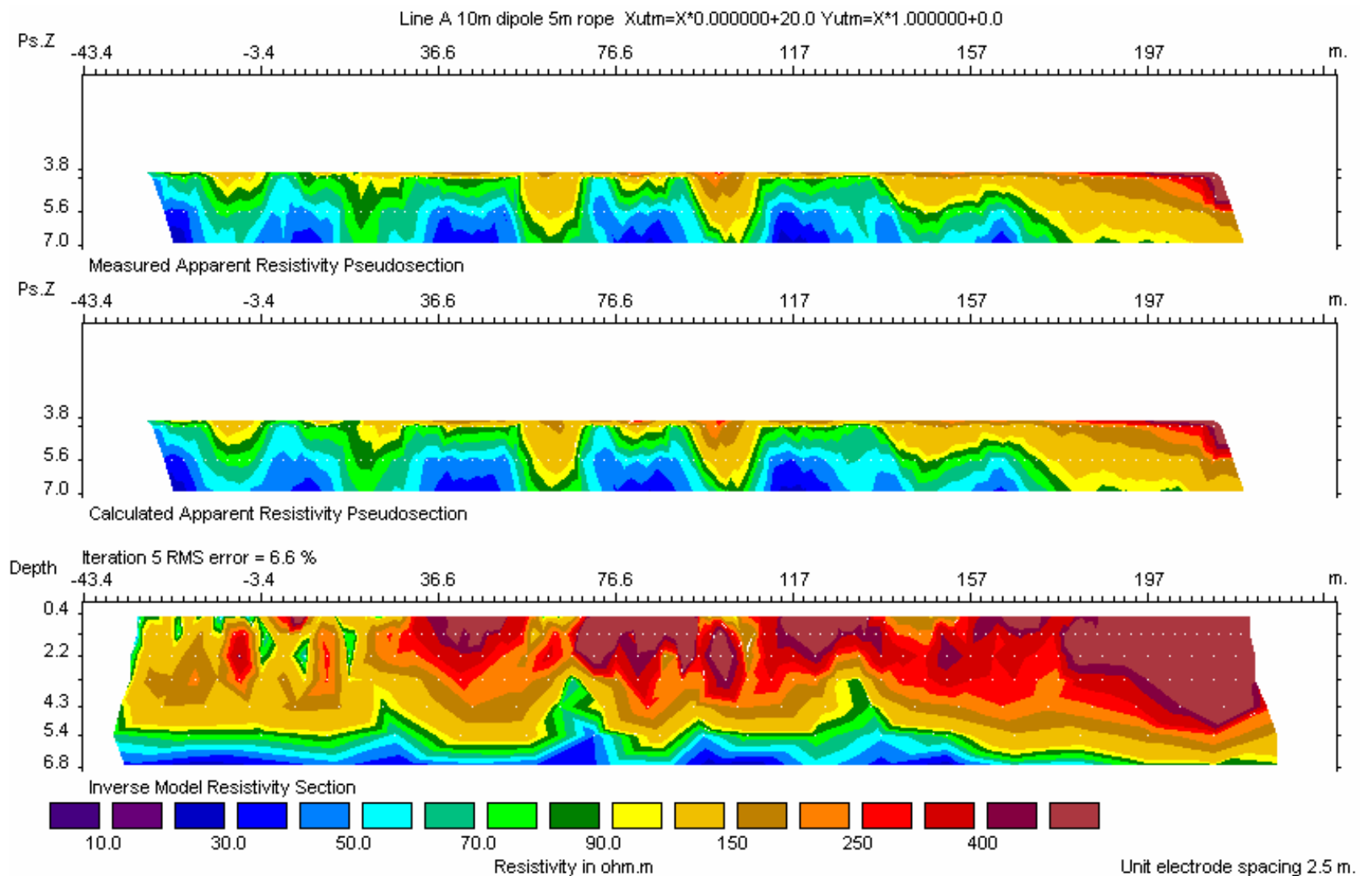


Line A - Pass 1 (5m Dipole with 5m Rope)

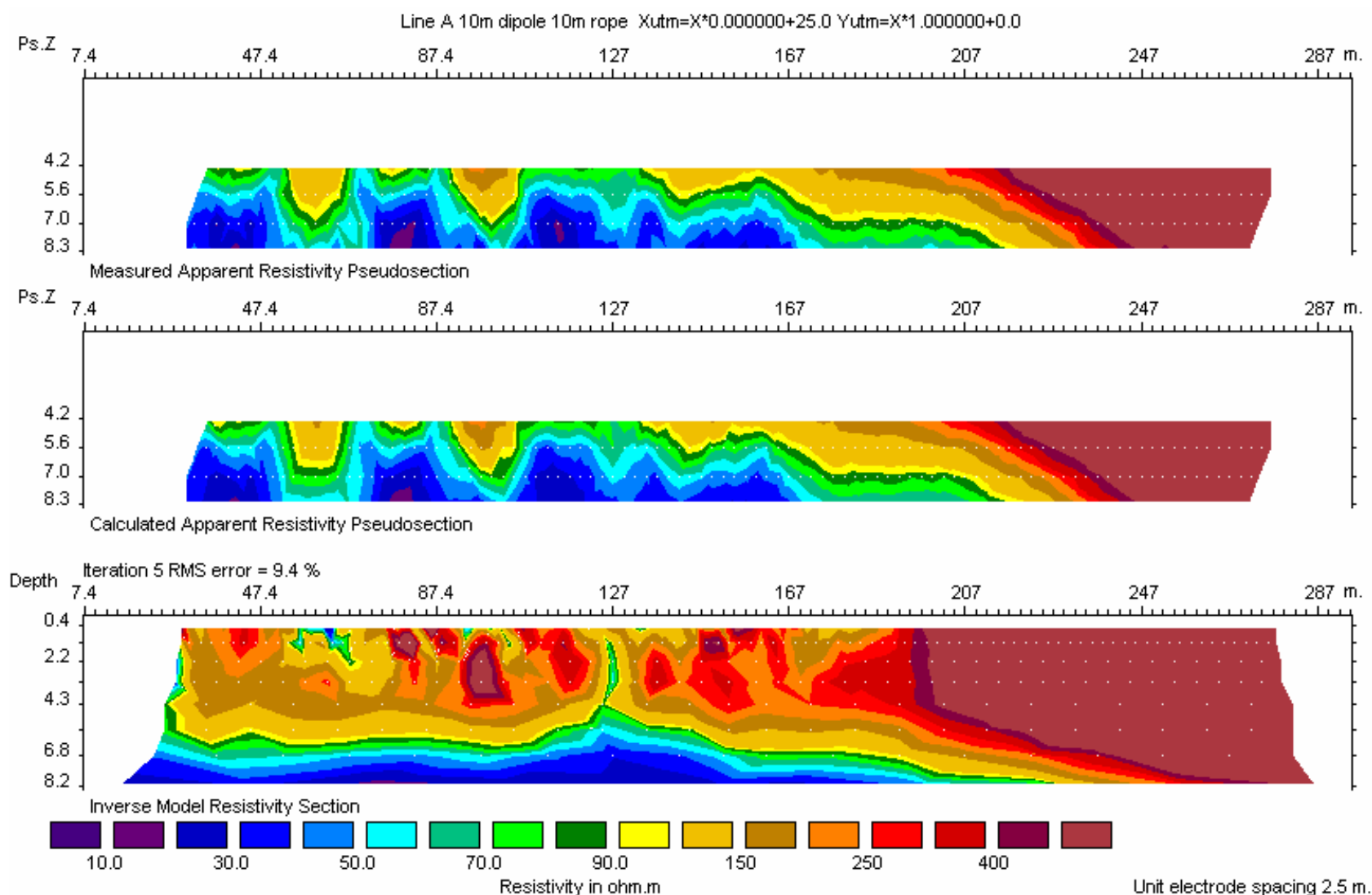


Line A - Pass 2 (5m Dipole with 10m Rope)

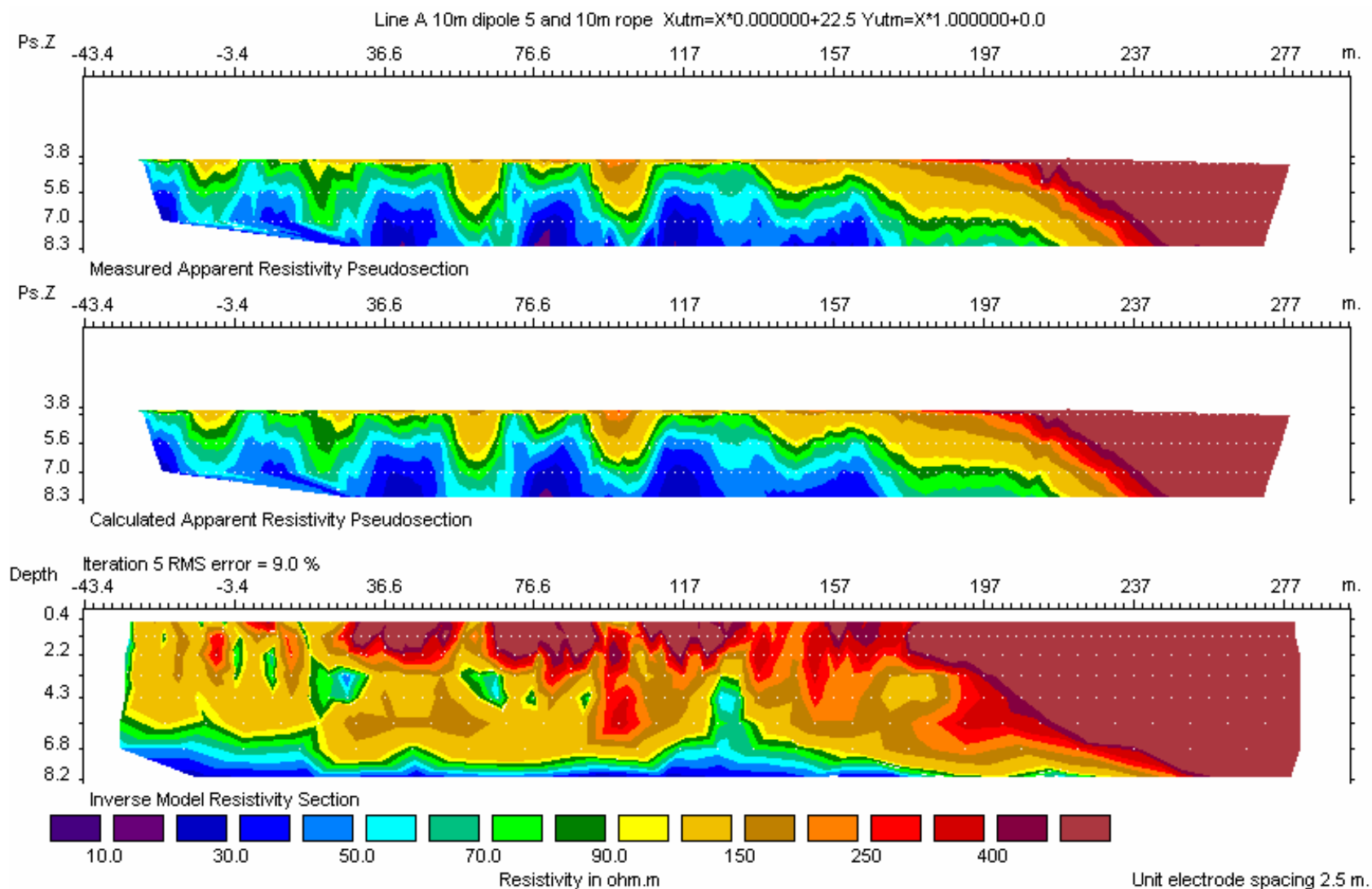




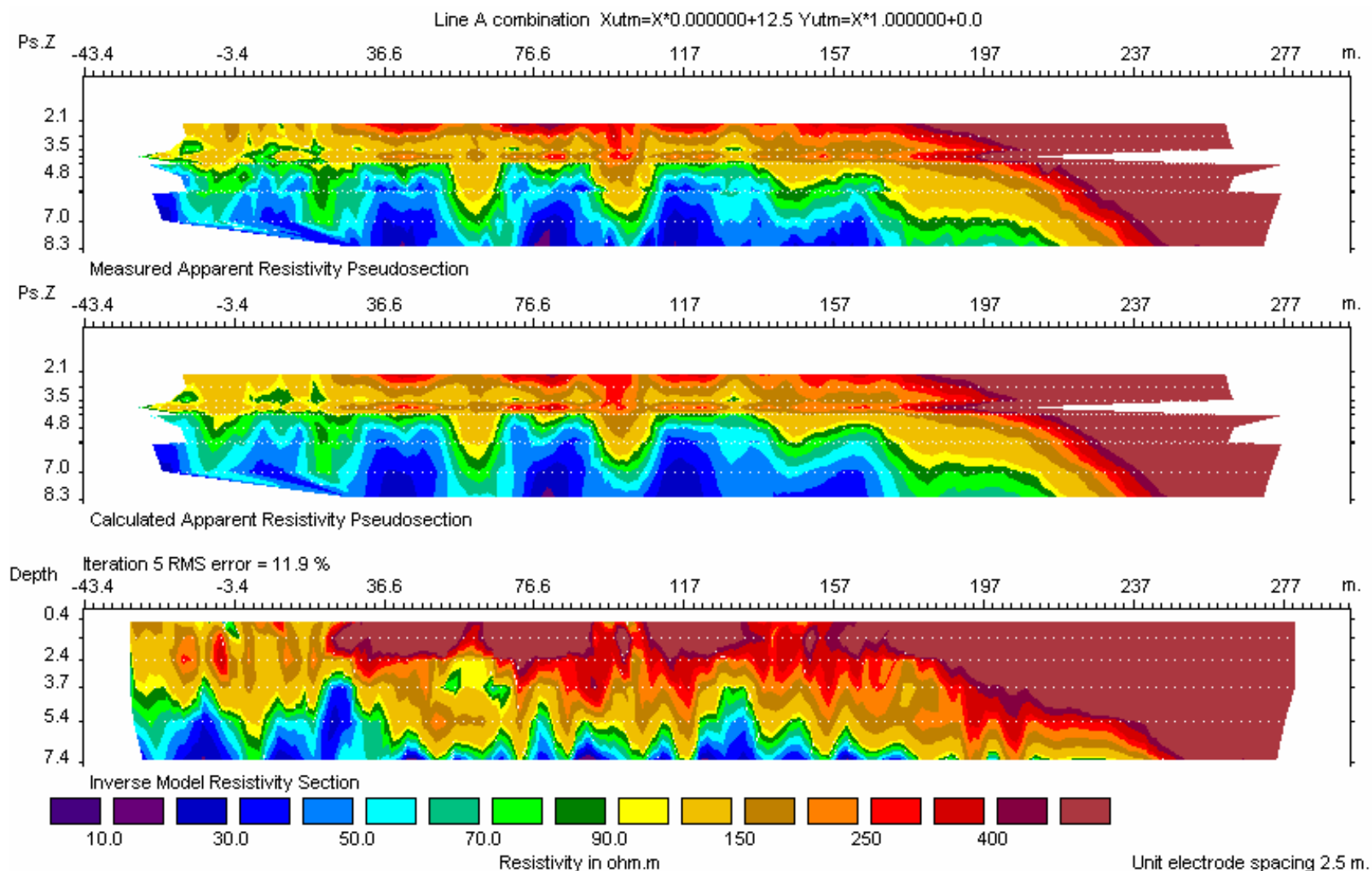
Line A – Pass 3 (10m Dipole with 5m Rope)



Line A – Pass 4 (10m Dipole with 10m Rope)

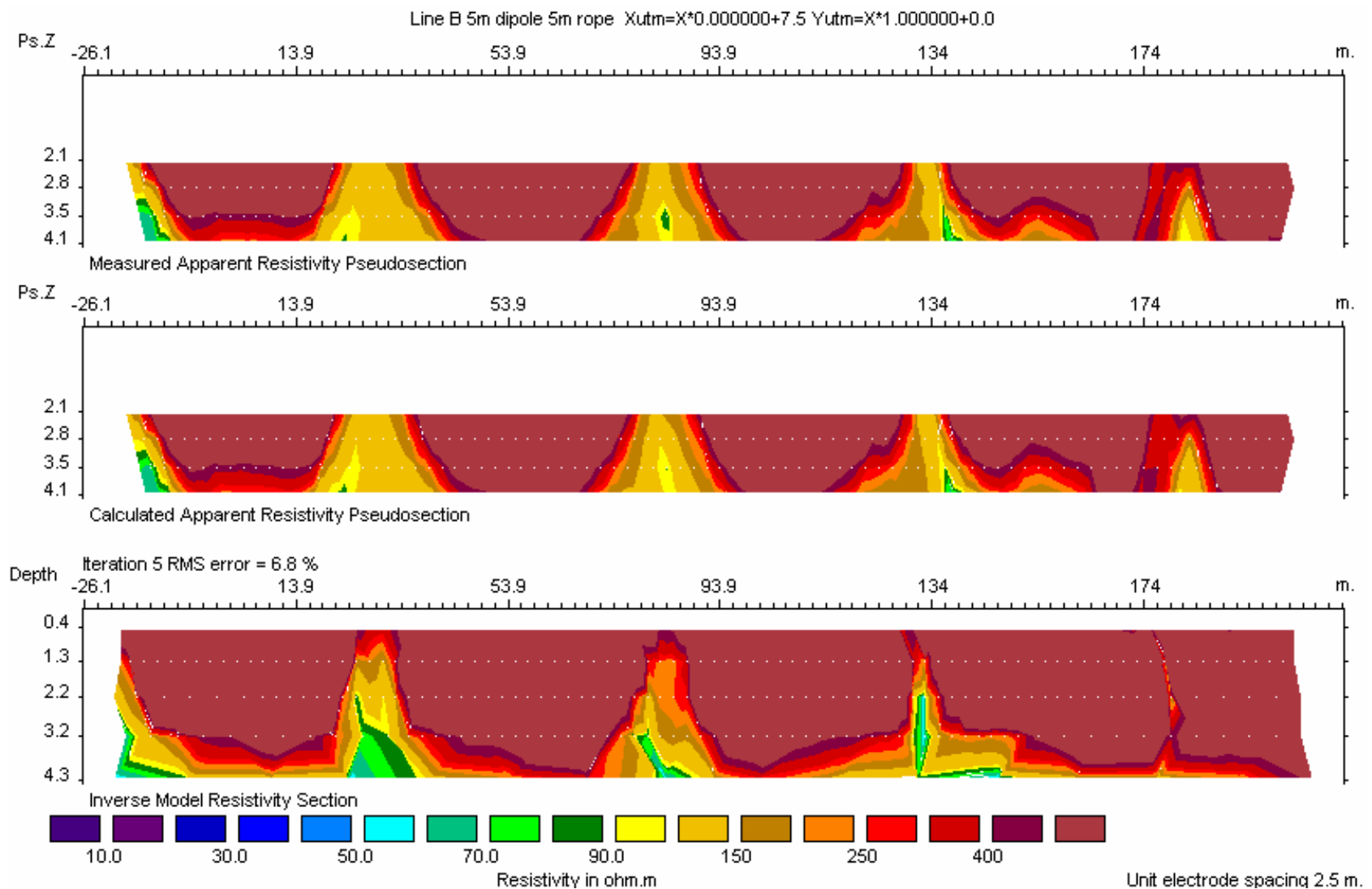


Line A – Combined Passes 3 & 4 (10m Dipoles)

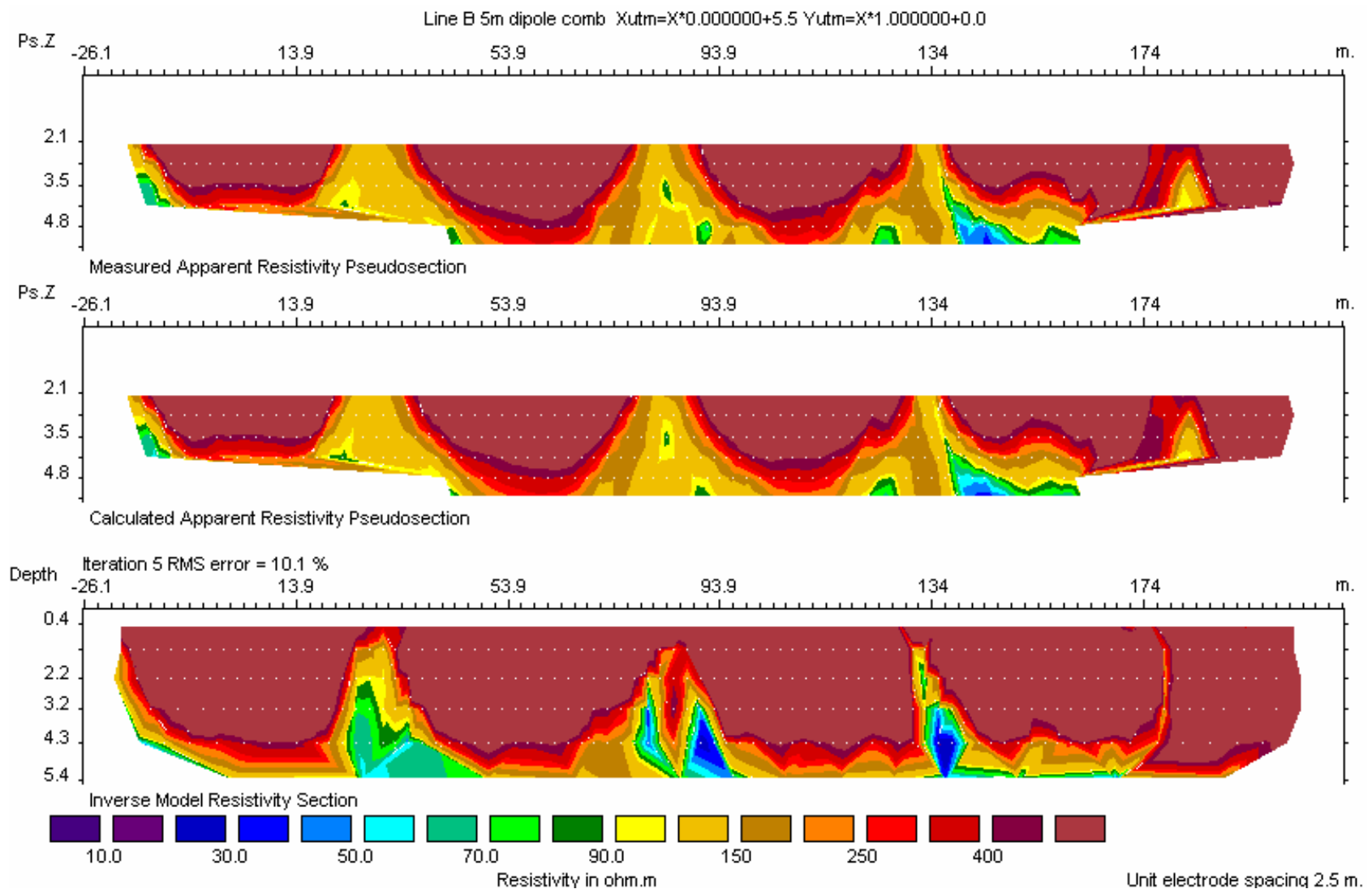


Line A – Combined Passes 1 Through 4

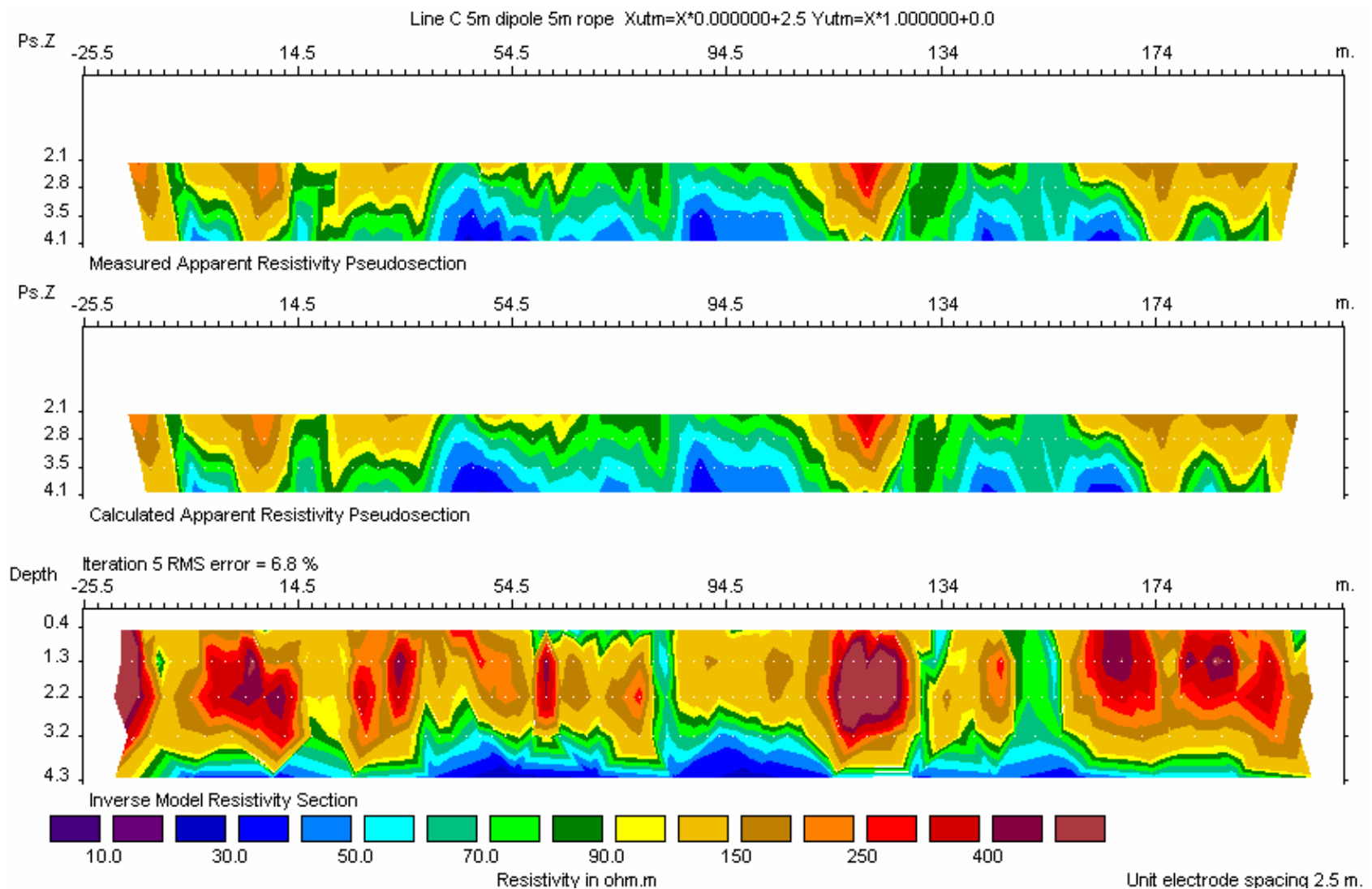




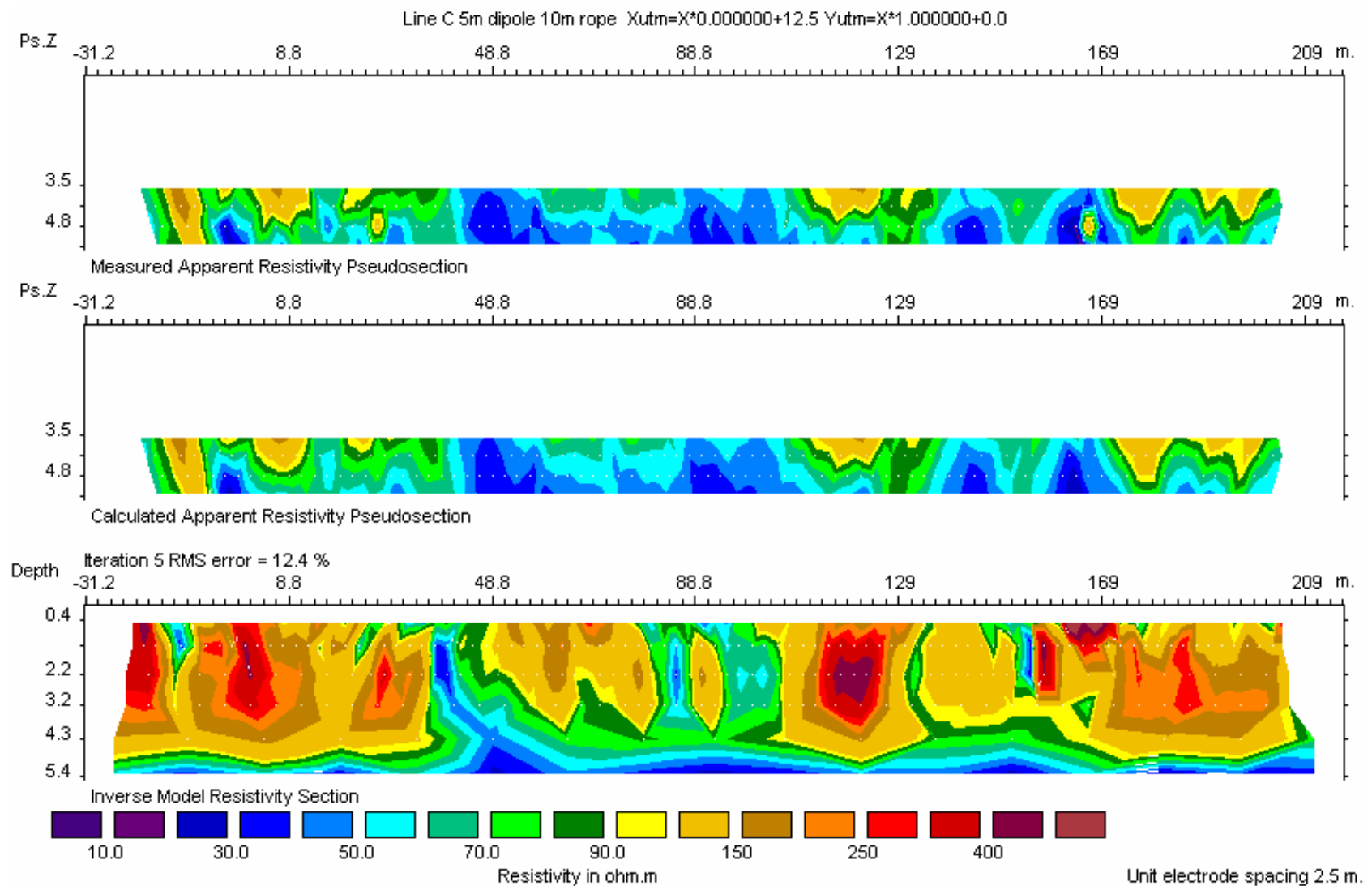
Line B – Pass 1 (5m Dipole with 5m Rope)



Line B – Combined Passes 1 & 2 (5m Dipoles)

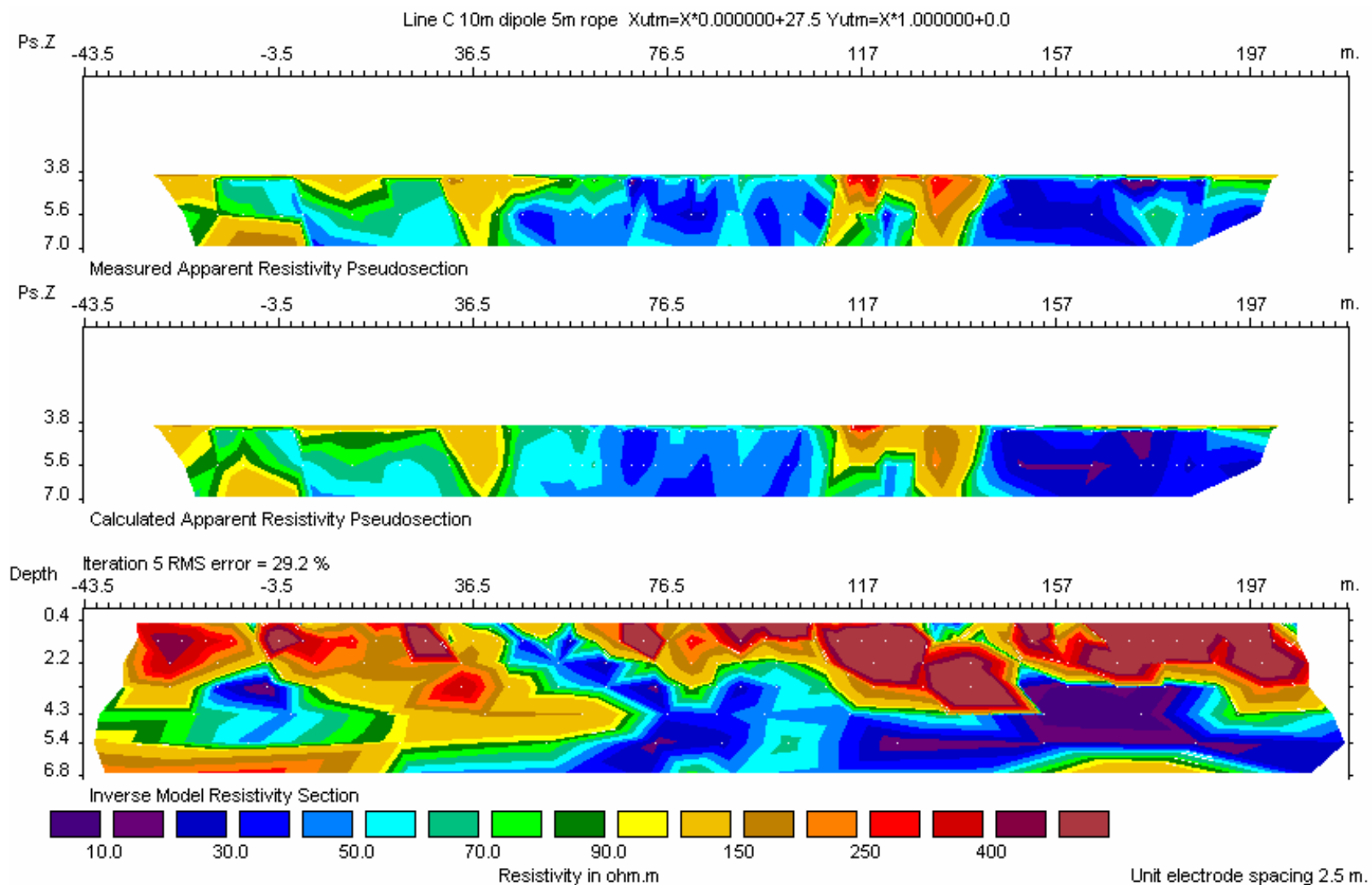


Line C – Pass 1 (5m Dipole with 5m Rope)

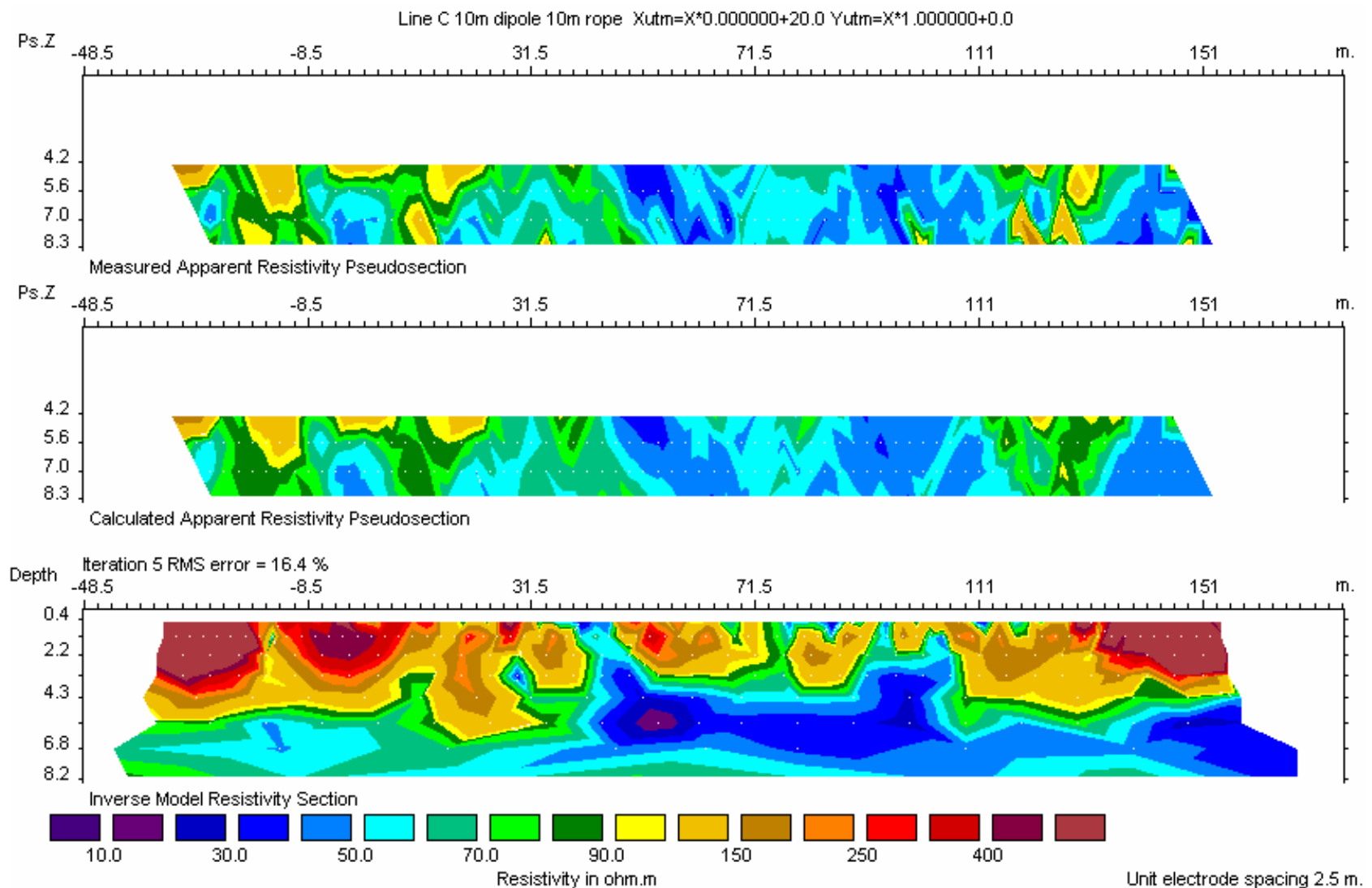


Line C – Pass 2 (5m Dipole with 10m Rope)

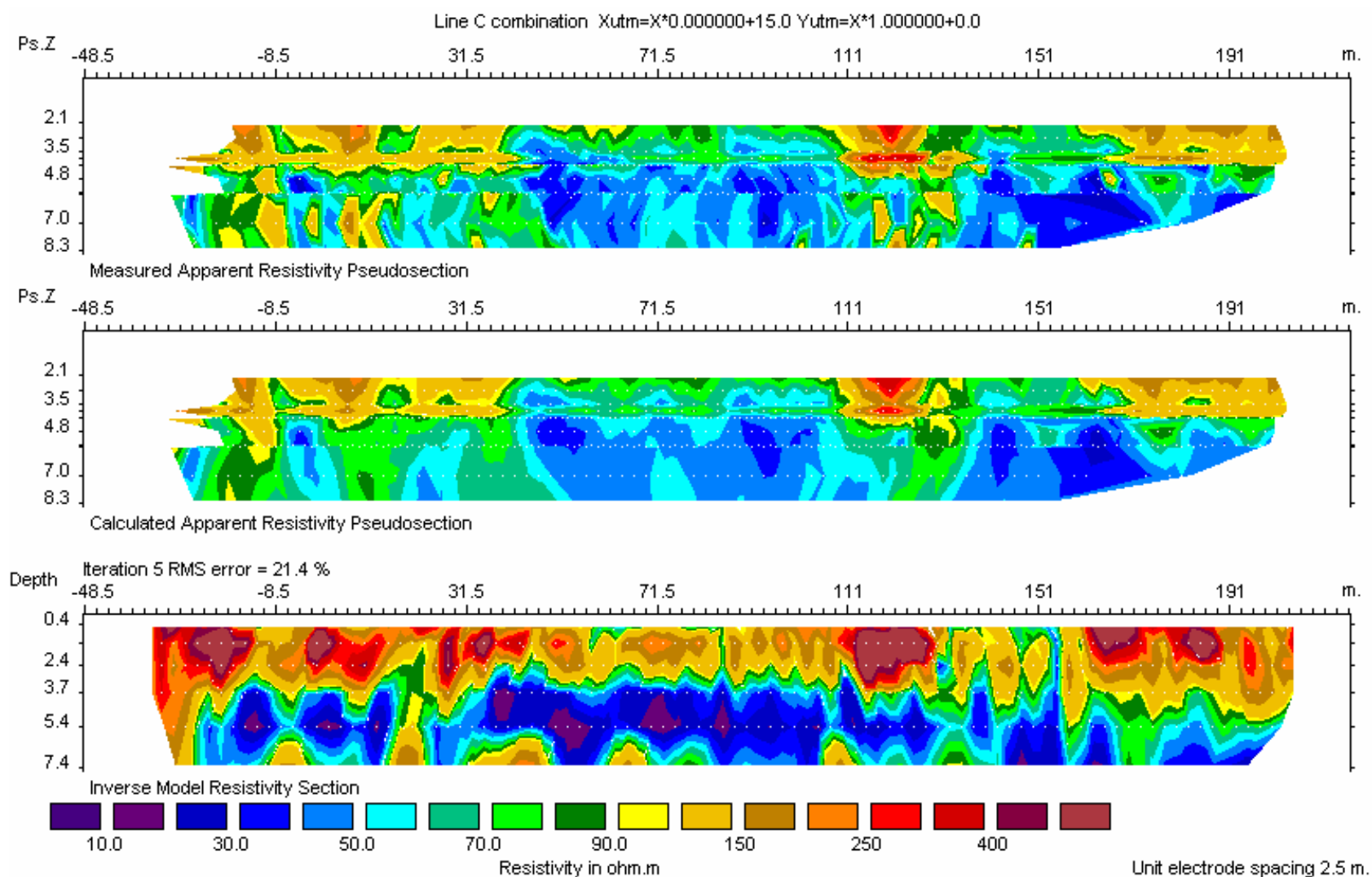




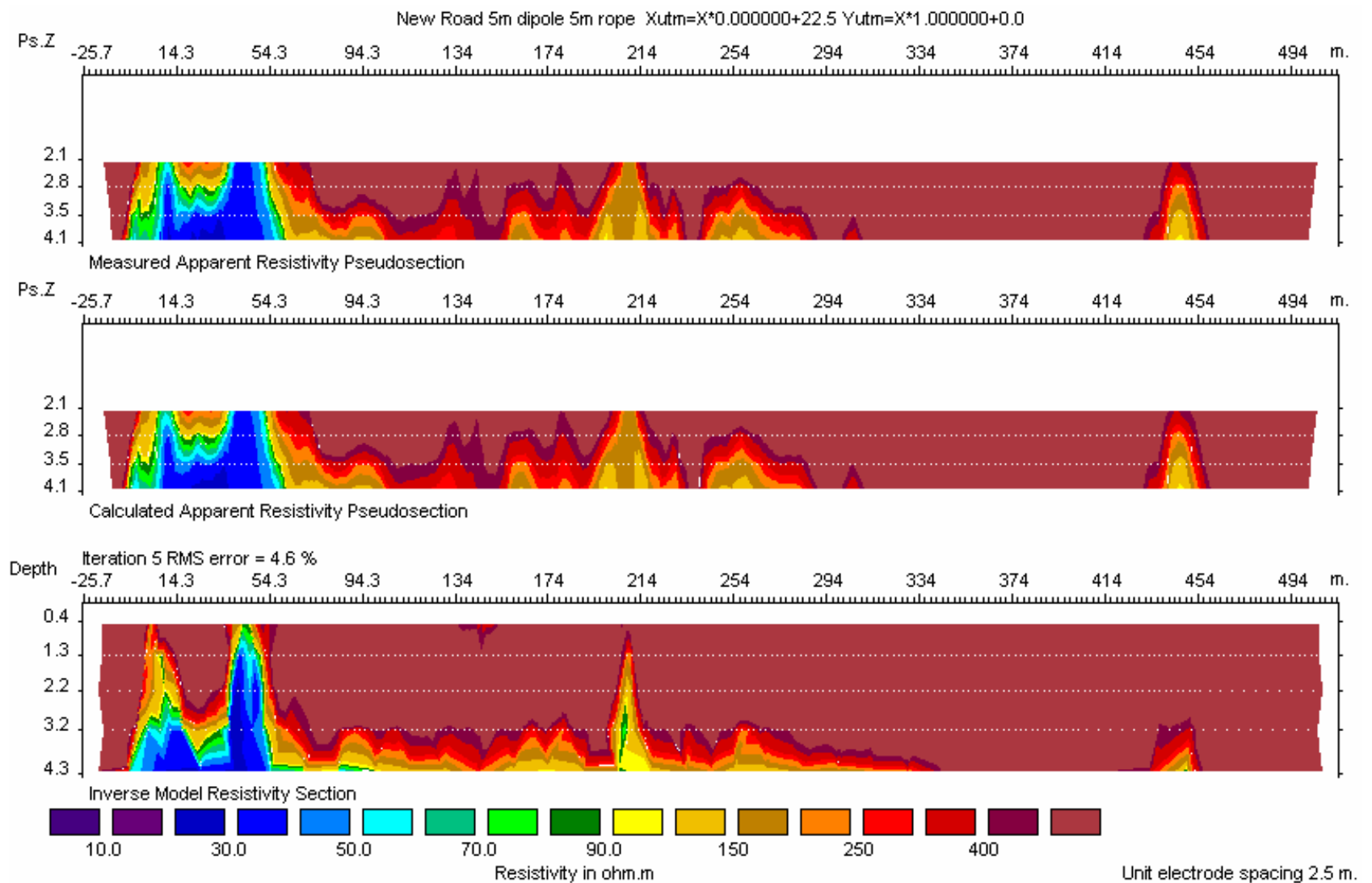
Line C – Pass 3 (10m Dipole with 5m Rope)



Line C – Pass 4 (10m Dipole with 10m Rope)

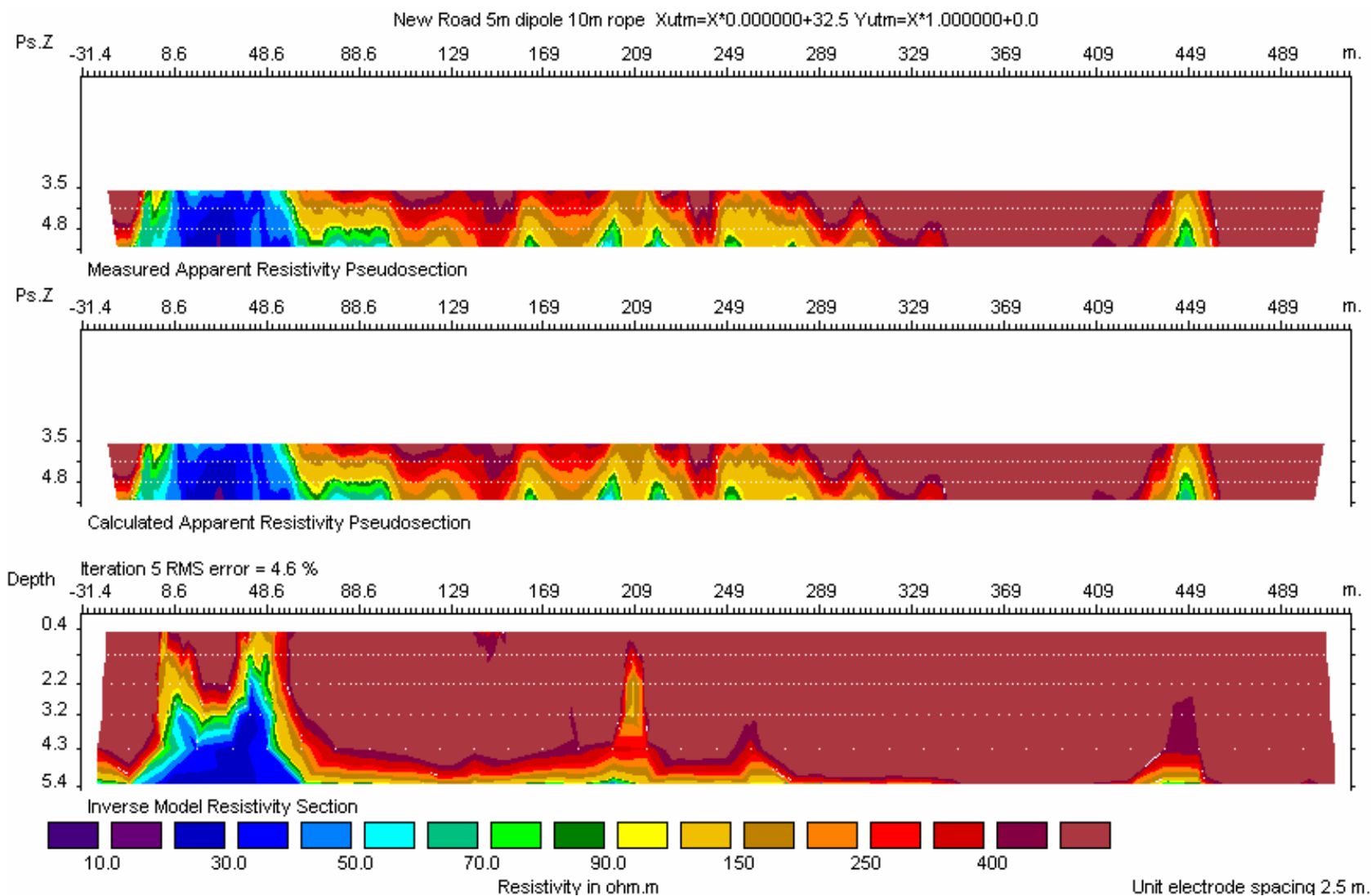


Line C – Combined Passes 1 Through 4

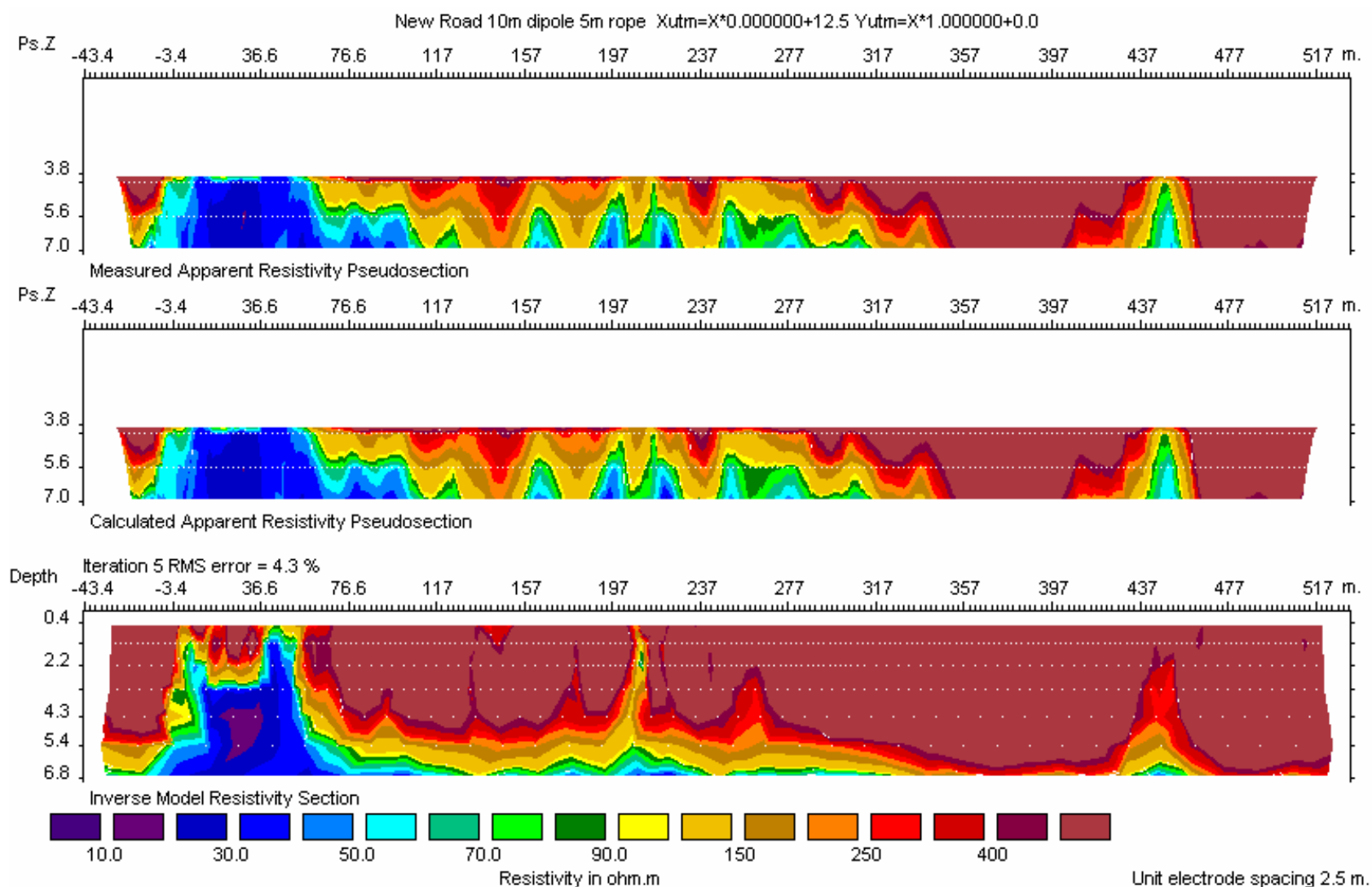


Line D – Pass 1 (5m Dipole with 5m Rope)

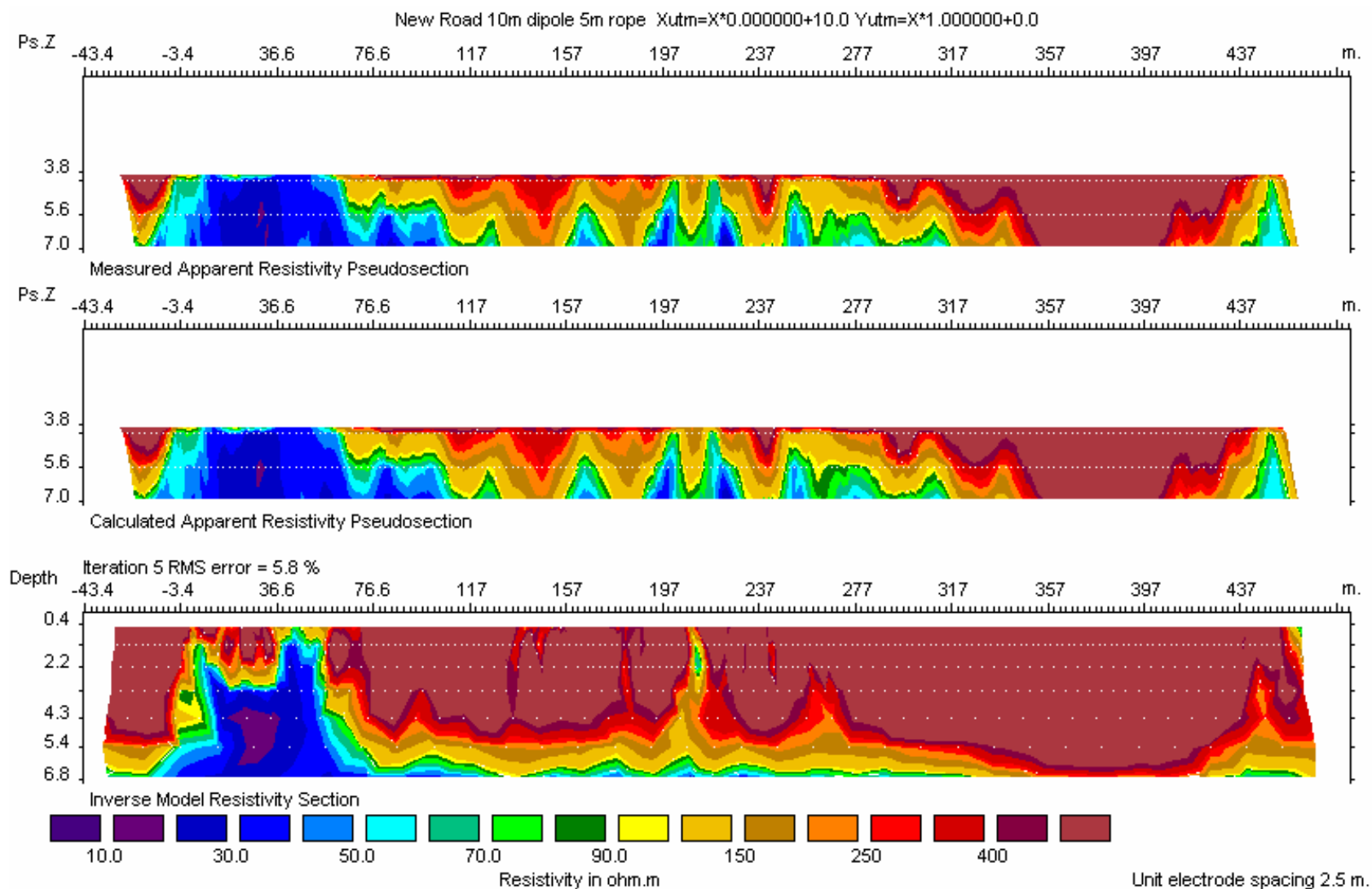




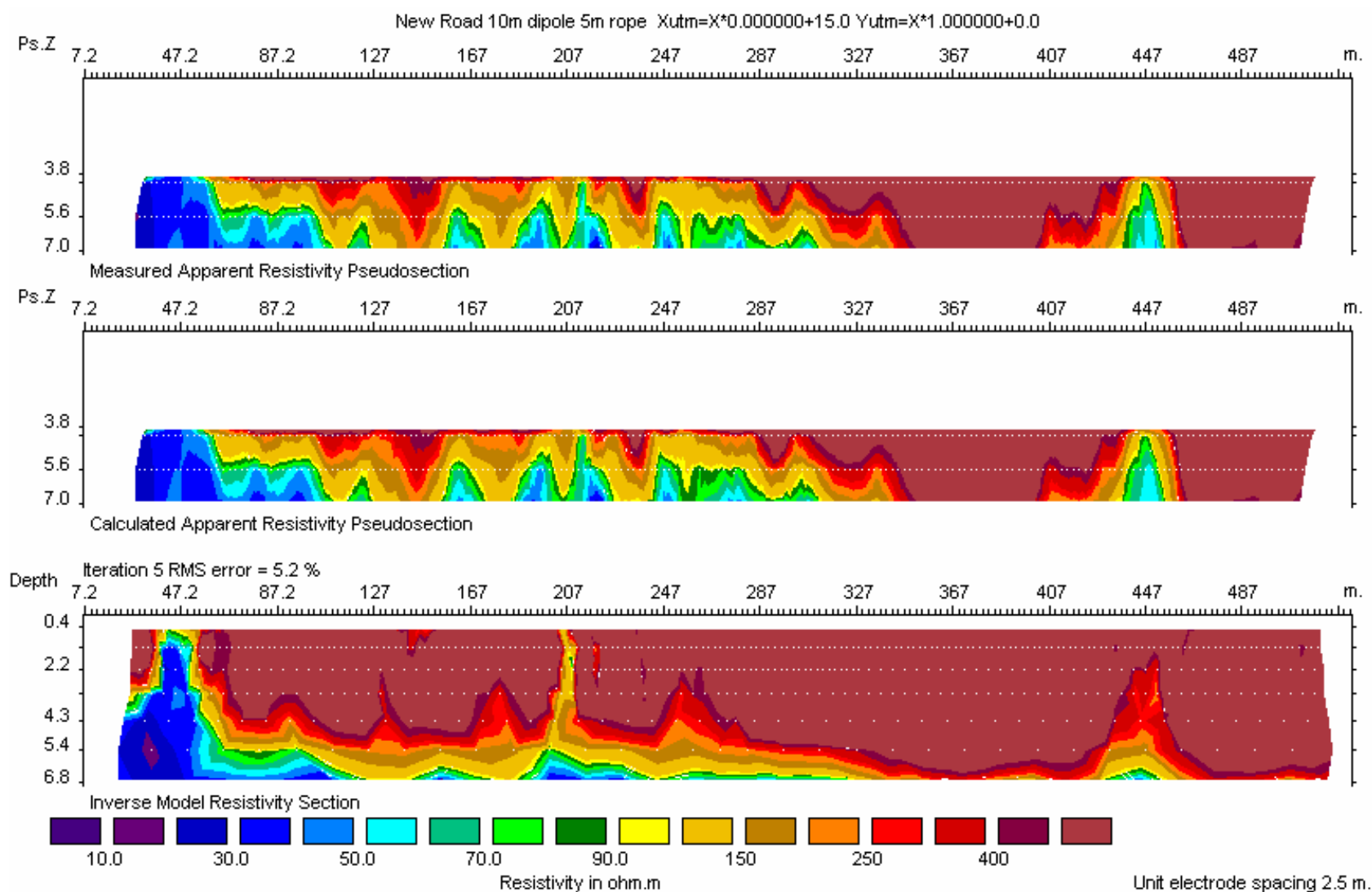
Line D – Pass 2 (5m Dipole with 10m Rope)



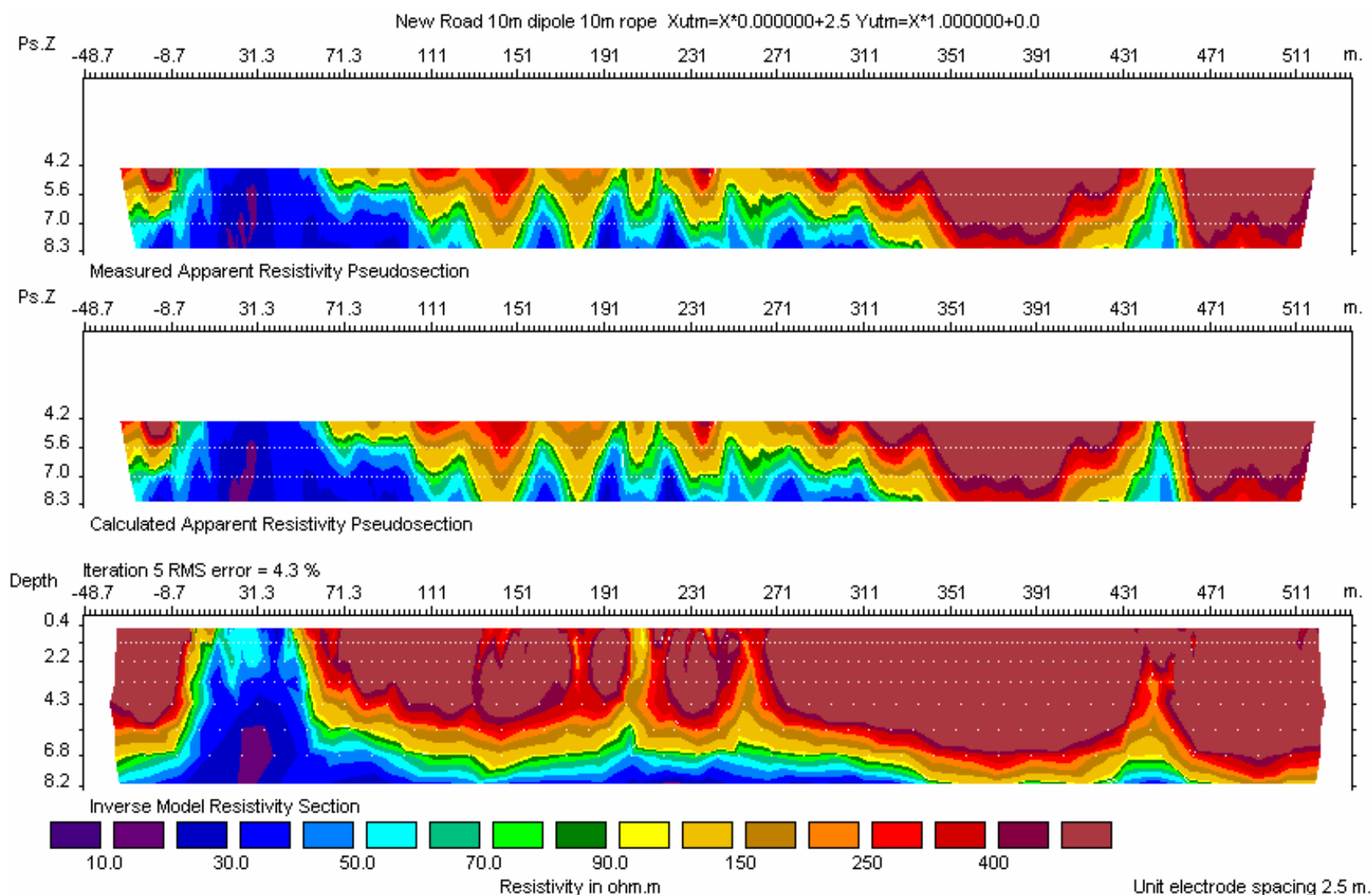
Line D – Pass 3A (10m Dipole with 5m Rope)



Line D – Pass 3B (10m Dipole with 5m Rope)

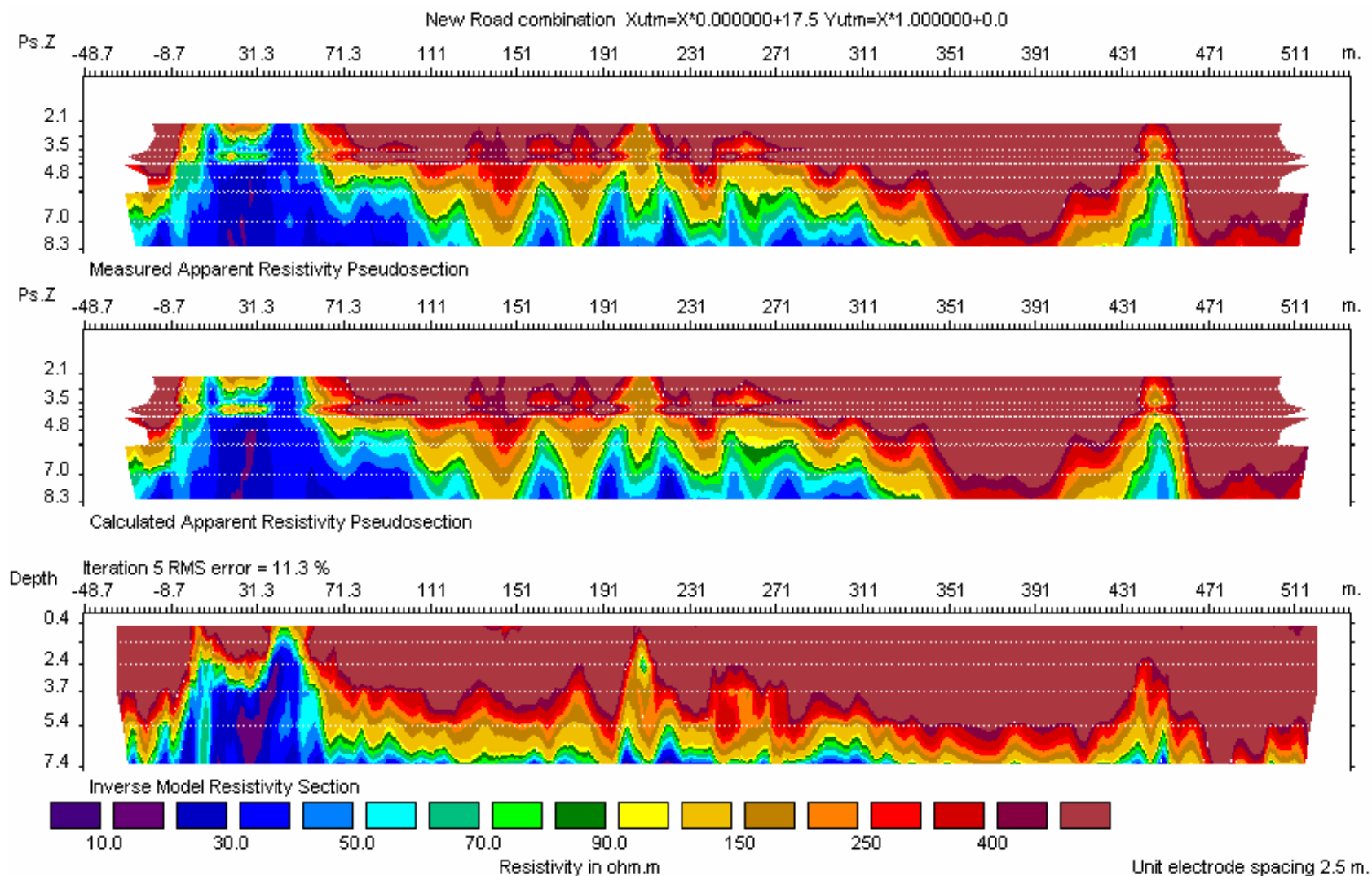


Line D – Pass 3C (10m Dipole with 5m Rope)



Line D – Pass 4 (10m Dipole with 10m Rope)

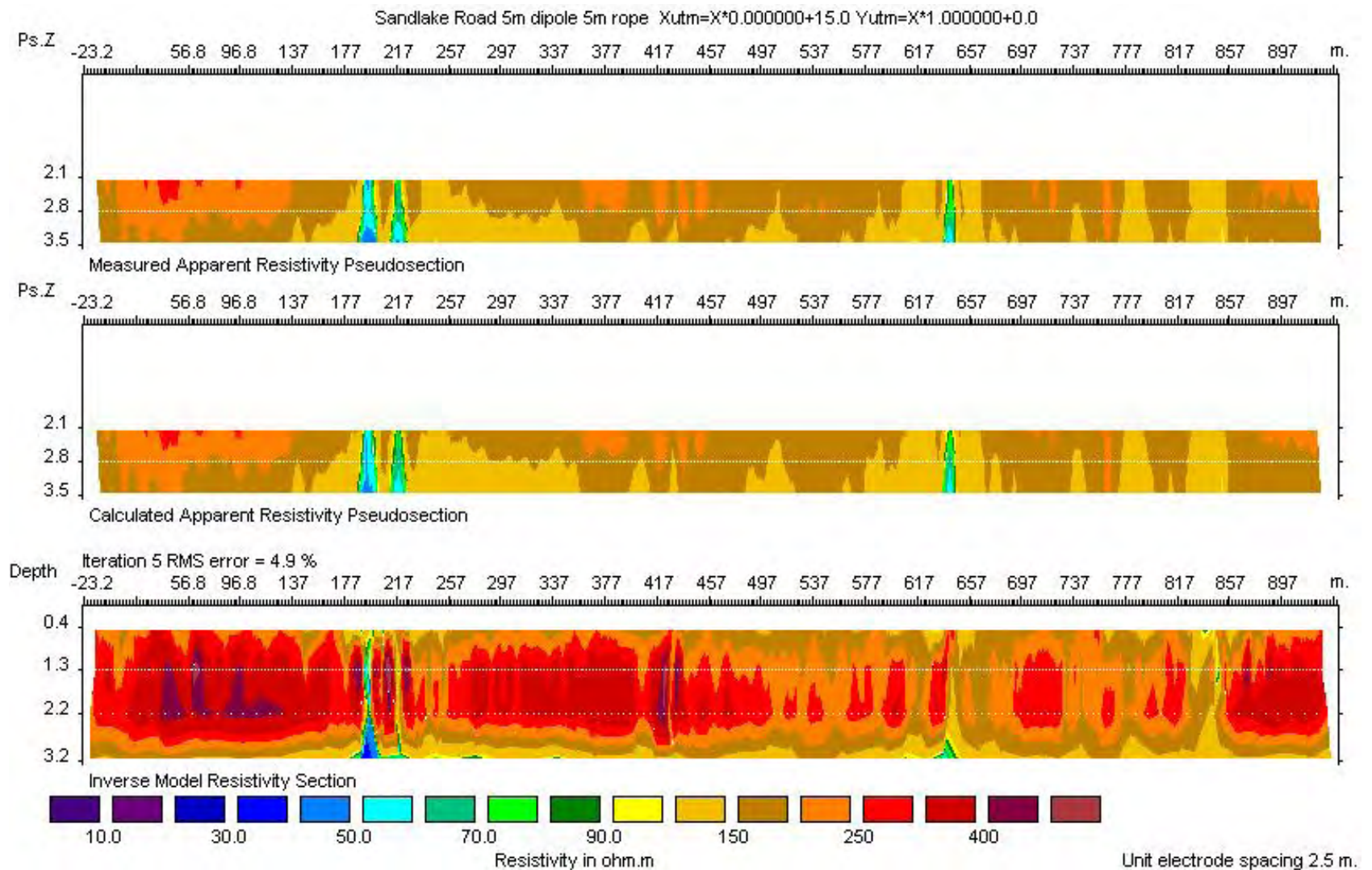




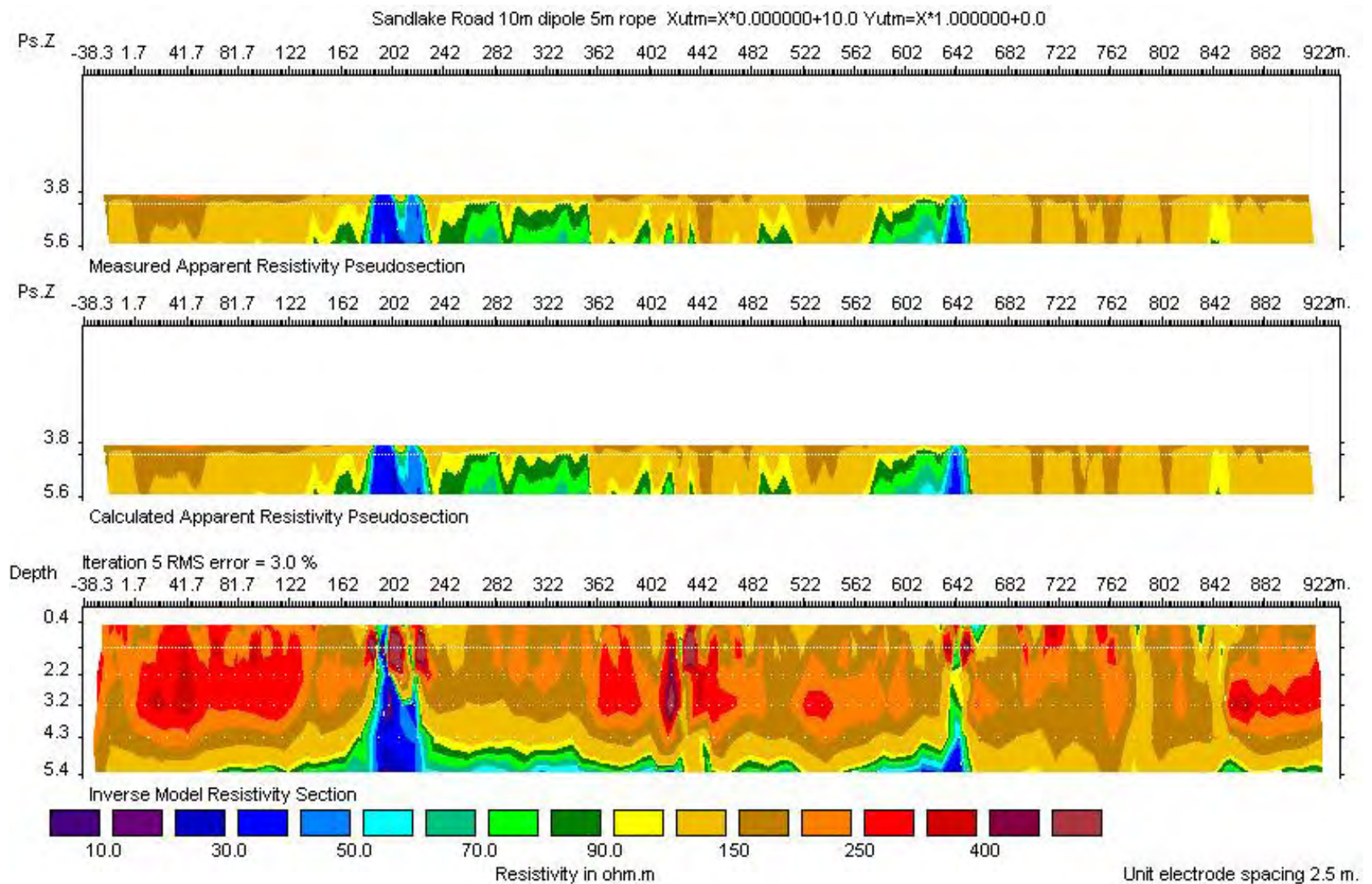
Line D – Combined Passes 1 Through 4

## **APPENDIX E**

### **SANDLAKE ROAD TEST SITE**

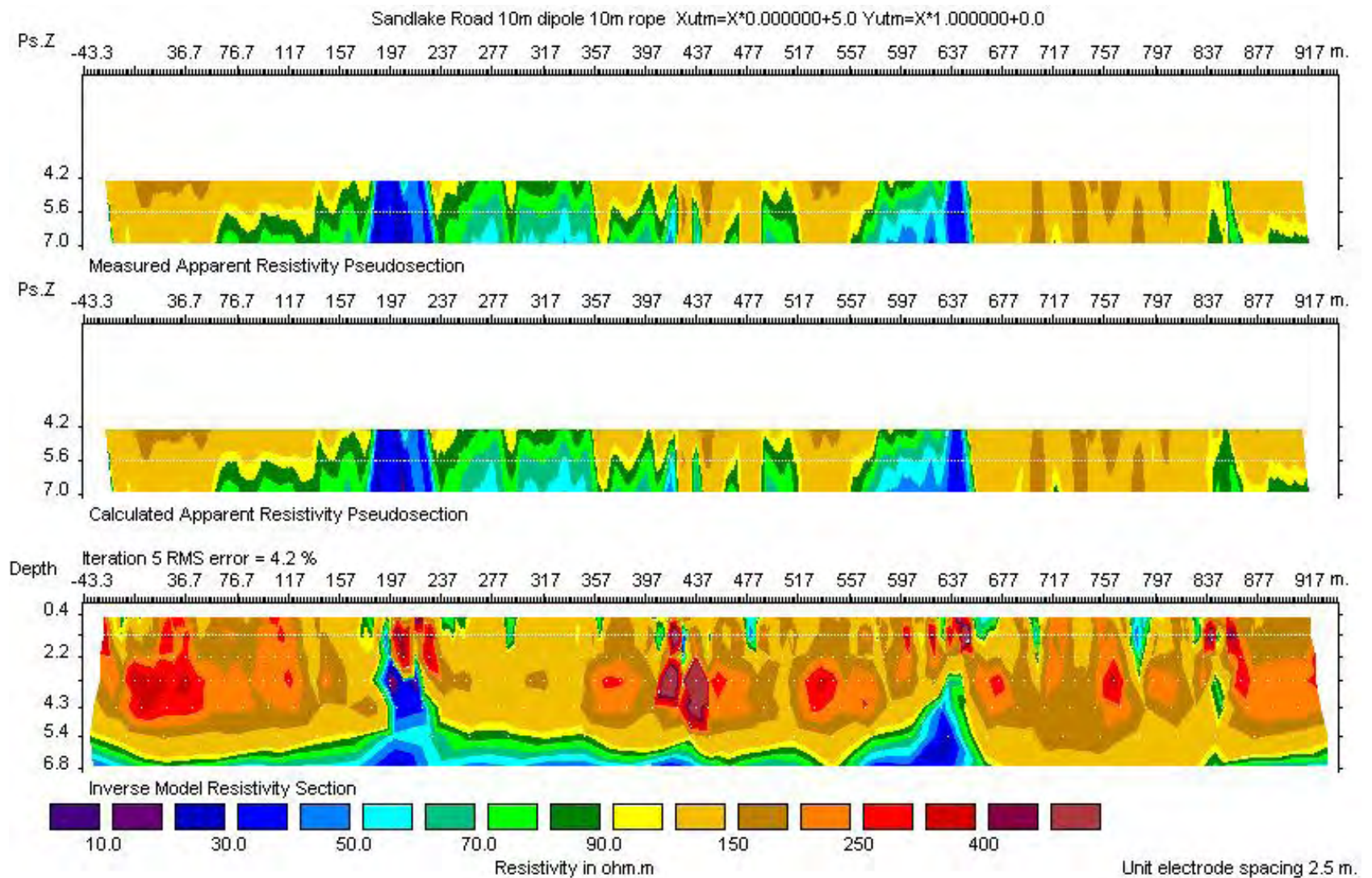


Pass 1 - 5m Dipole with 5m Rope



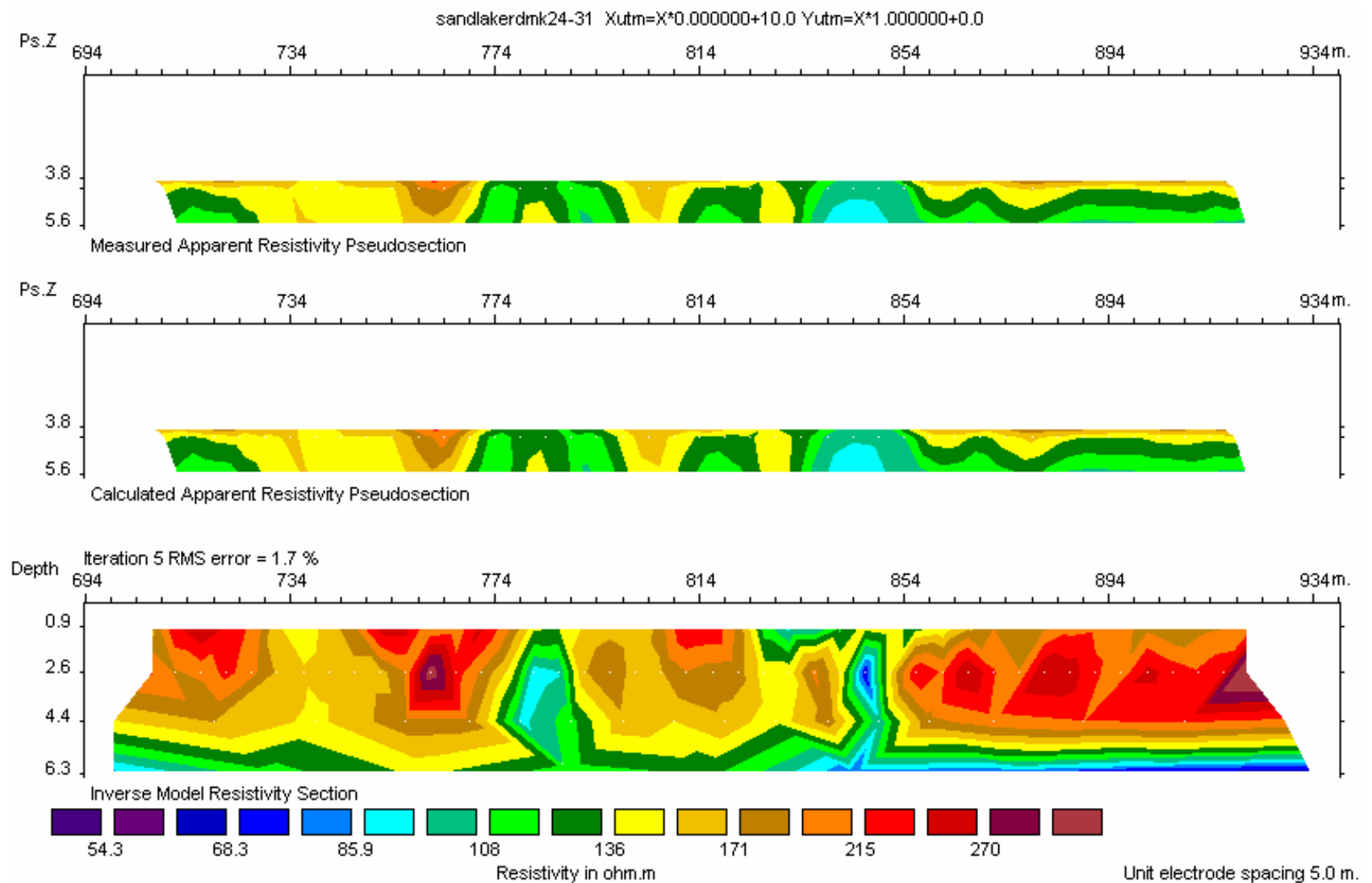
Pass 2 - 10m Dipole with 5m Rope



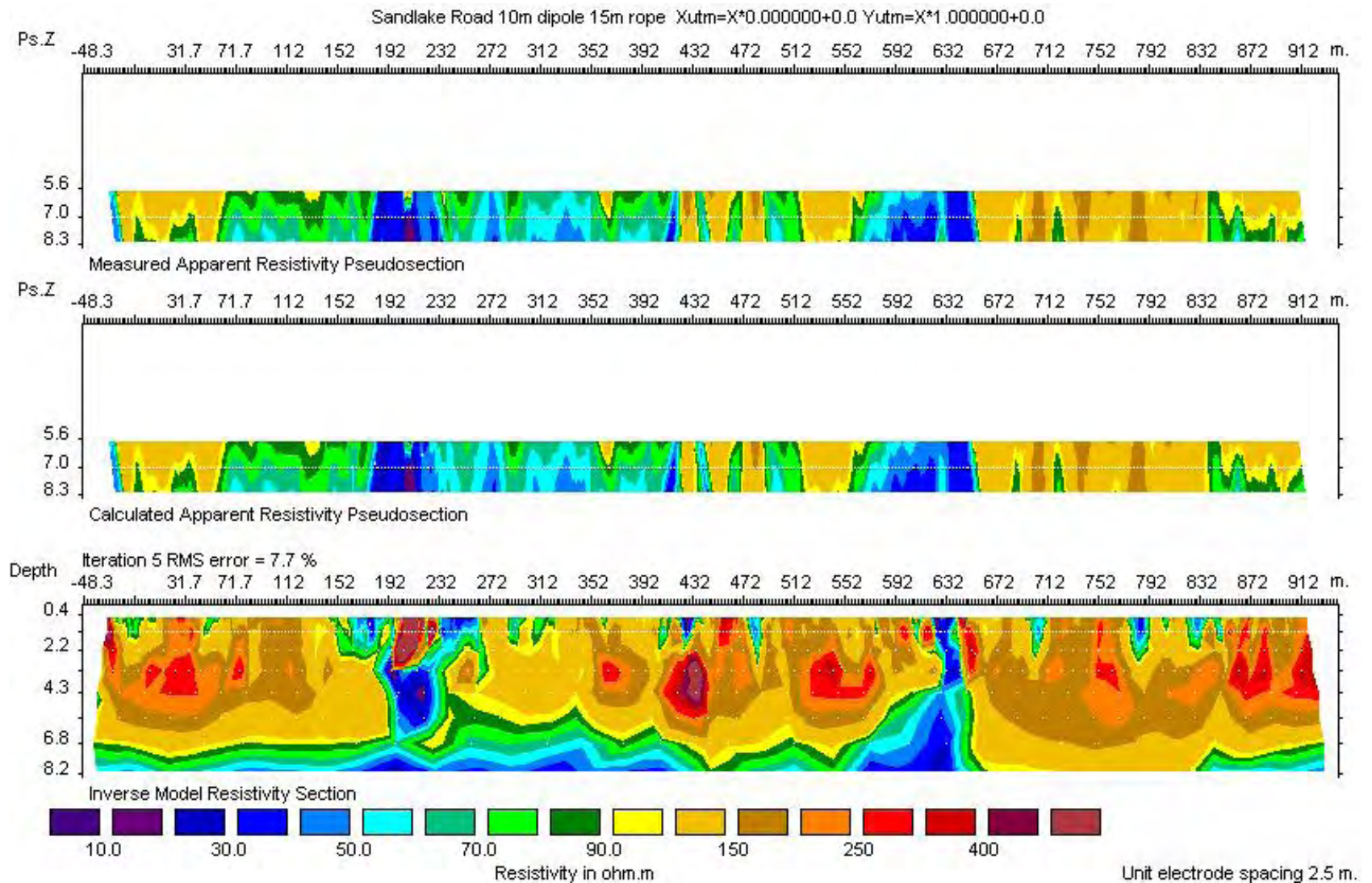


Pass 3 - 10m Dipole with 10m Rope



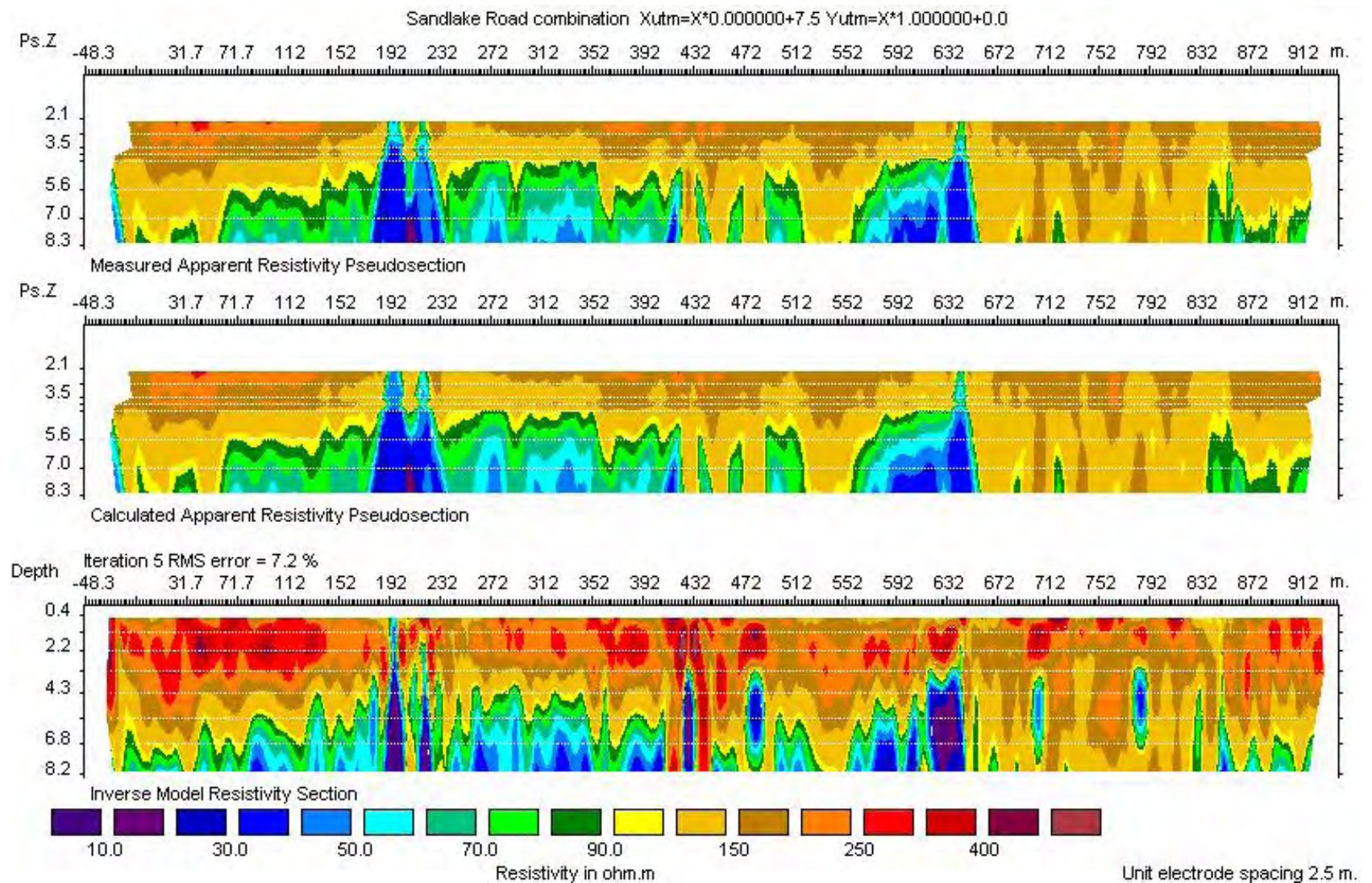


**Pass 3 - 10m Dipole with 10m Rope  
(Higher Resolution Scale at "Dip" Area)**



Pass 4 - 10m Dipole with 15m Rope





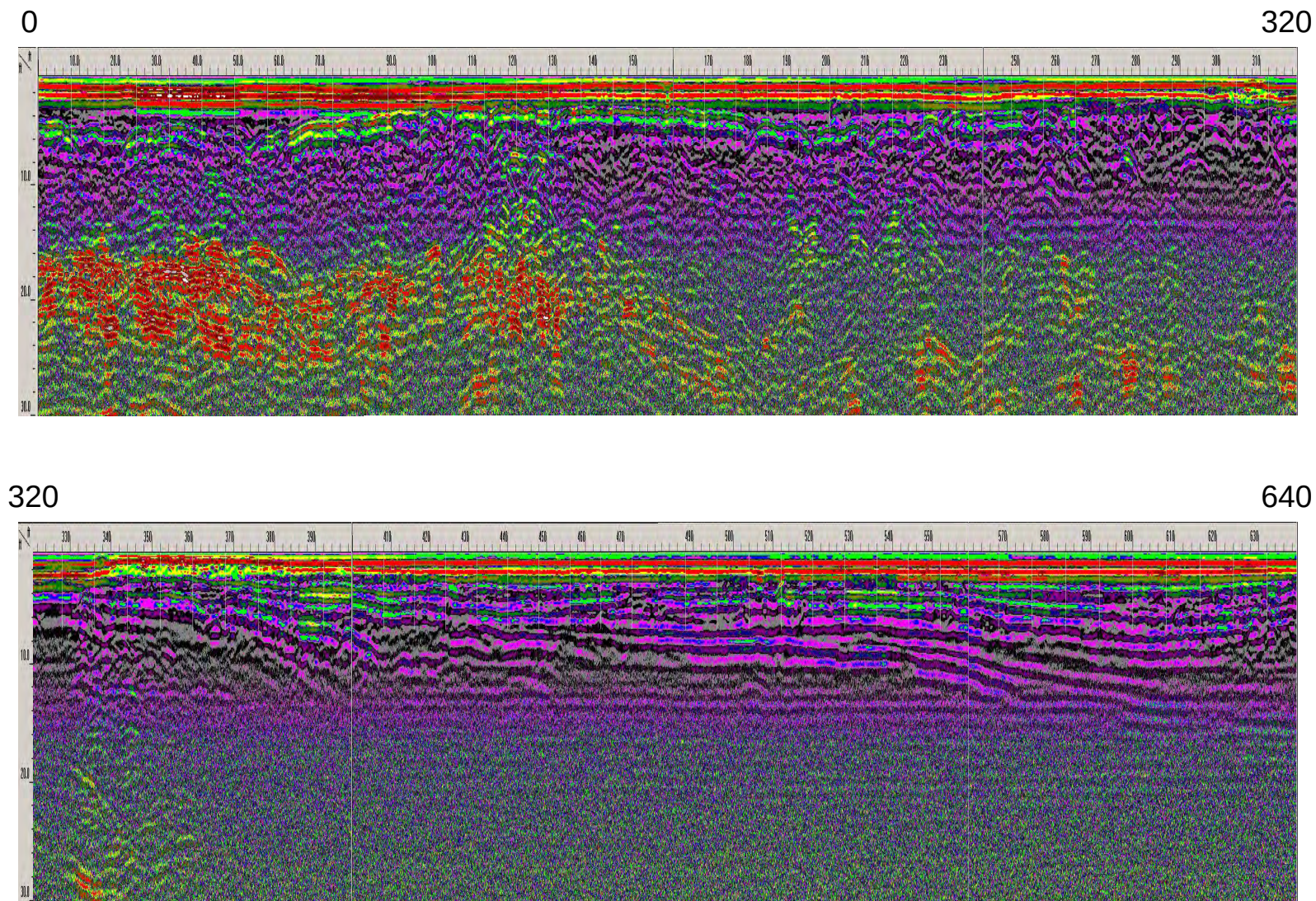
Model for Combined Passes 1 Through 4



Florida Department of Transportation  
Research Project No. BD-498  
Ardaman & Associates, Inc.

SANDLAKE ROAD TEST DATA  
GROUND PENETRATING RADAR RESULTS

FIGURE  
E7



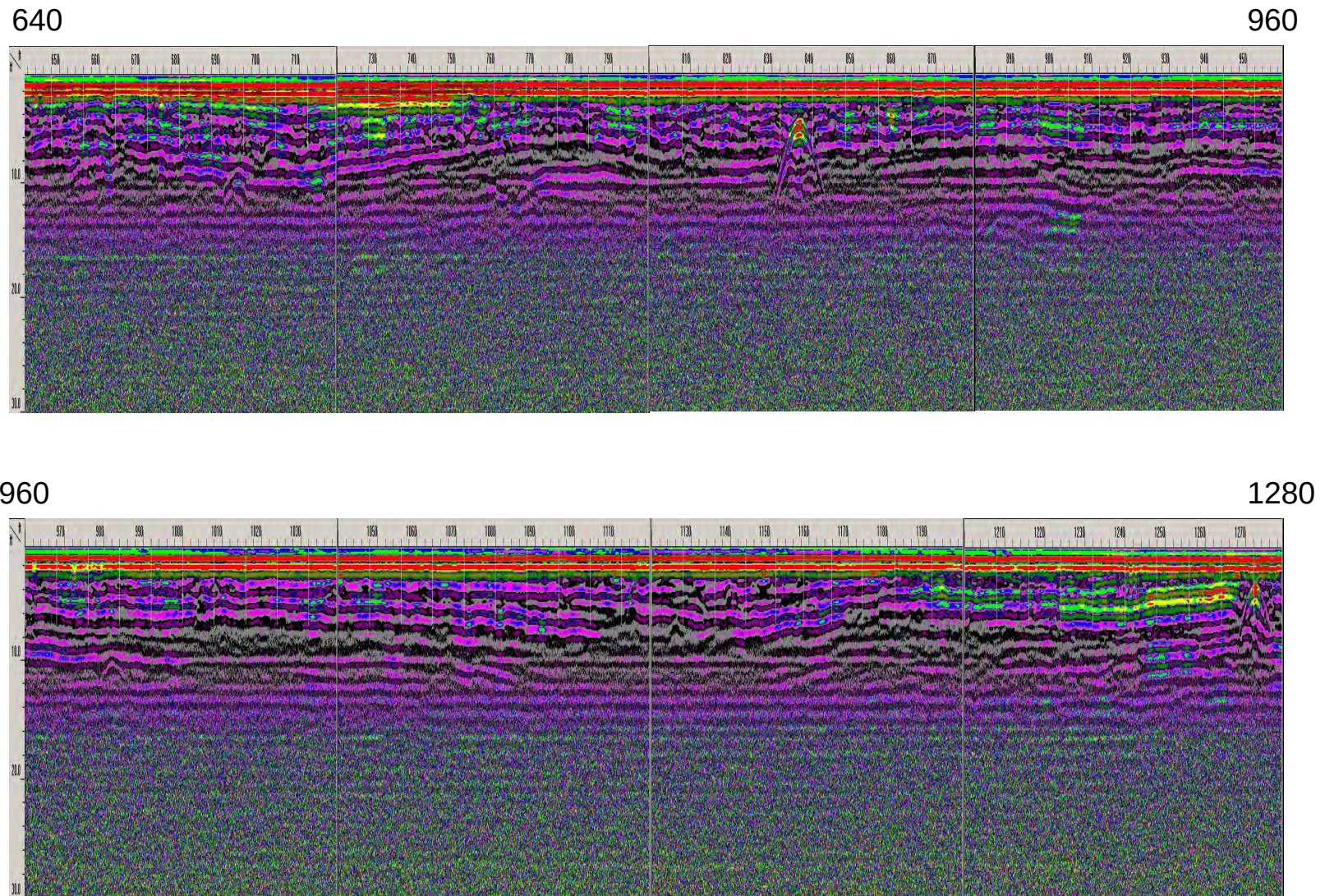
GPR Results (0- 640 Feet)



Florida Department of Transportation  
Research Project No. BD-498  
Ardaman & Associates, Inc.

SANDLAKE ROAD TEST DATA  
GROUND PENETRATING RADAR RESULTS

FIGURE  
E8

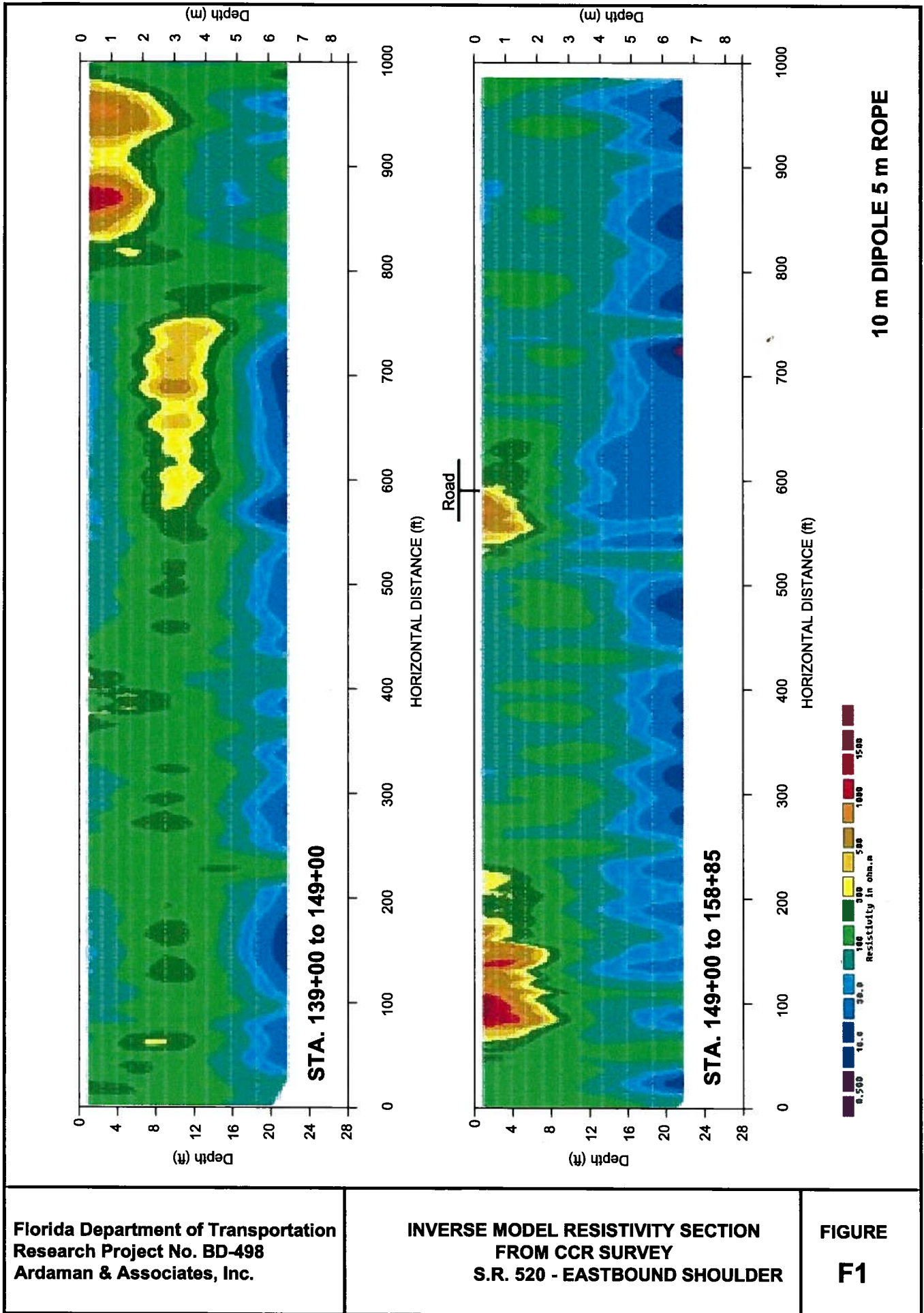


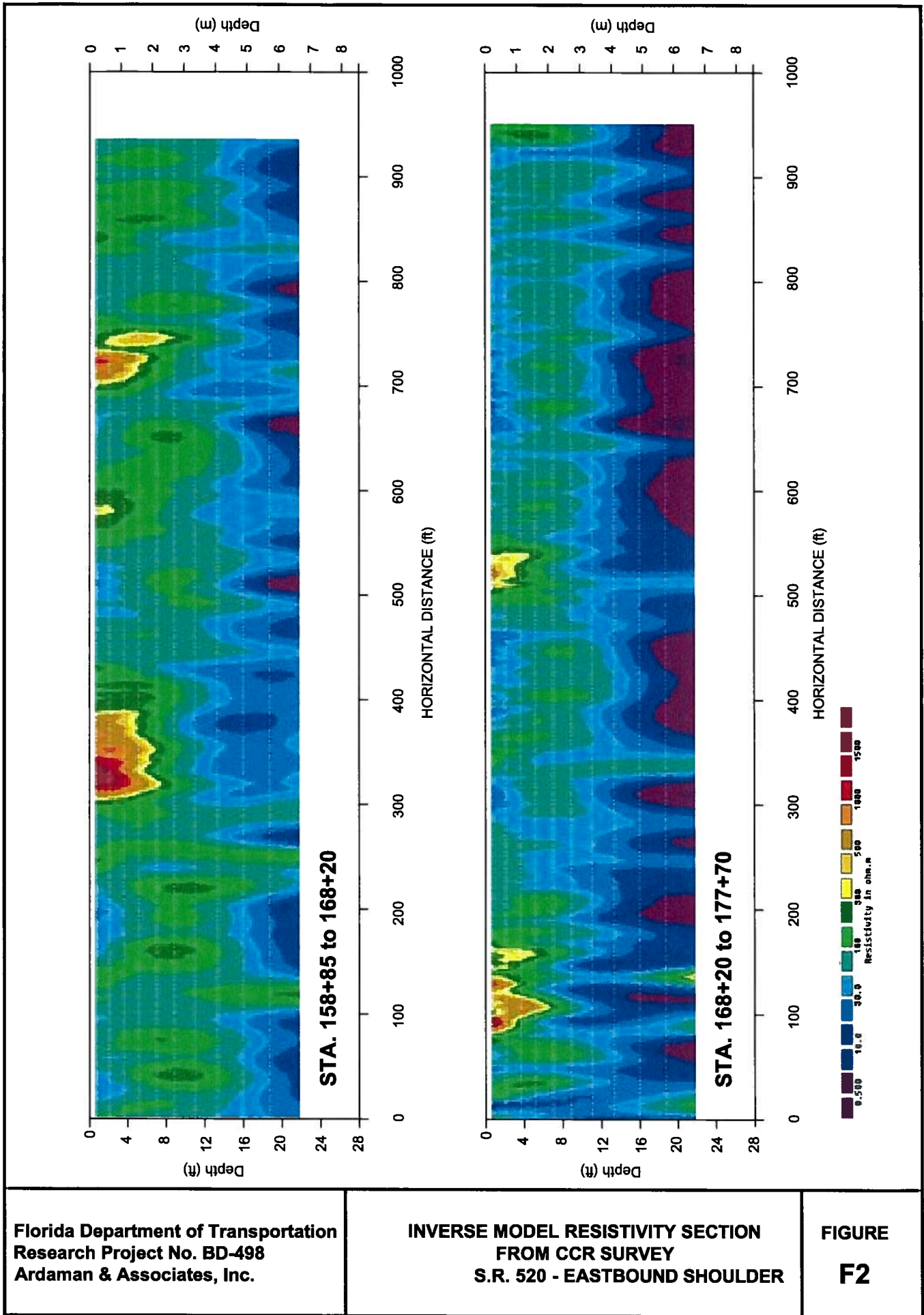
GPR Results (640- 1280 Feet)

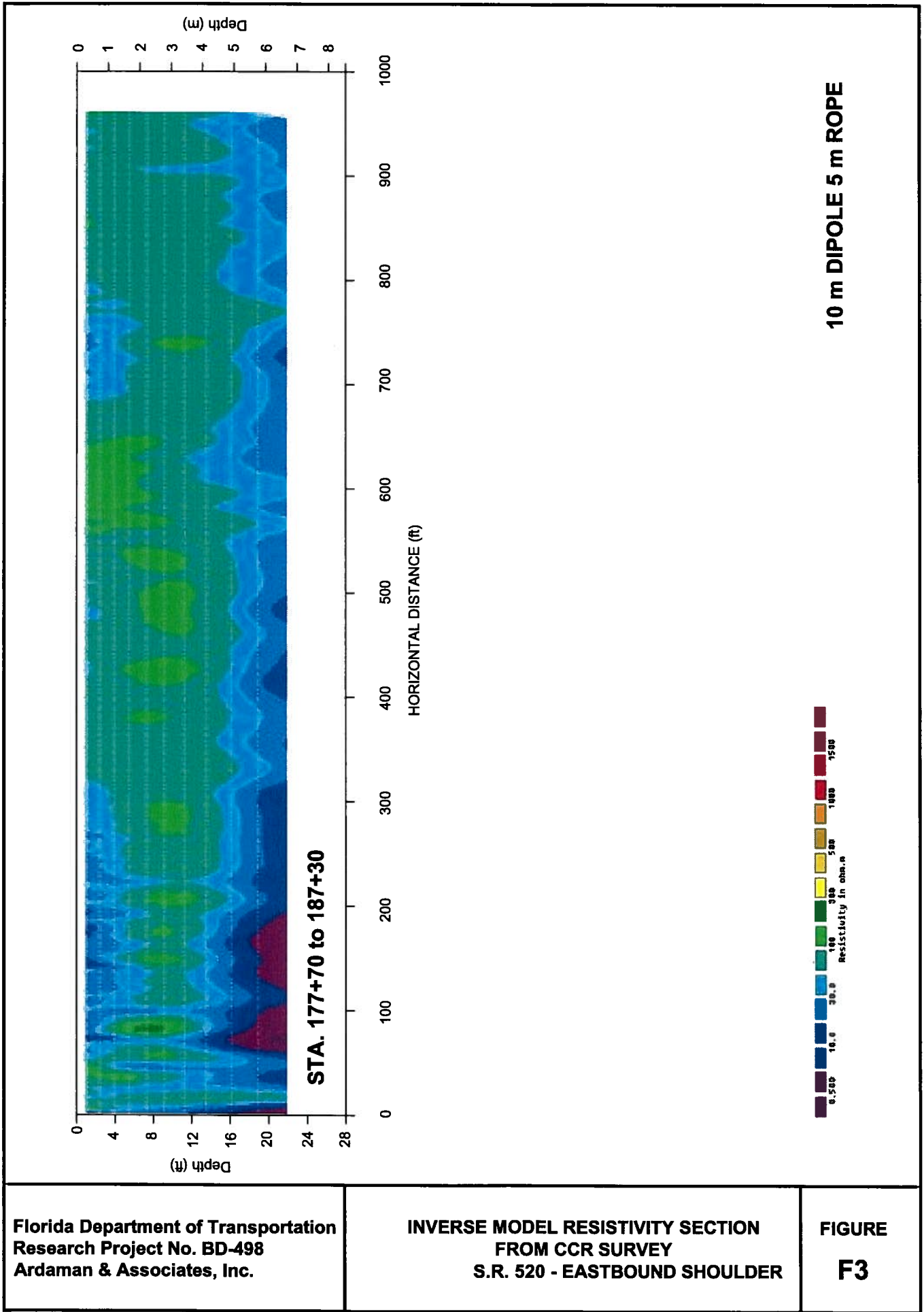


## **APPENDIX F**

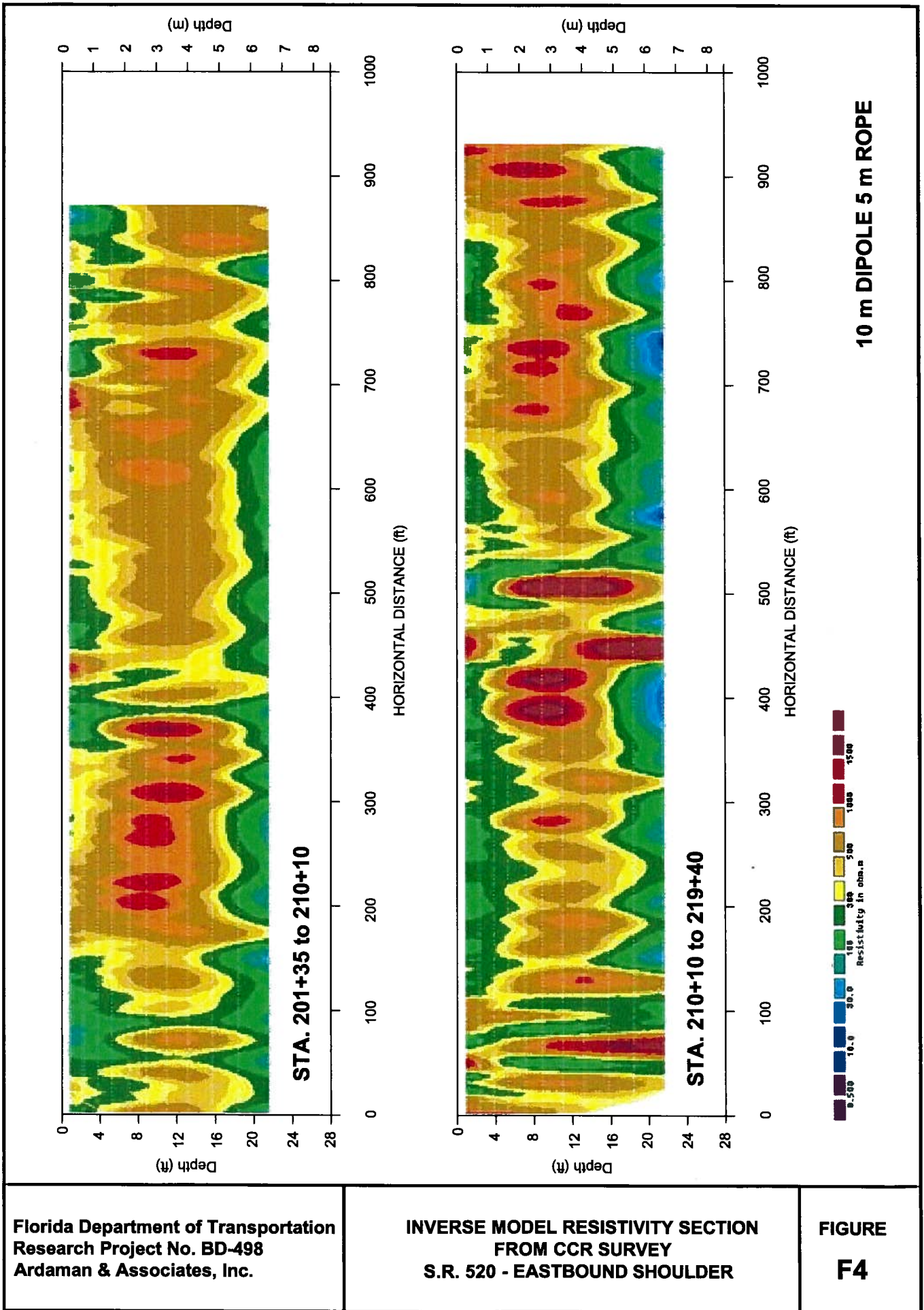
### **S.R. 520 TEST DATA**

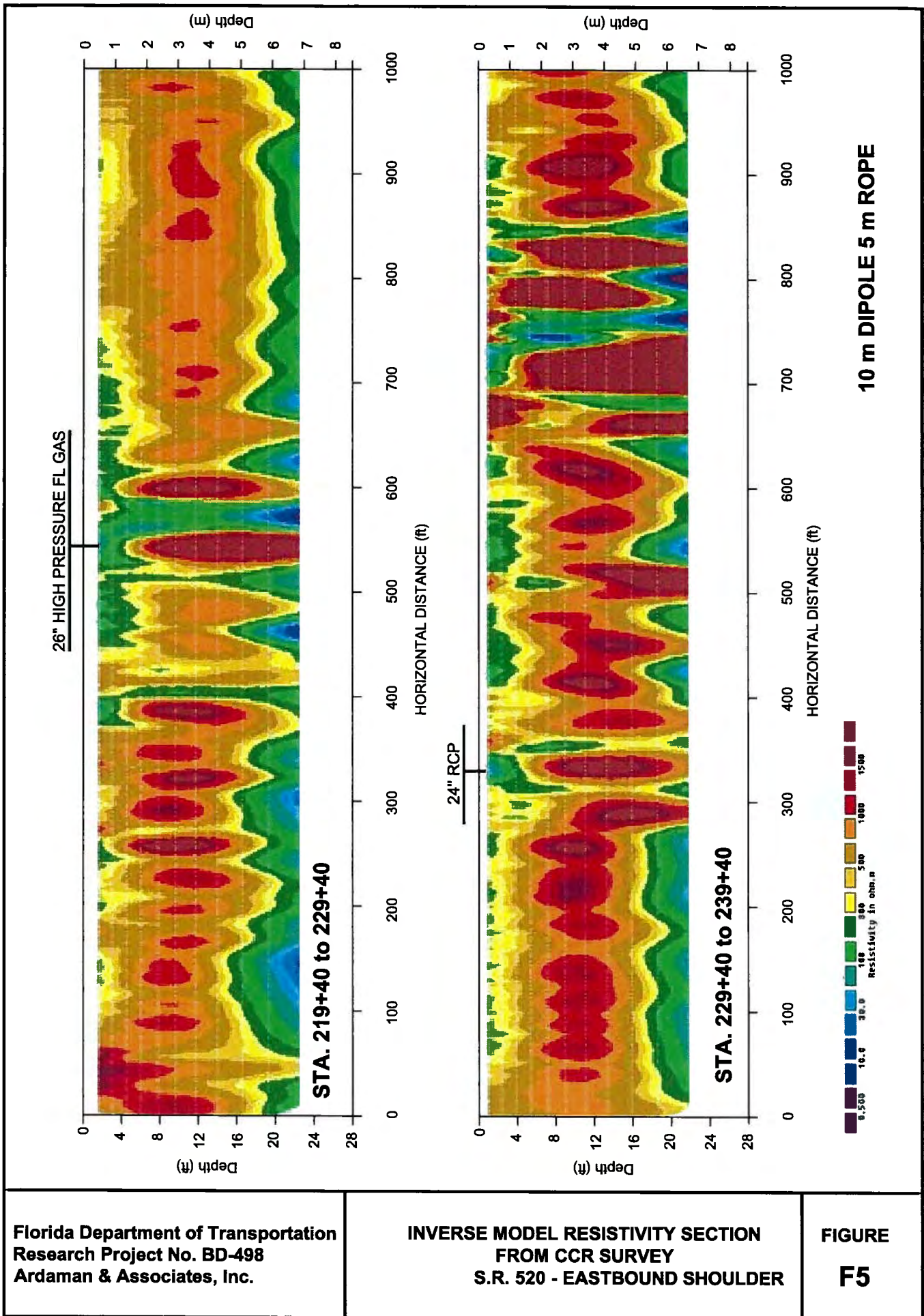










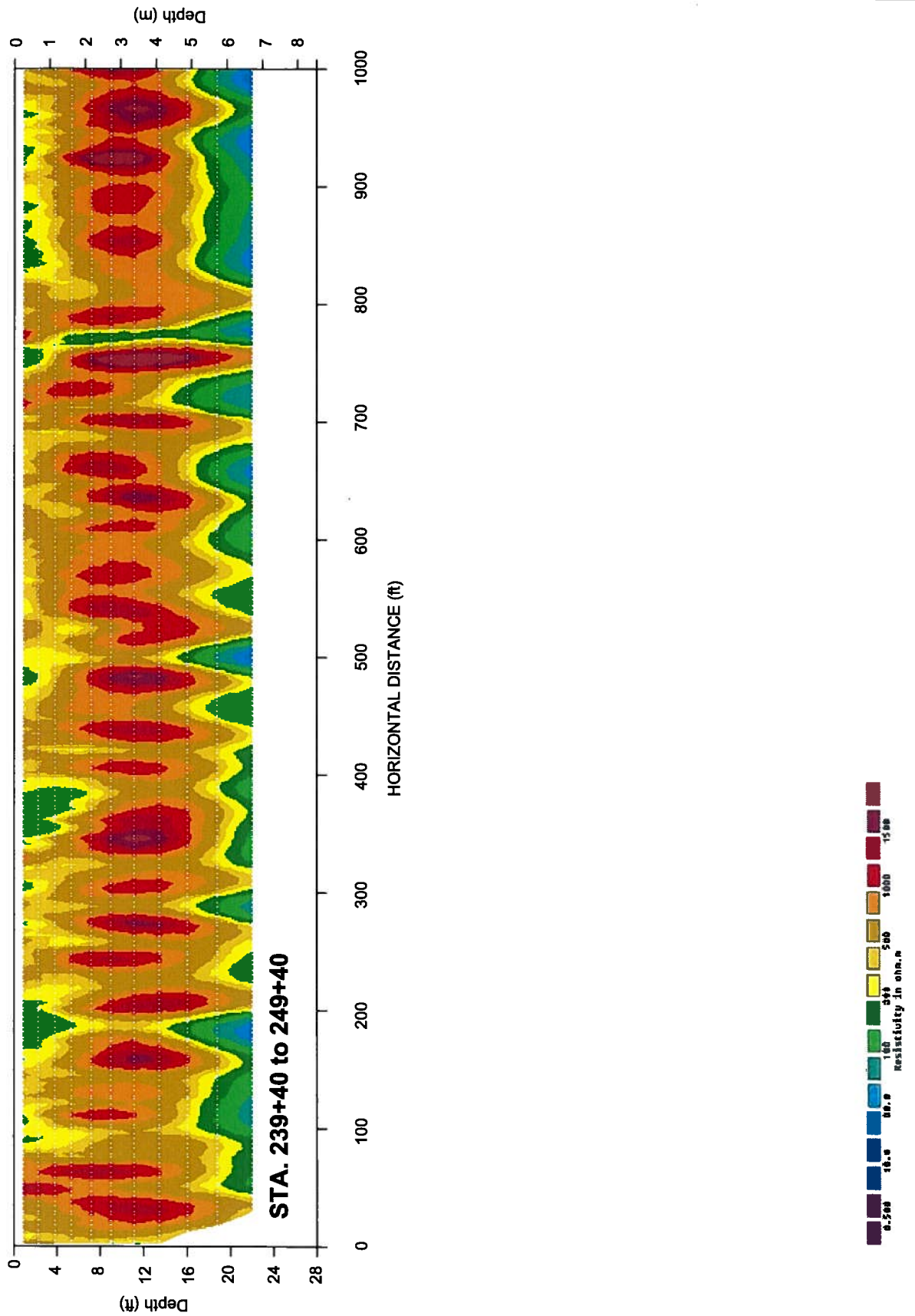


Florida Department of Transportation  
Research Project No. BD-498  
Ardaman & Associates, Inc.

INVERSE MODEL RESISTIVITY SECTION  
FROM CCR SURVEY  
S.R. 520 - EASTBOUND SHOULDER

FIGURE  
F5

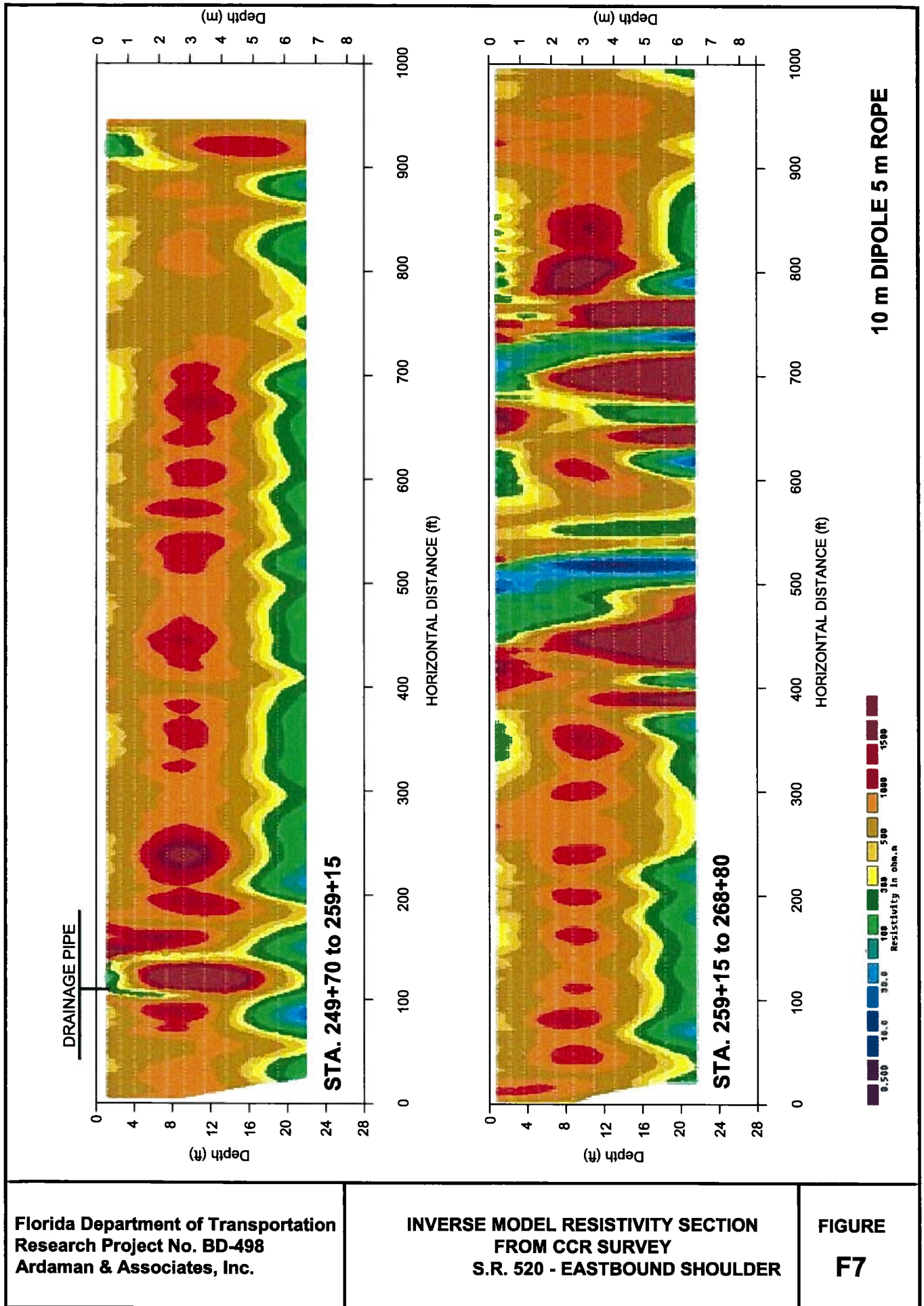




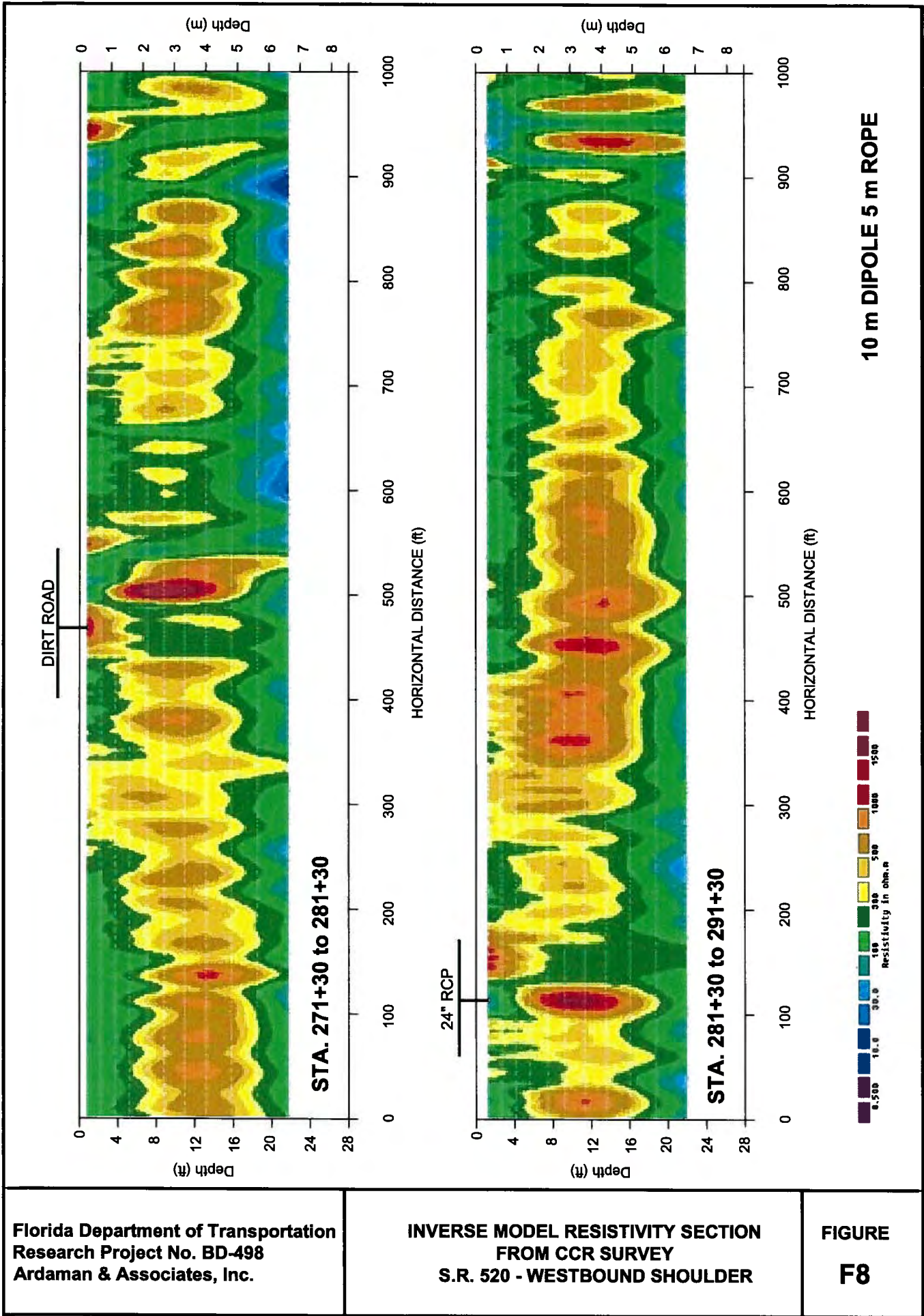
Florida Department of Transportation  
 Research Project No. BD-498  
 Ardaman & Associates, Inc.

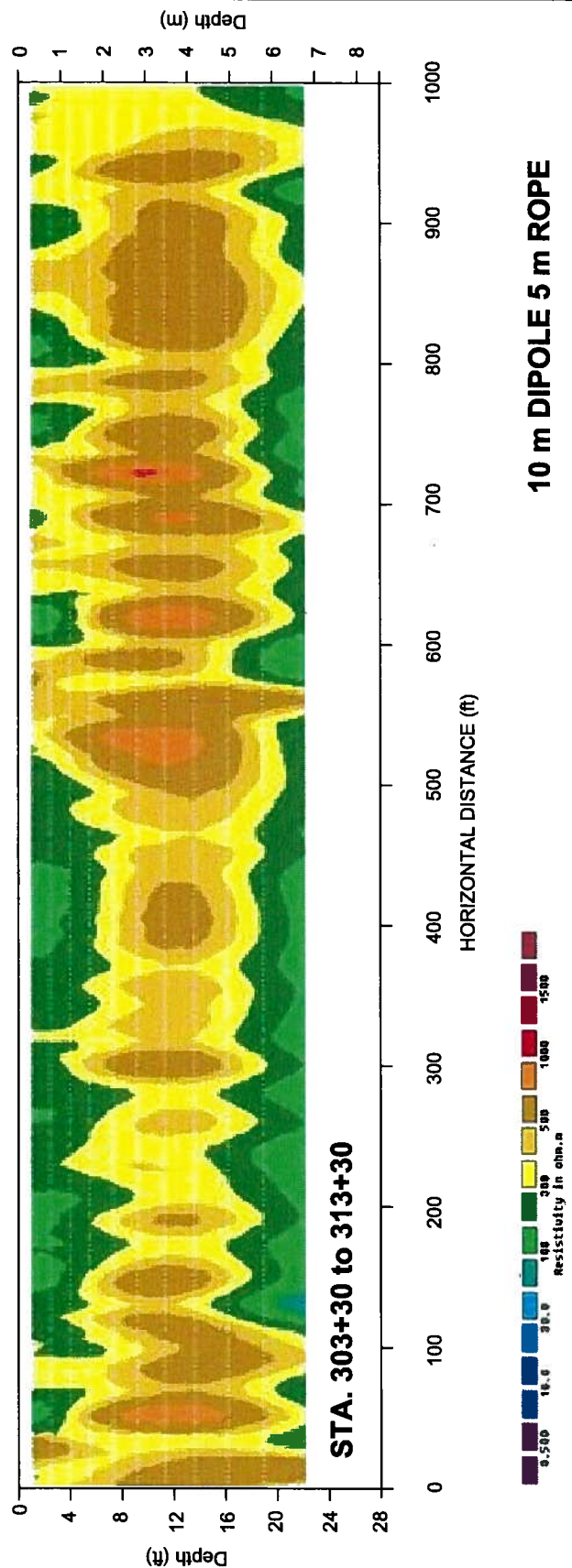
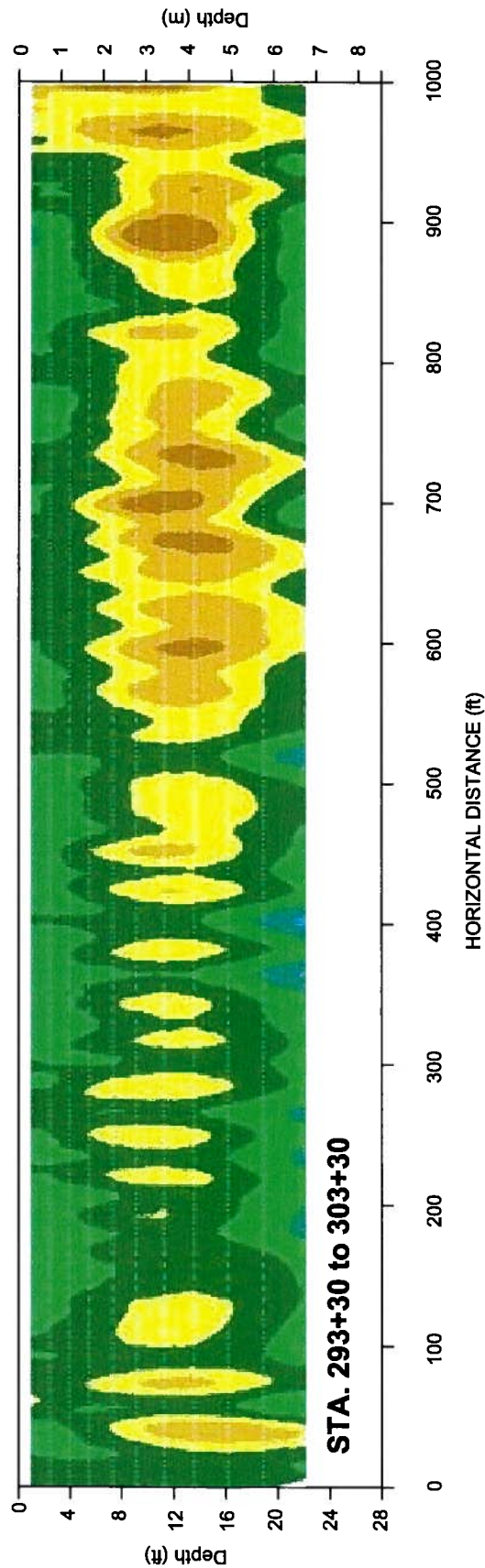
INVERSE MODEL RESISTIVITY SECTION  
 FROM CCR SURVEY  
 S.R. 520 - EASTBOUND SHOULDER

FIGURE  
**F6**









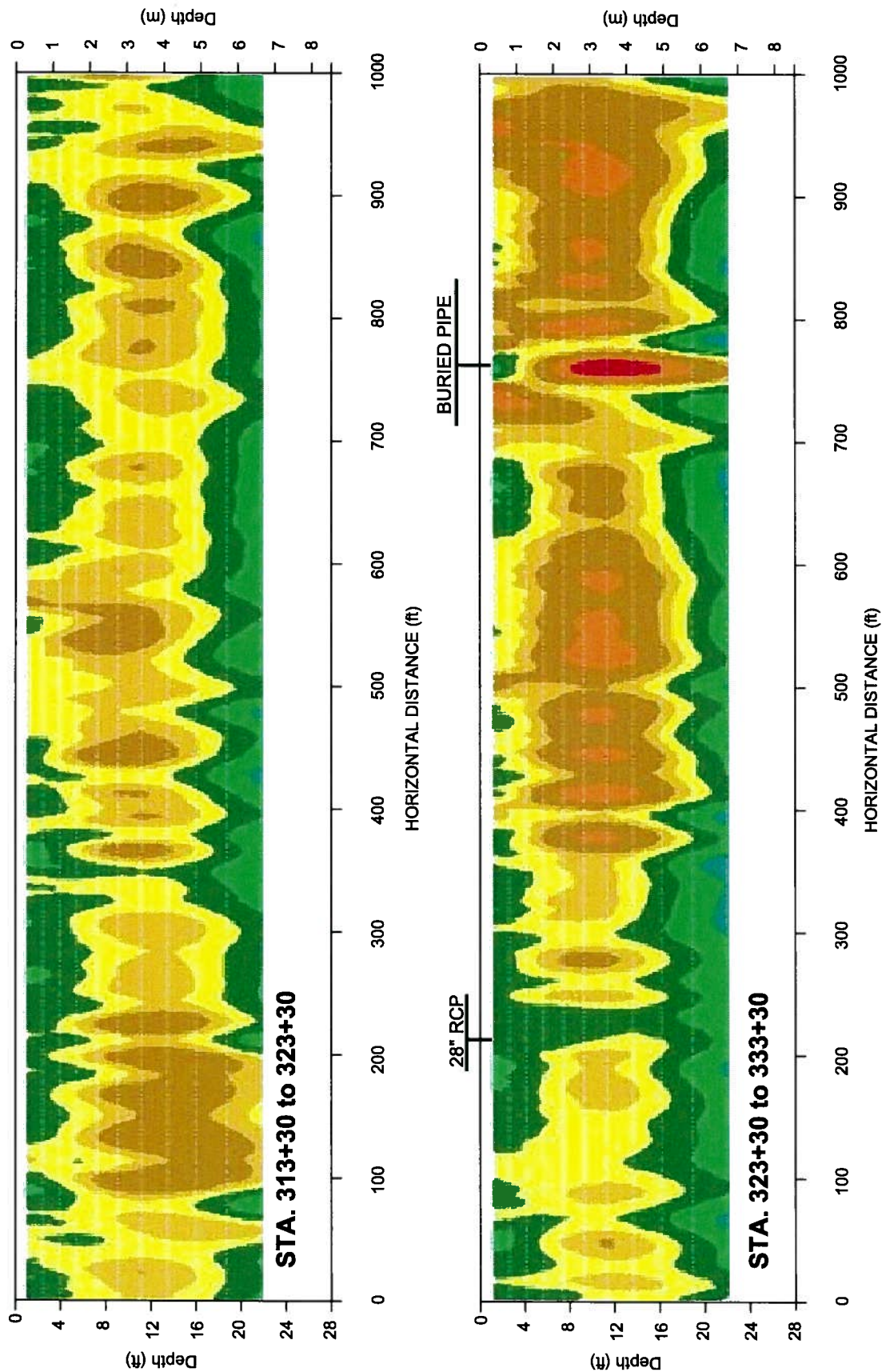
**10 m DIPOLE 5 m ROPE**

Florida Department of Transportation  
Research Project No. BD-498  
Ardaman & Associates, Inc.

INVERSE MODEL RESISTIVITY SECTION  
FROM CCR SURVEY  
S.R. 520 - WESTBOUND SHOULDER

FIGURE  
**F9**



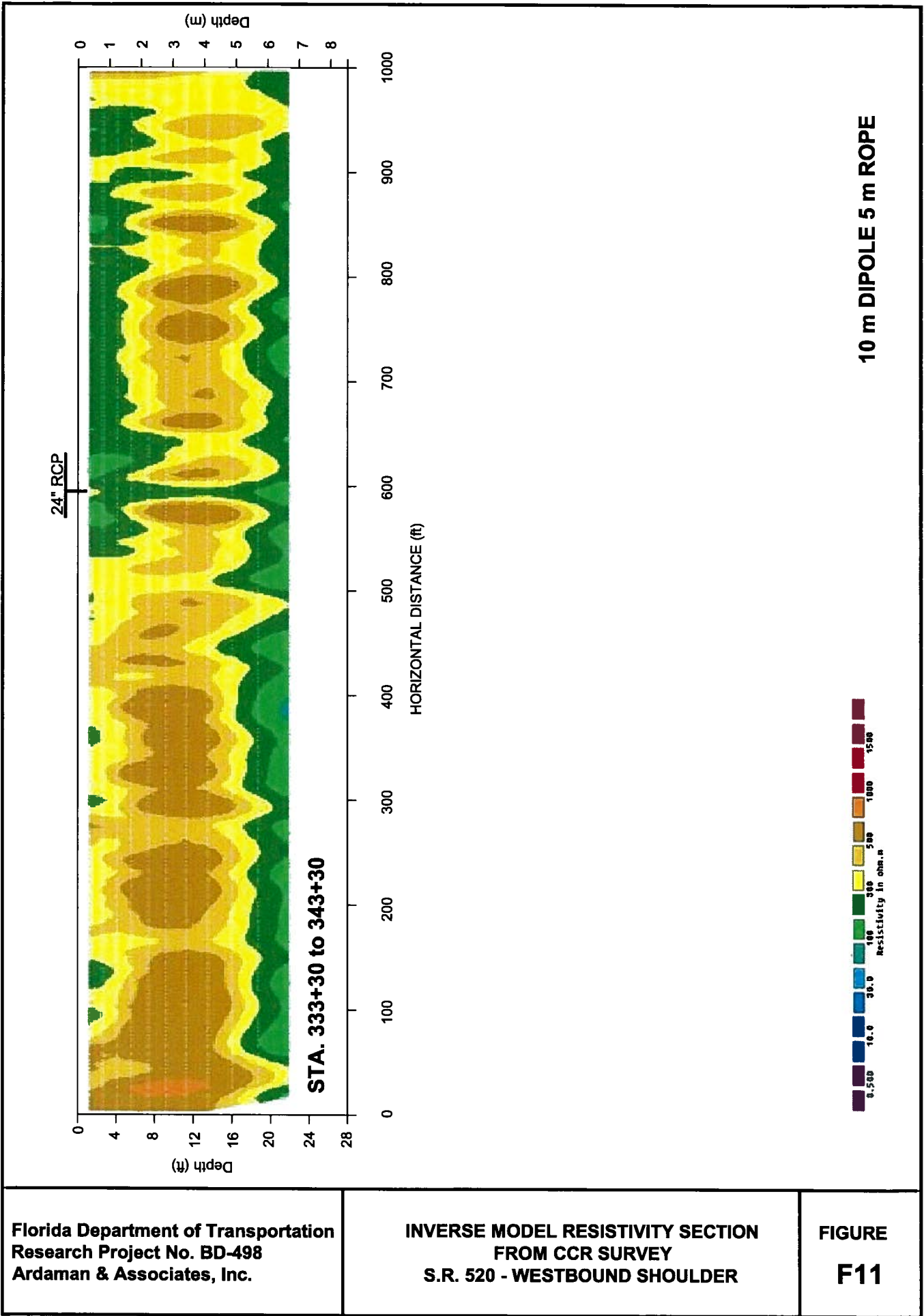


10 m DIPOLE 5 m ROPE

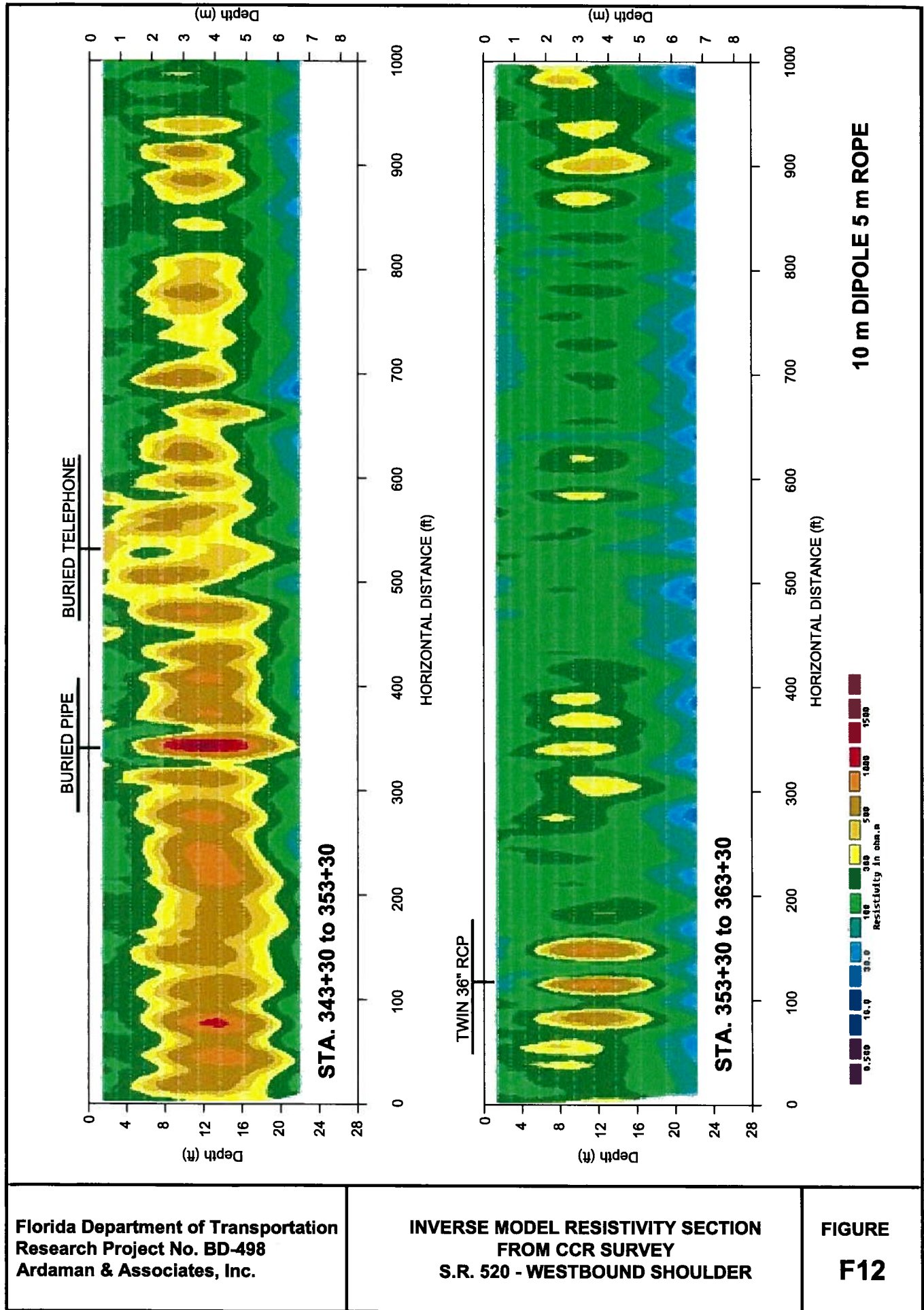
Florida Department of Transportation  
Research Project No. BD-498  
Ardaman & Associates, Inc.

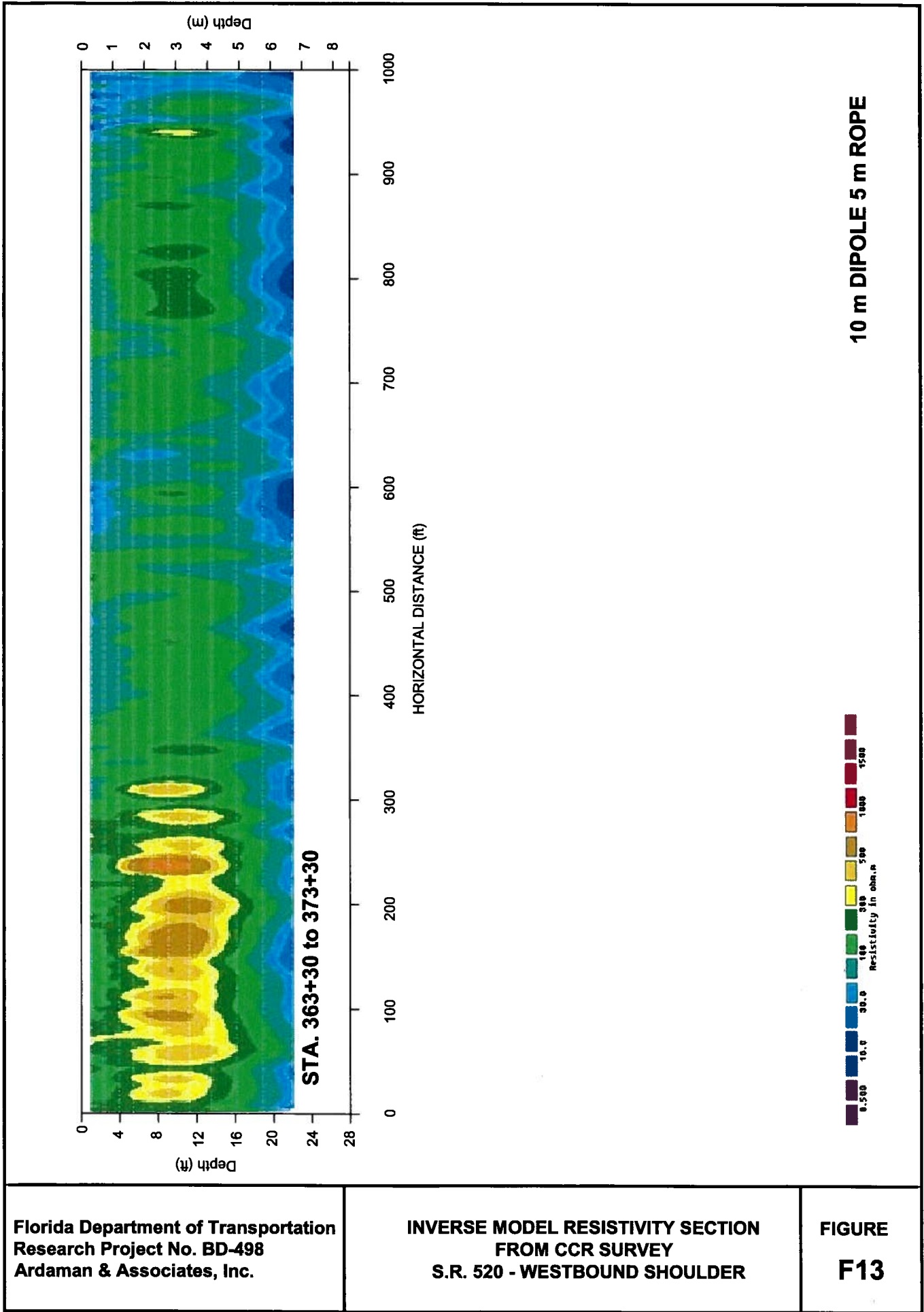
INVERSE MODEL RESISTIVITY SECTION  
FROM CCR SURVEY  
S.R. 520 - WESTBOUND SHOULDER

FIGURE  
F10





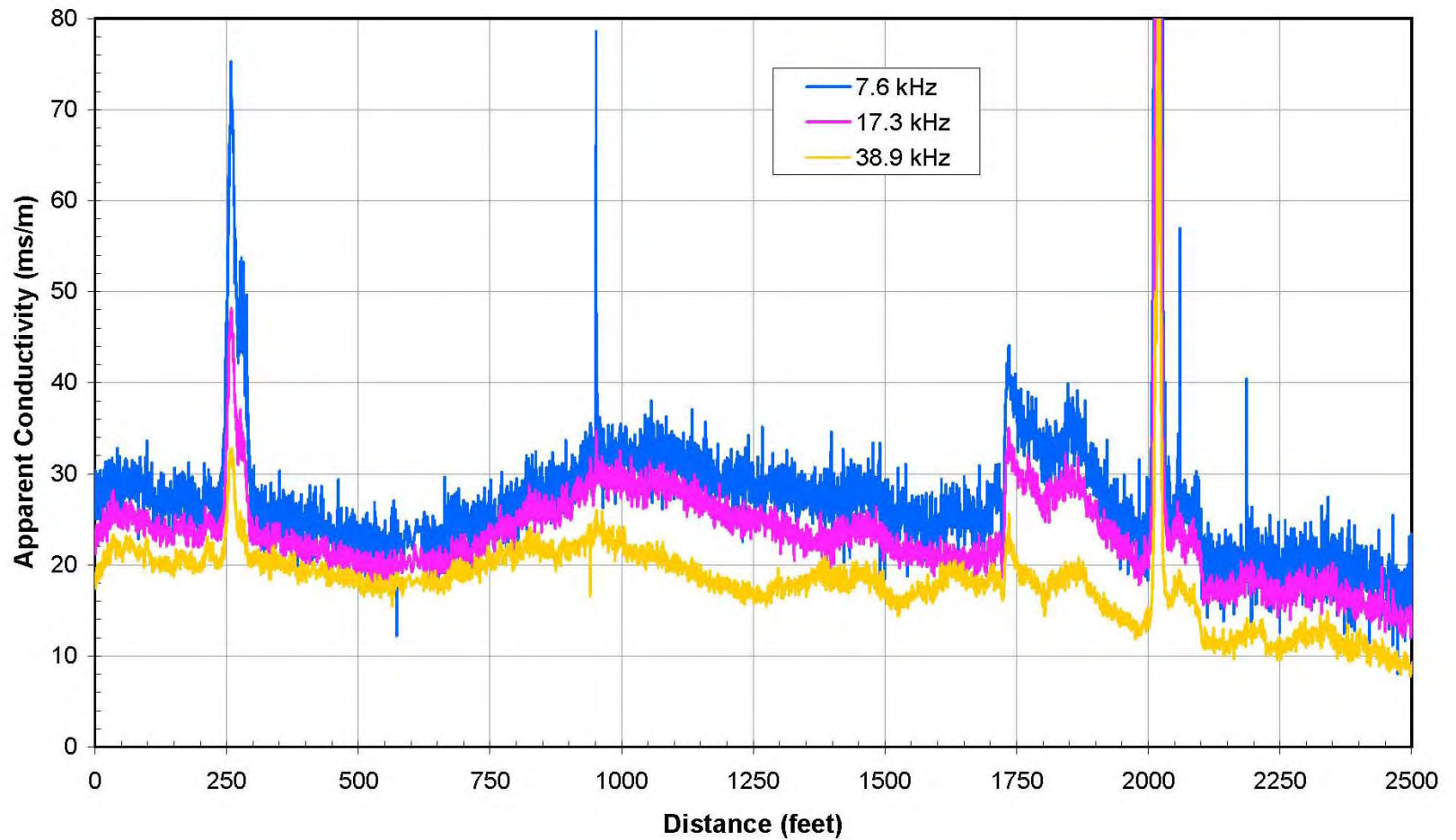




Florida Department of Transportation  
Research Project No. BD-498  
Ardaman & Associates, Inc.

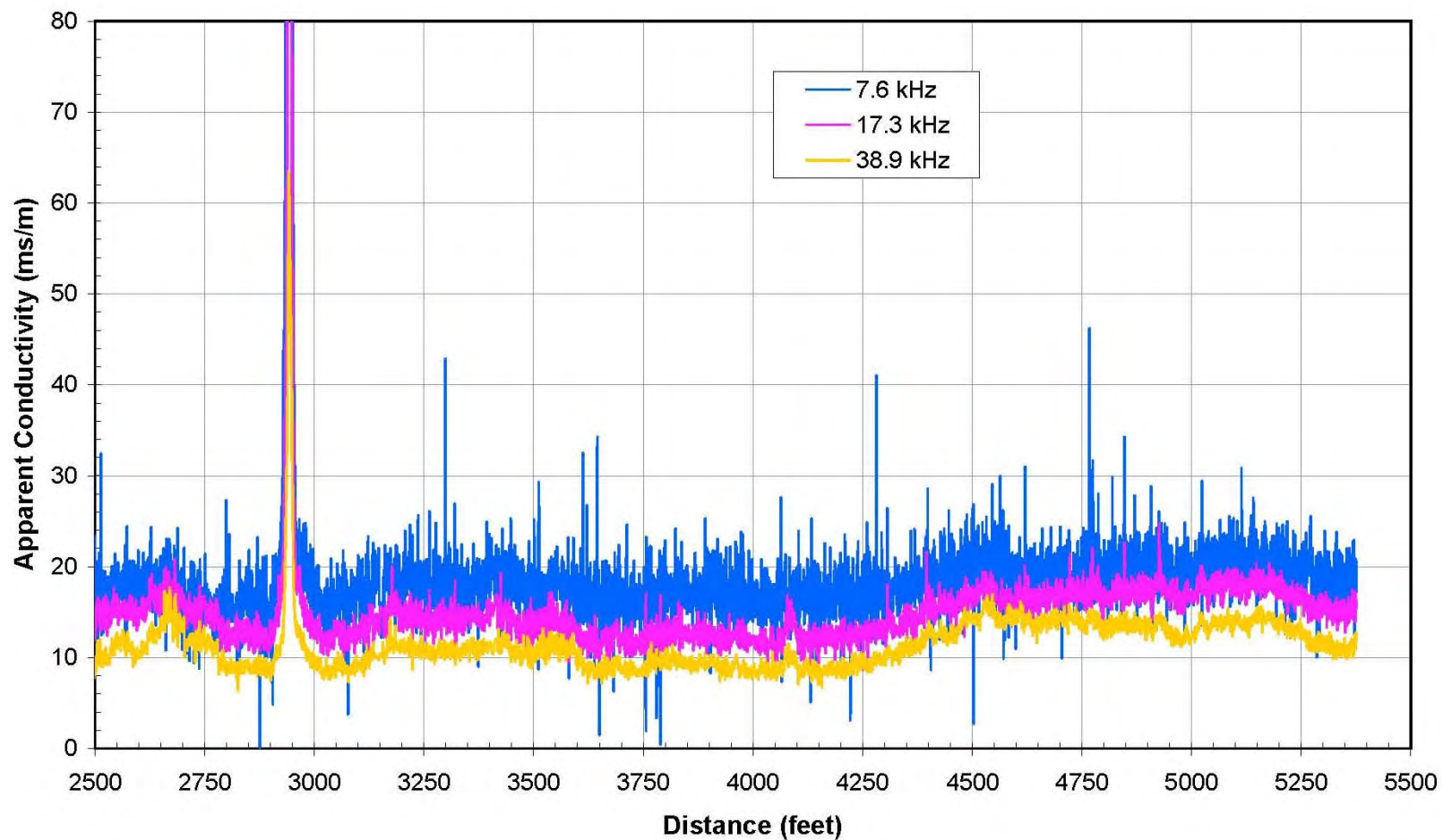
INVERSE MODEL RESISTIVITY SECTION  
FROM CCR SURVEY  
S.R. 520 - WESTBOUND SHOULDER

FIGURE  
F13



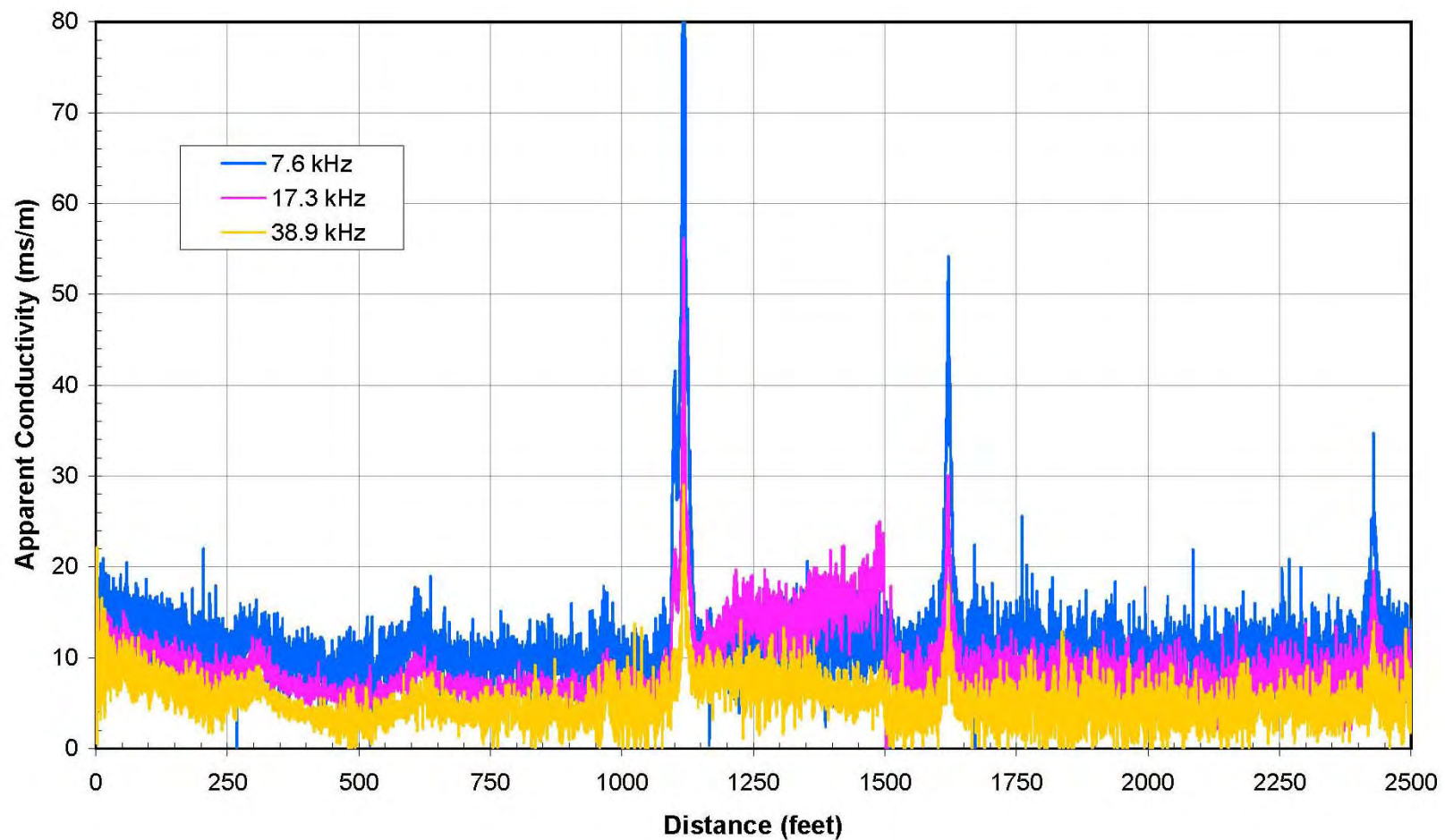
Line 1 – GEM2 Terrain Conductivity Data (0–2500 Feet)



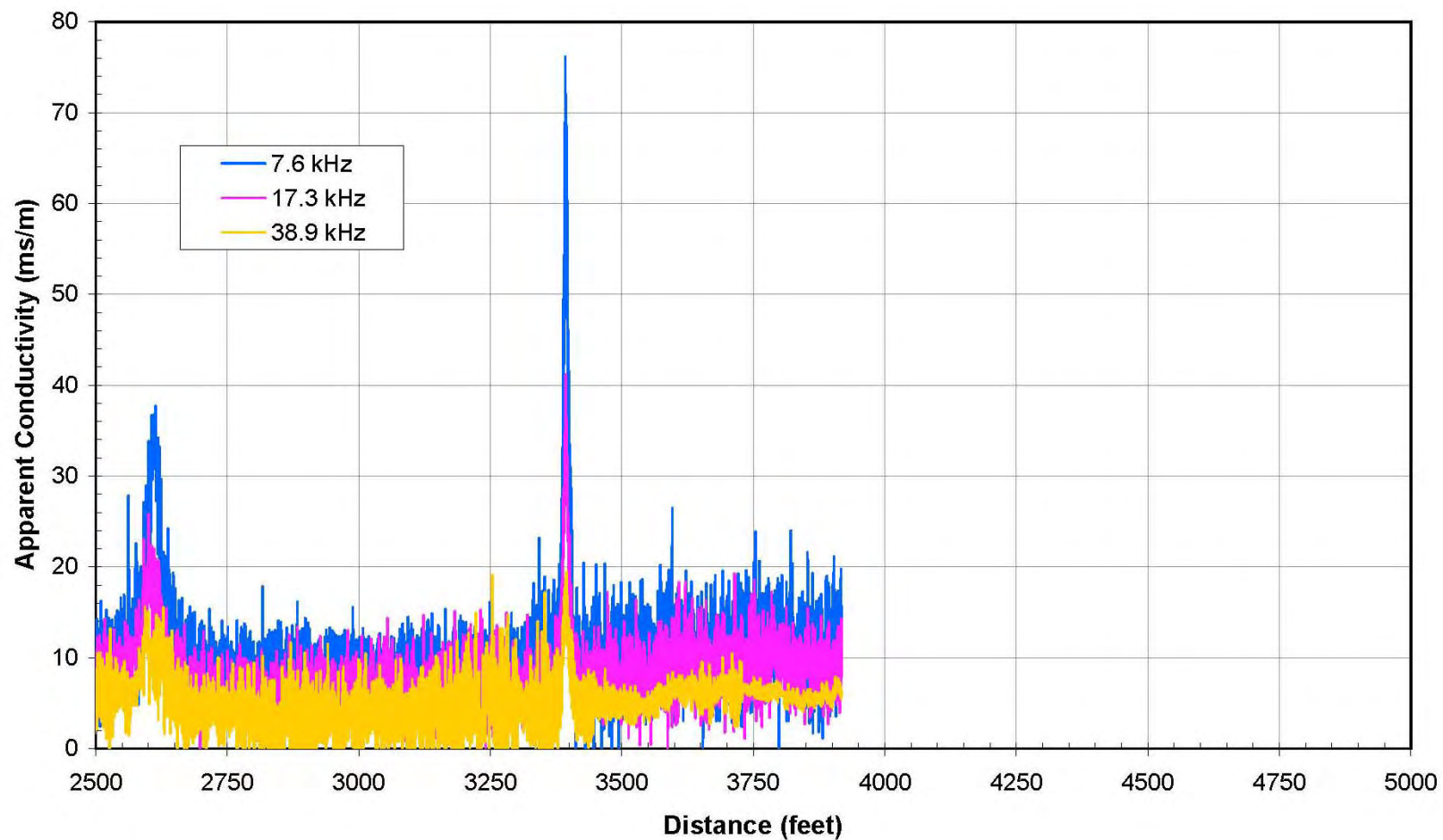


Line 1 – GEM2 Terrain Conductivity Data (2500–5400 Feet)

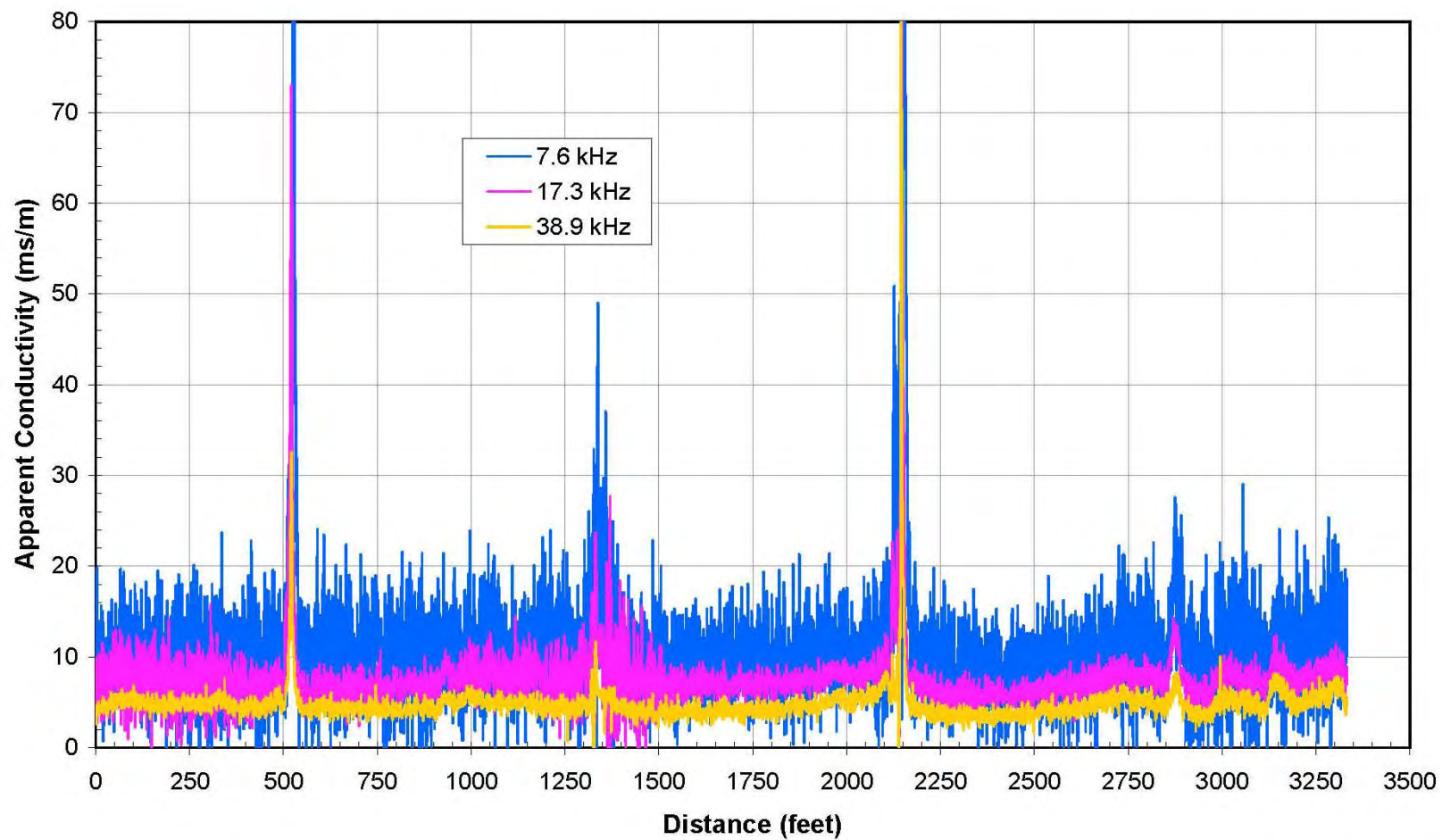




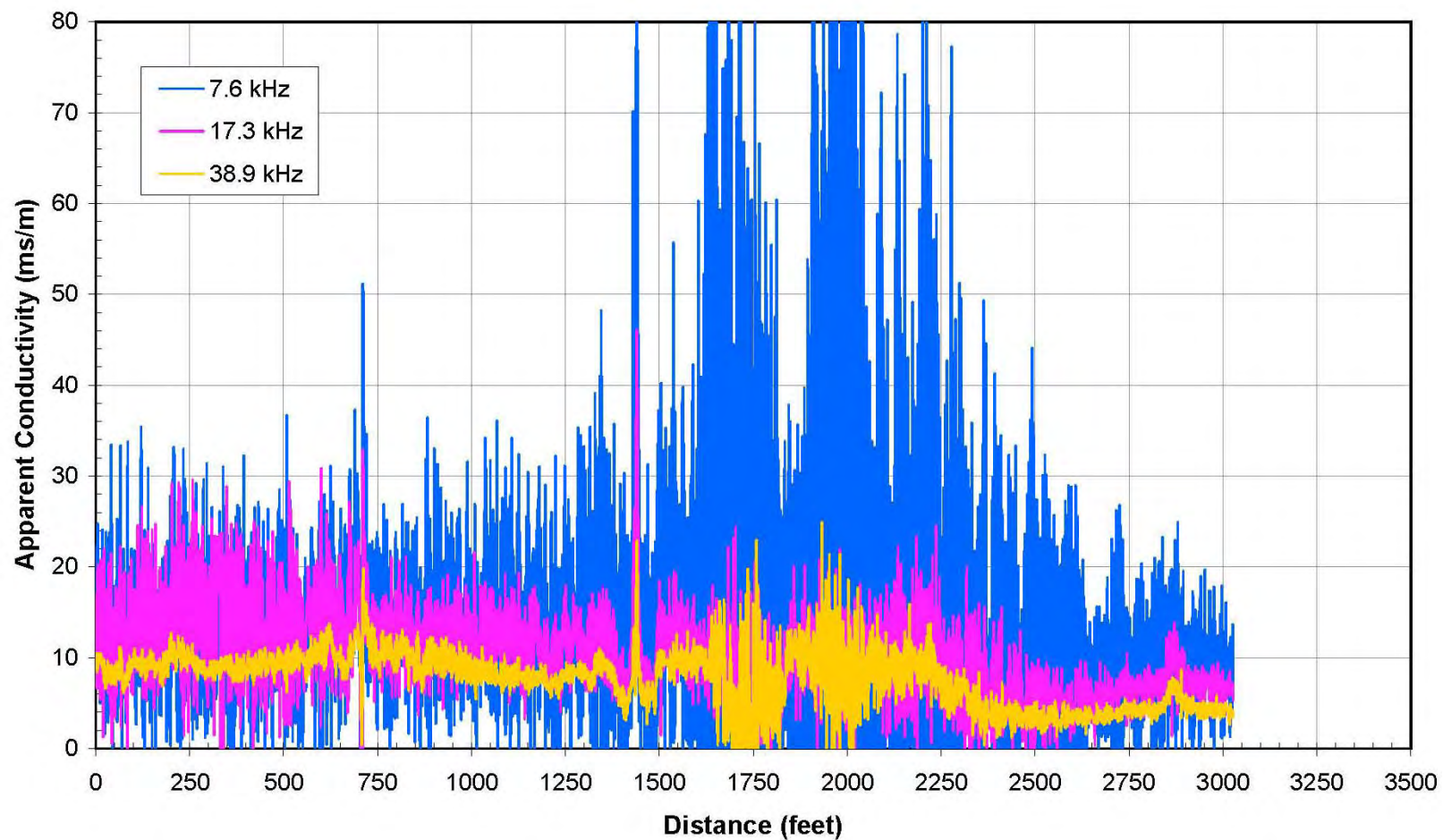
Line 2 – GEM2 Terrain Conductivity Data (0–2500 Feet)



Line 2 – GEM2 Terrain Conductivity Data (2500-3925 Feet)

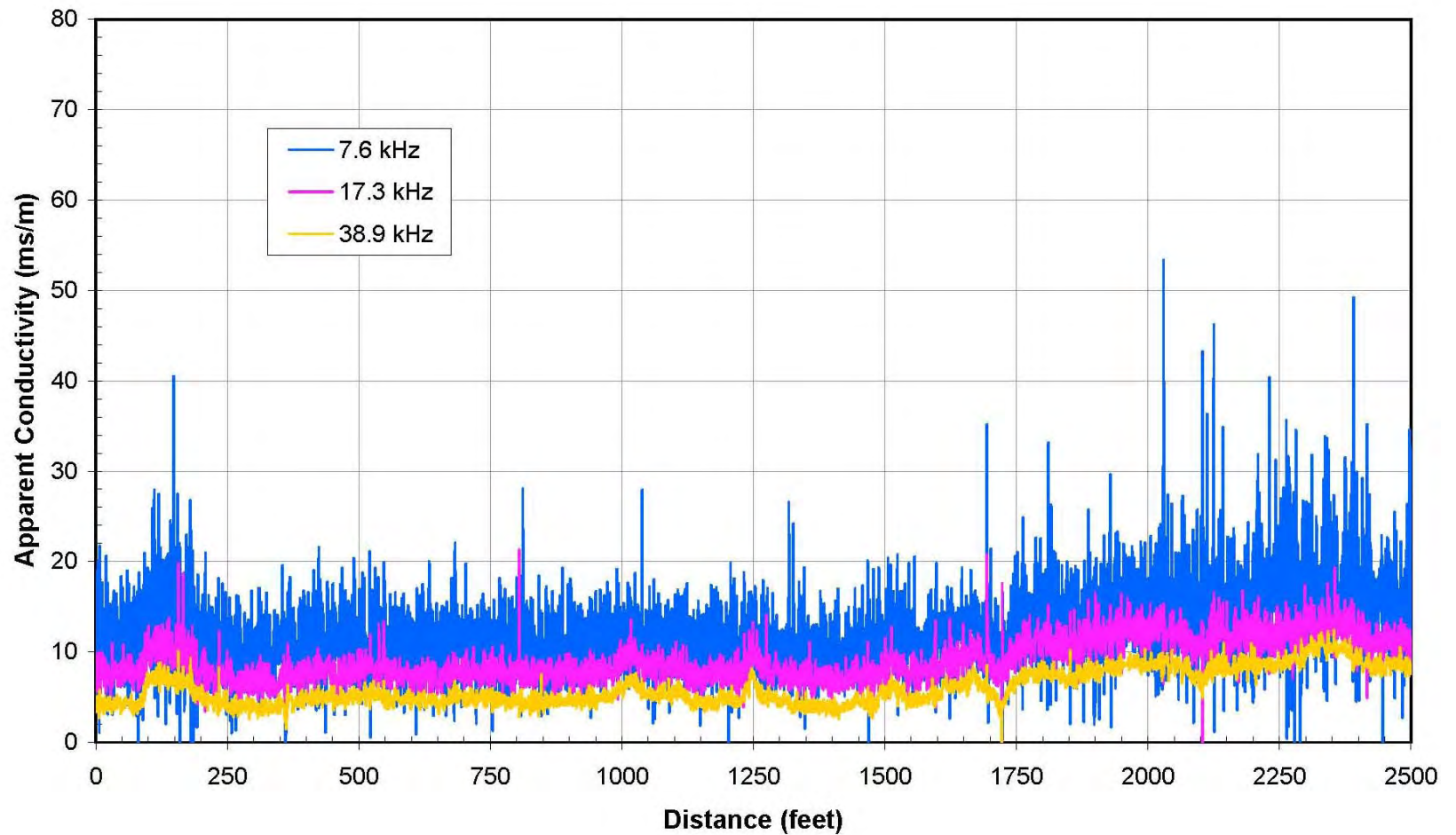


Line 3 – GEM2 Terrain Conductivity Data

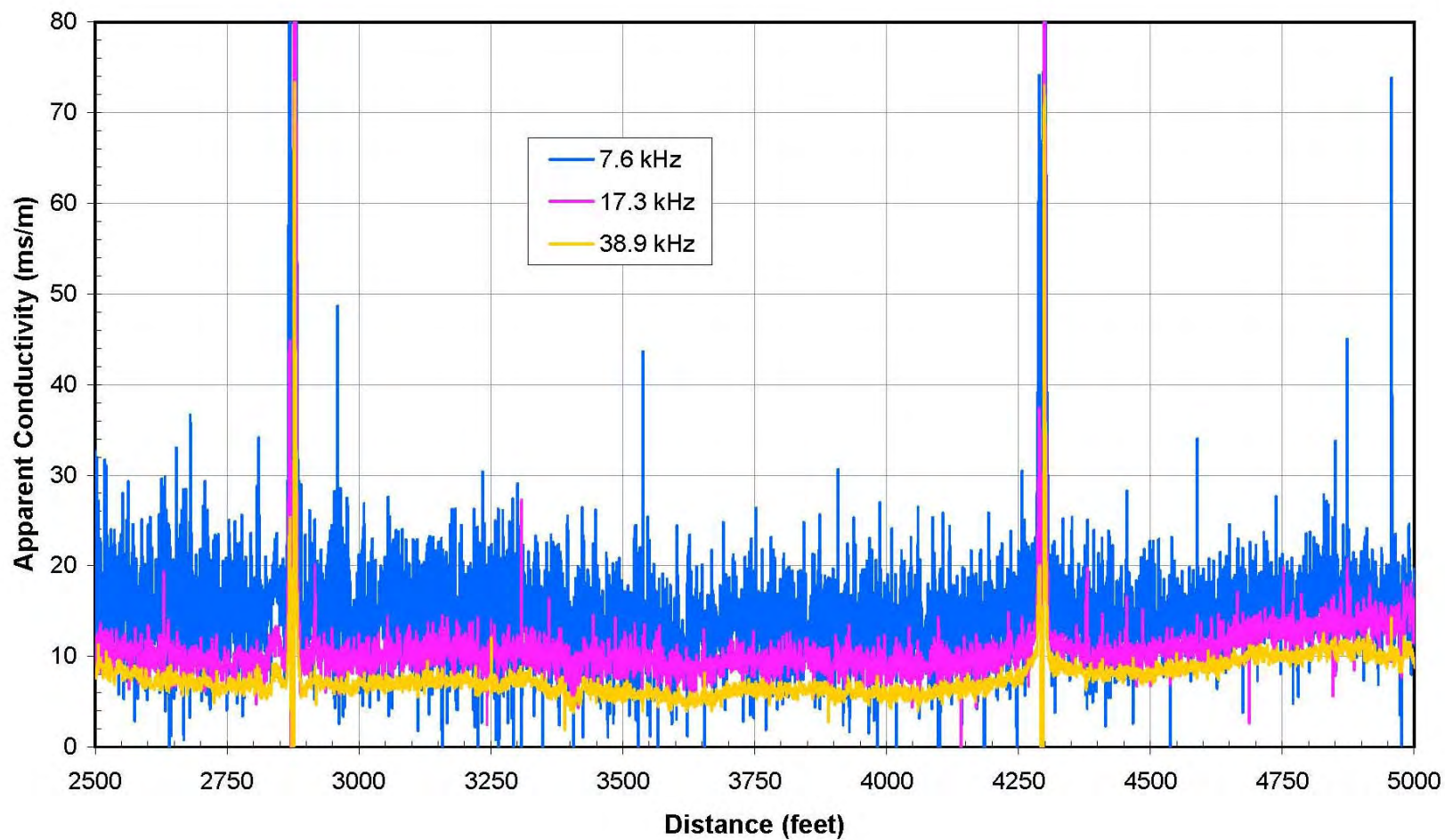


Line 4 – GEM2 Terrain Conductivity Data

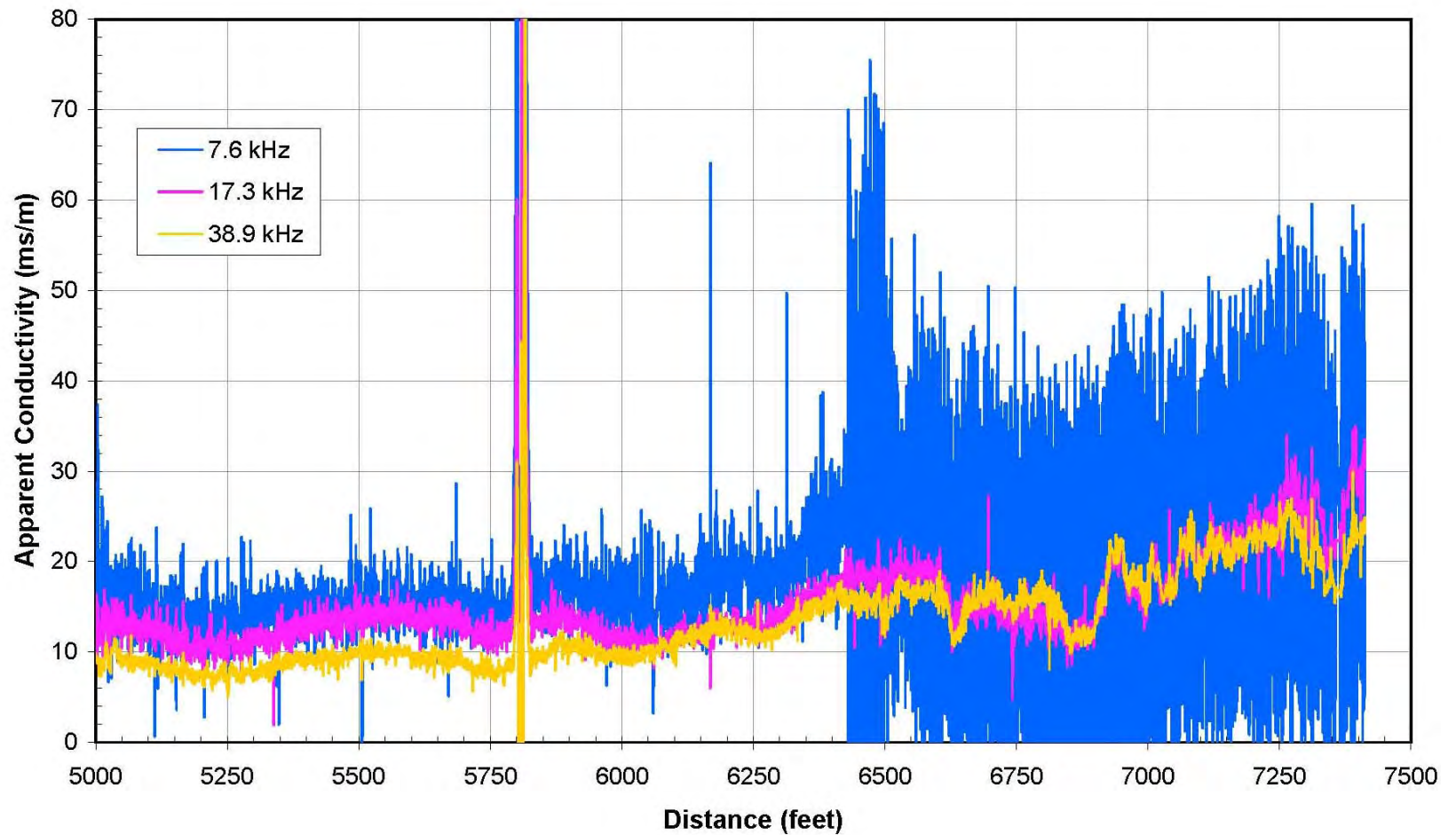




Line 5 – GEM2 Terrain Conductivity Data (0–2500 Feet)

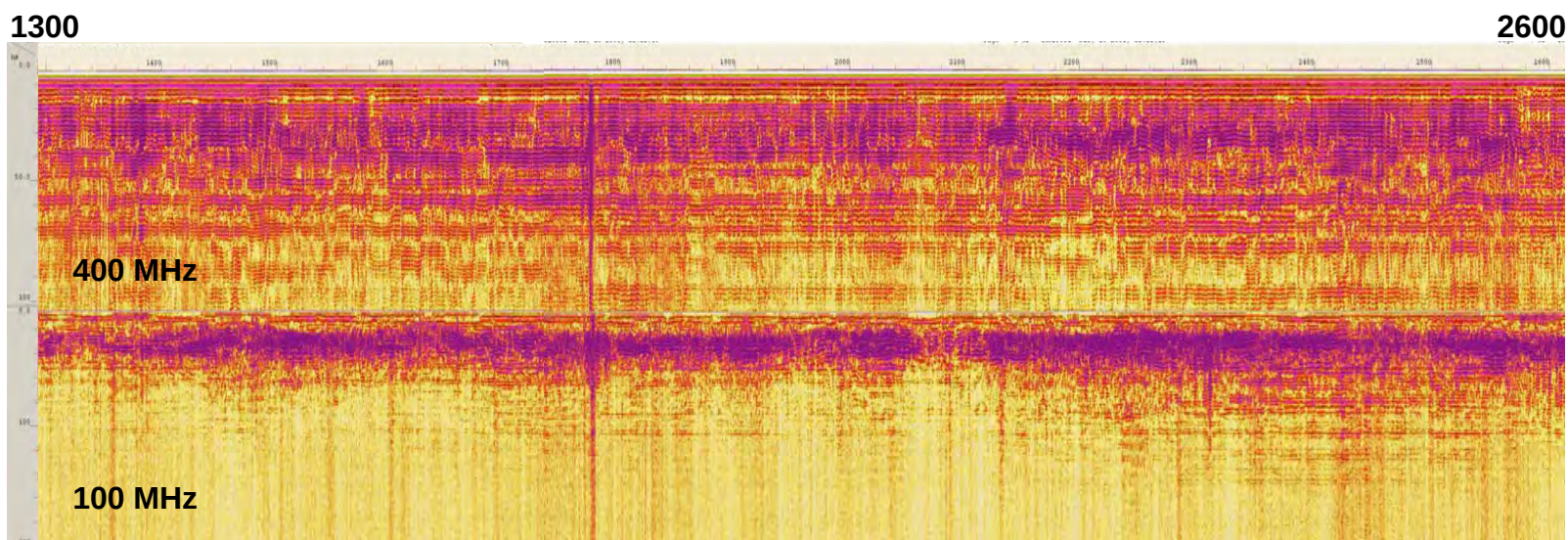
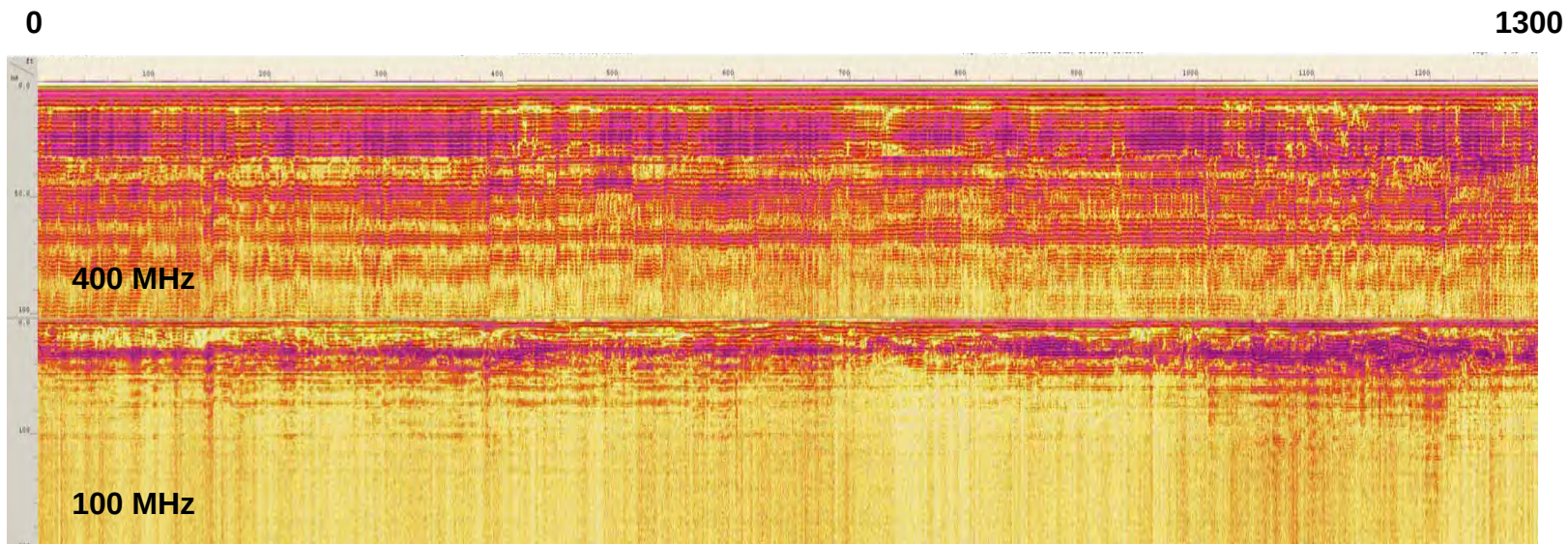


Line 5 – GEM2 Terrain Conductivity Data (2500–5000 Feet)



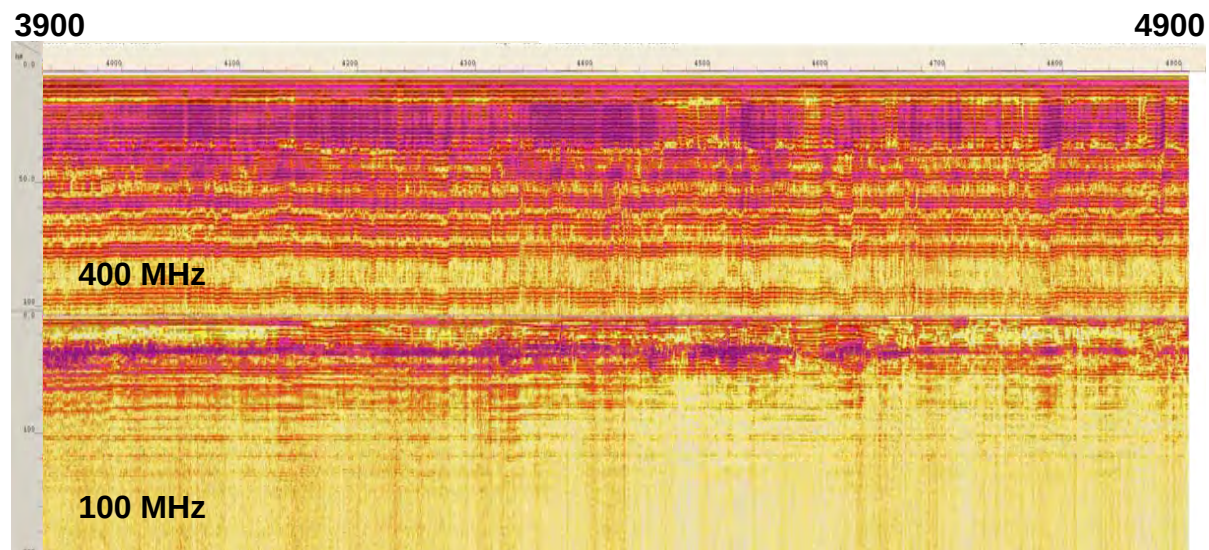
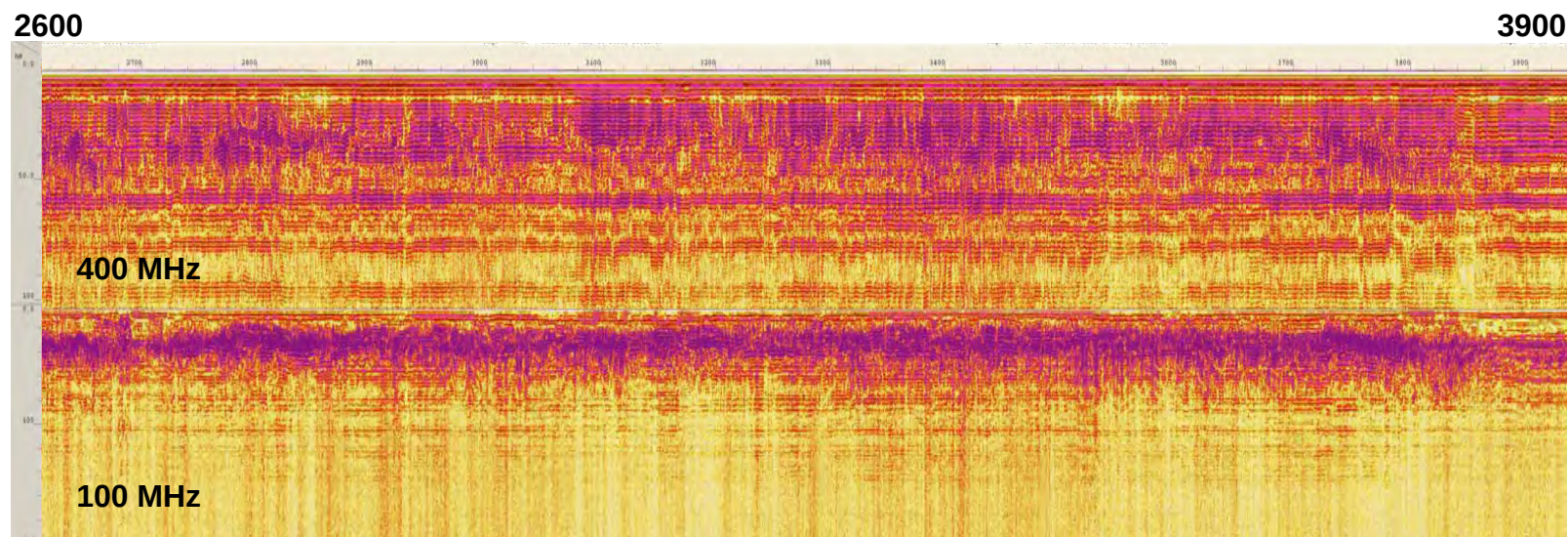
Line 5 – GEM2 Terrain Conductivity Data (5000–7400 Feet)





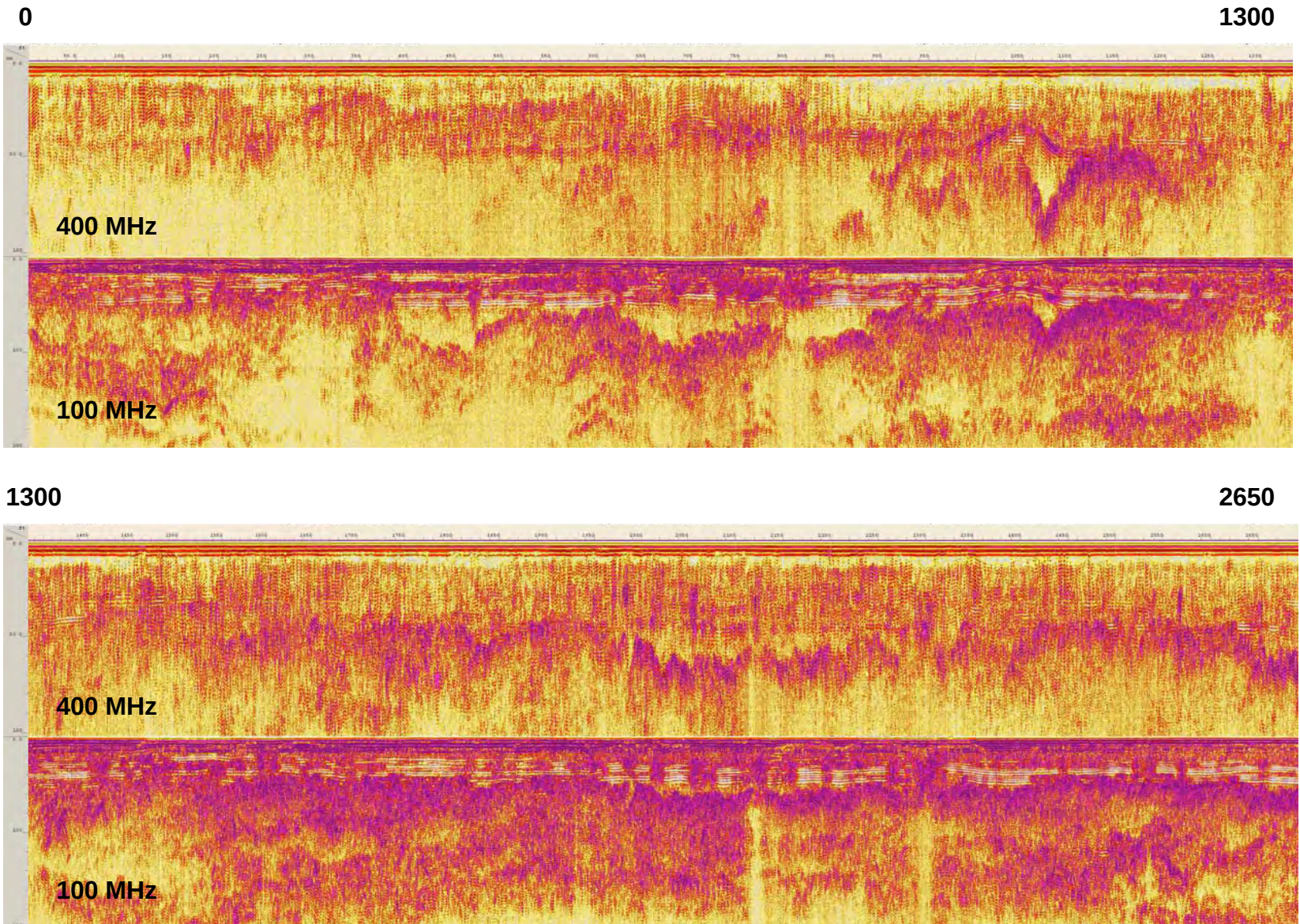
Line 1 (1 – 2600 Feet)





Line 1 (2600 – 4900 Feet)



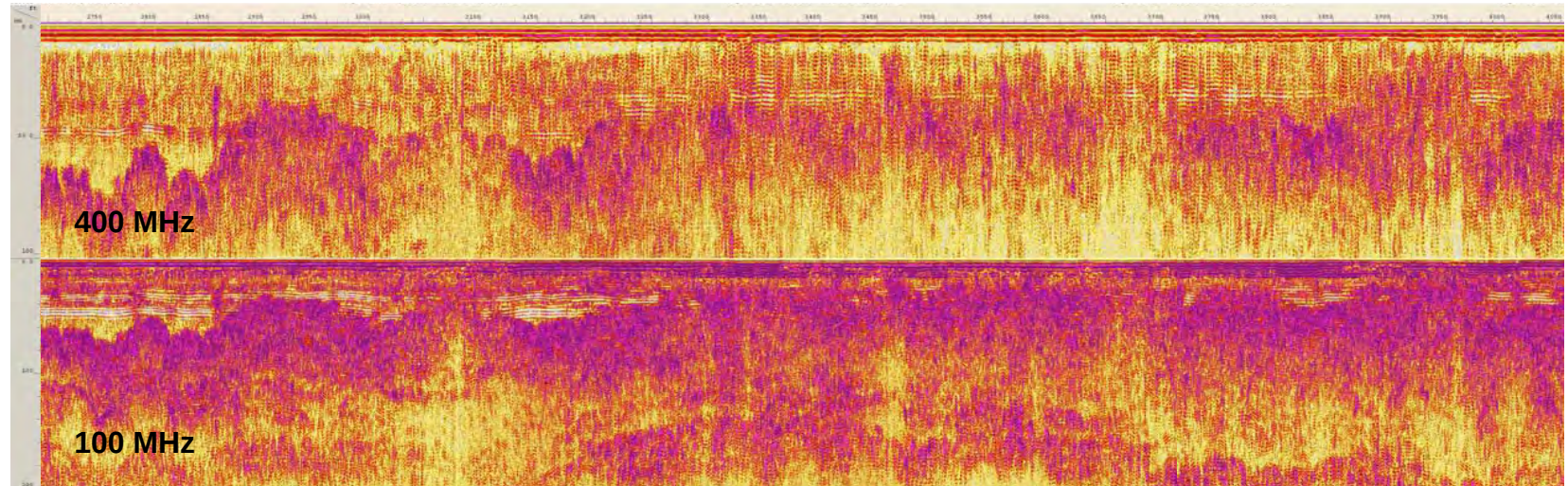


Line 2 (0 – 2650 Feet)



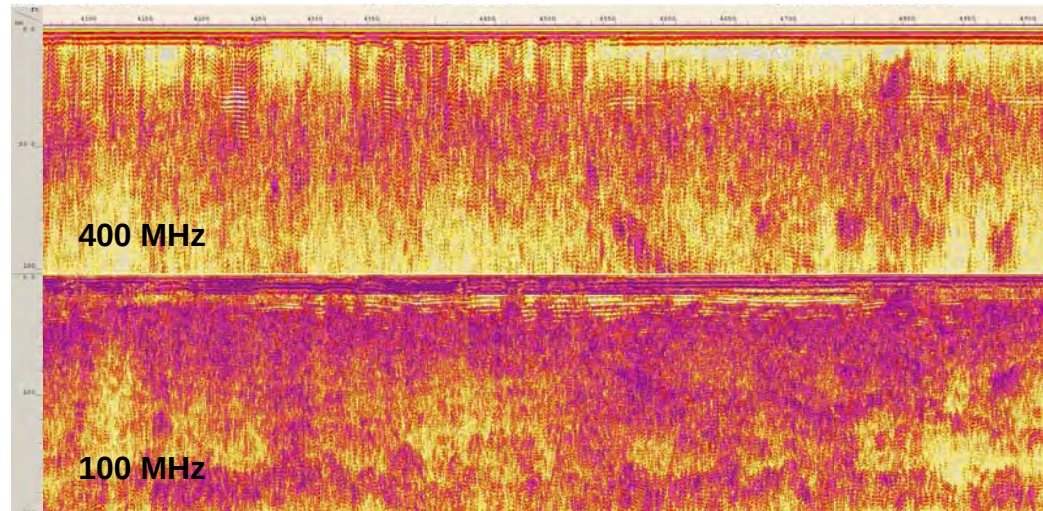
2700

4000



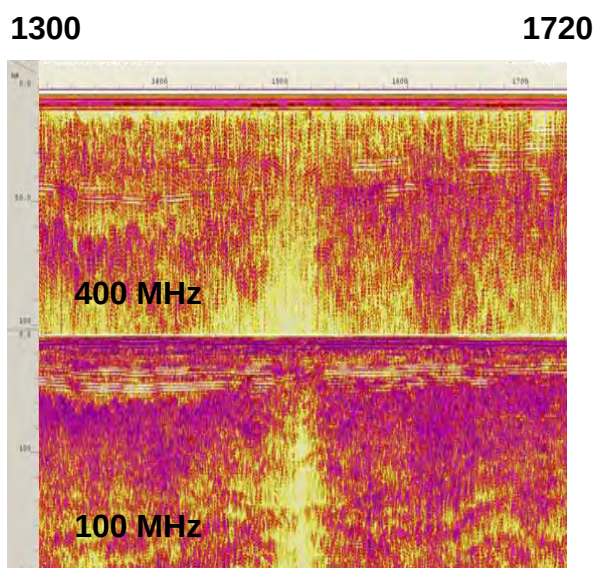
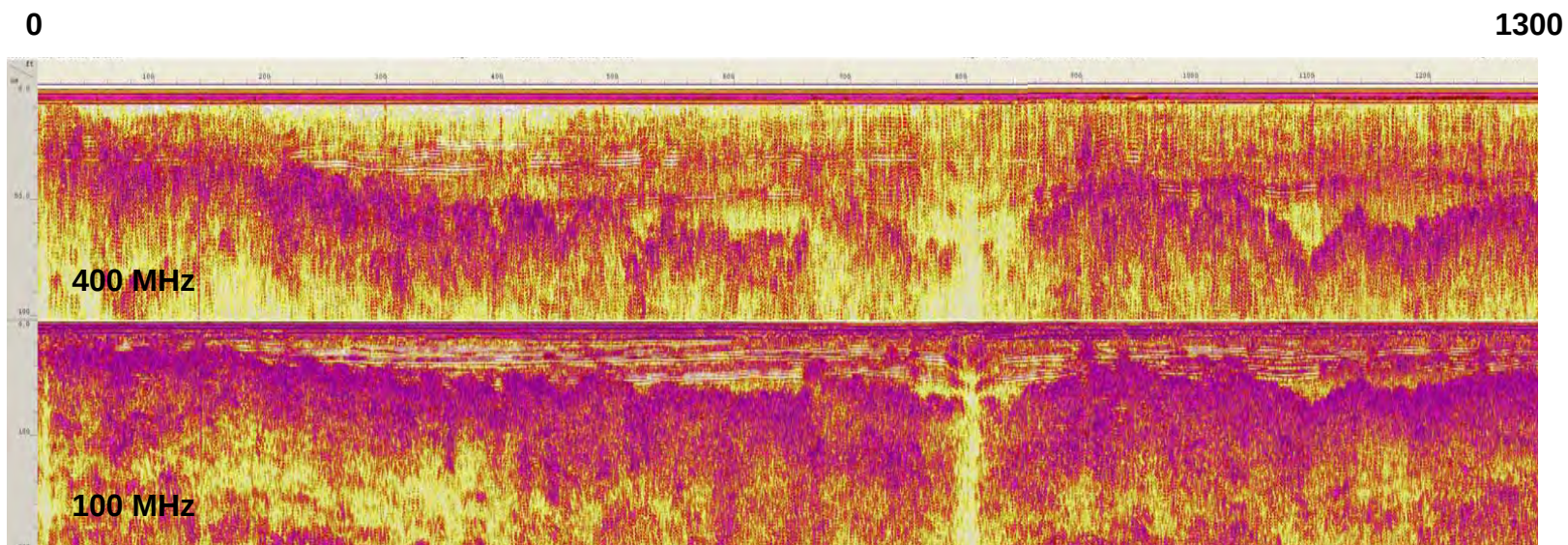
4000

4900



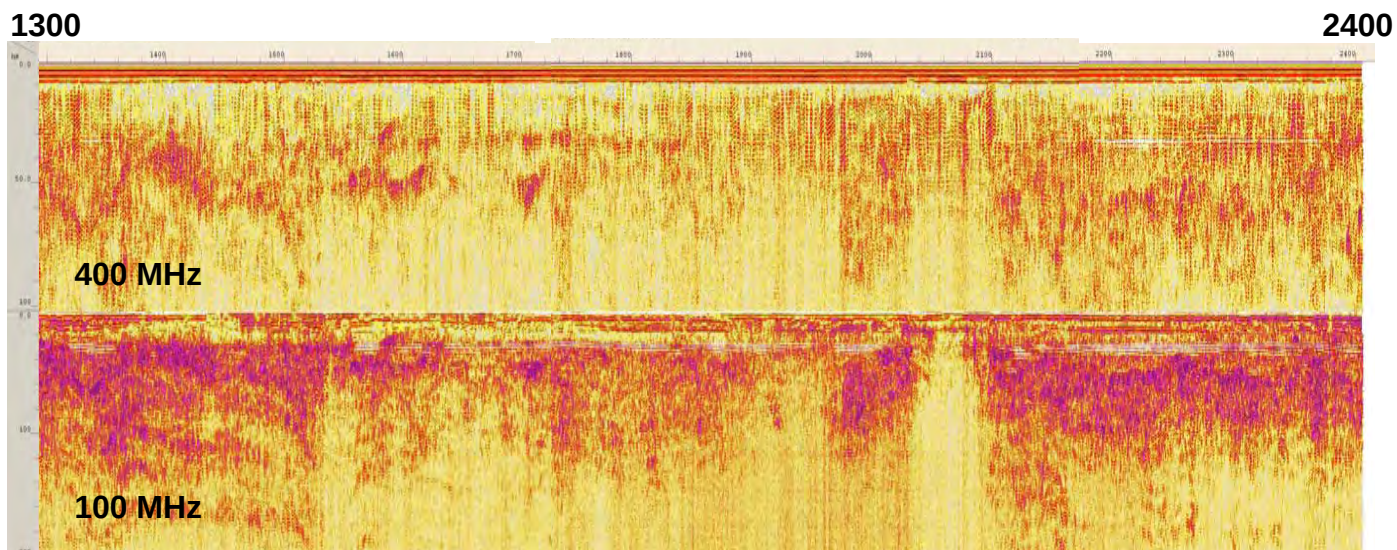
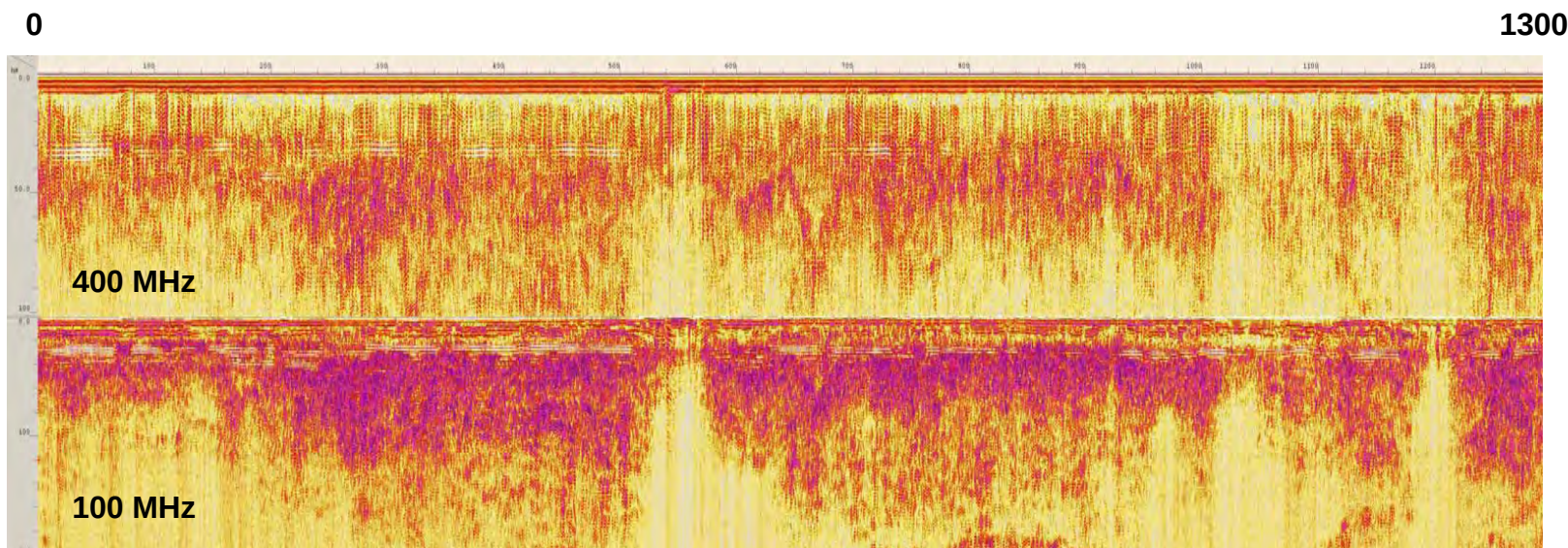
Line 2 (2700 – 4900 Feet)





Line 3 (0 – 1720 Feet)



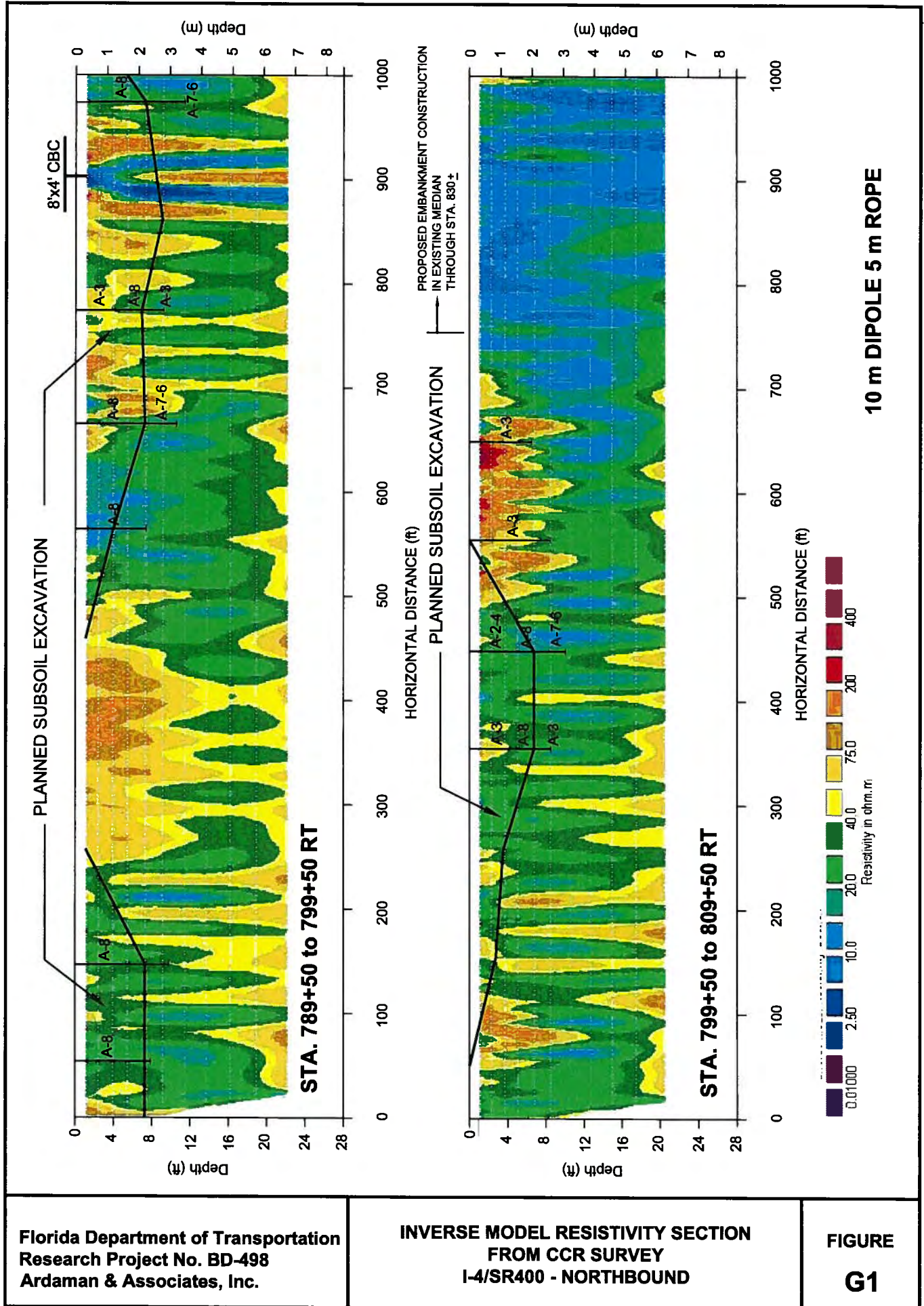


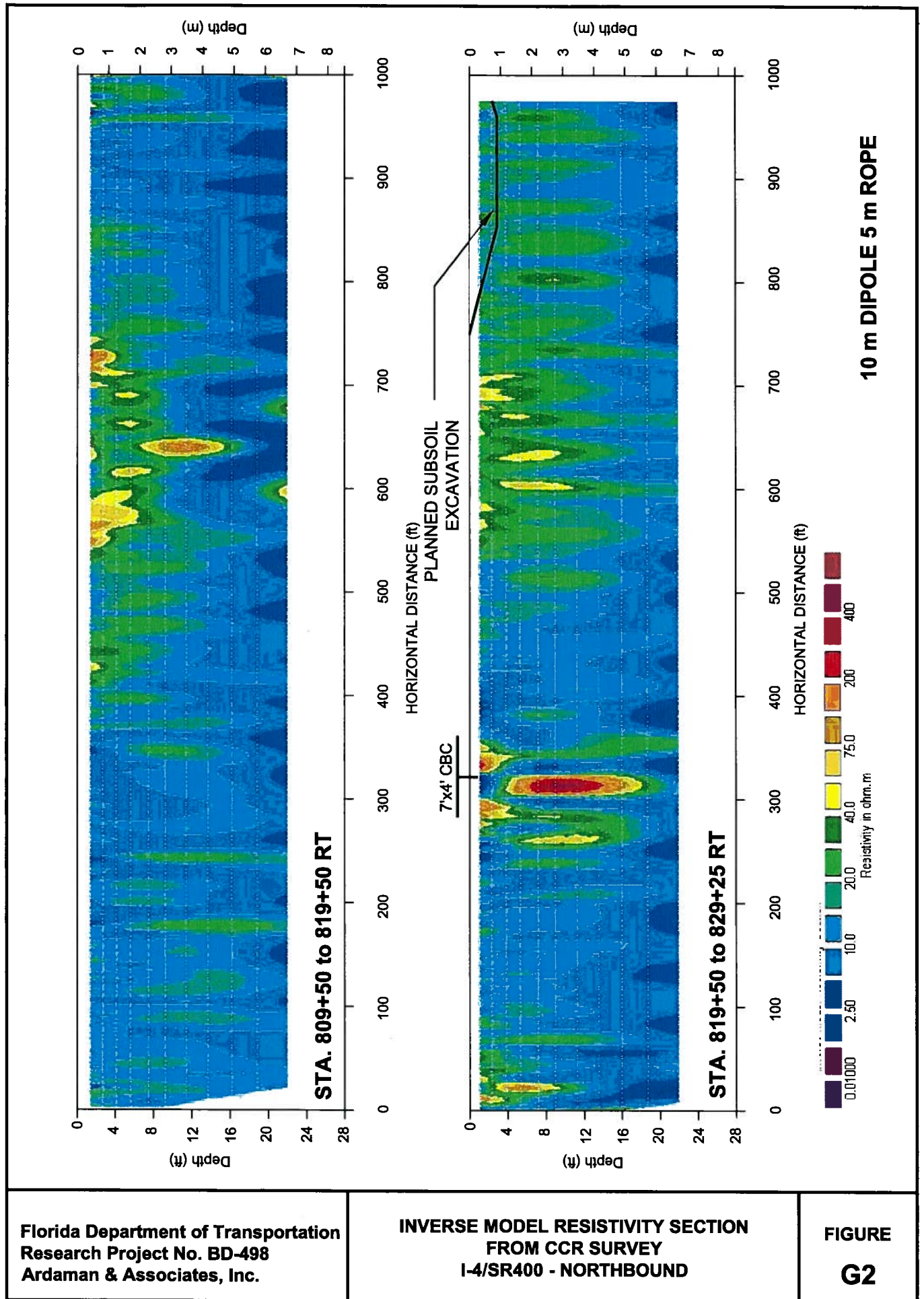
Line 4 (0 – 2400 Feet)

## **APPENDIX G**

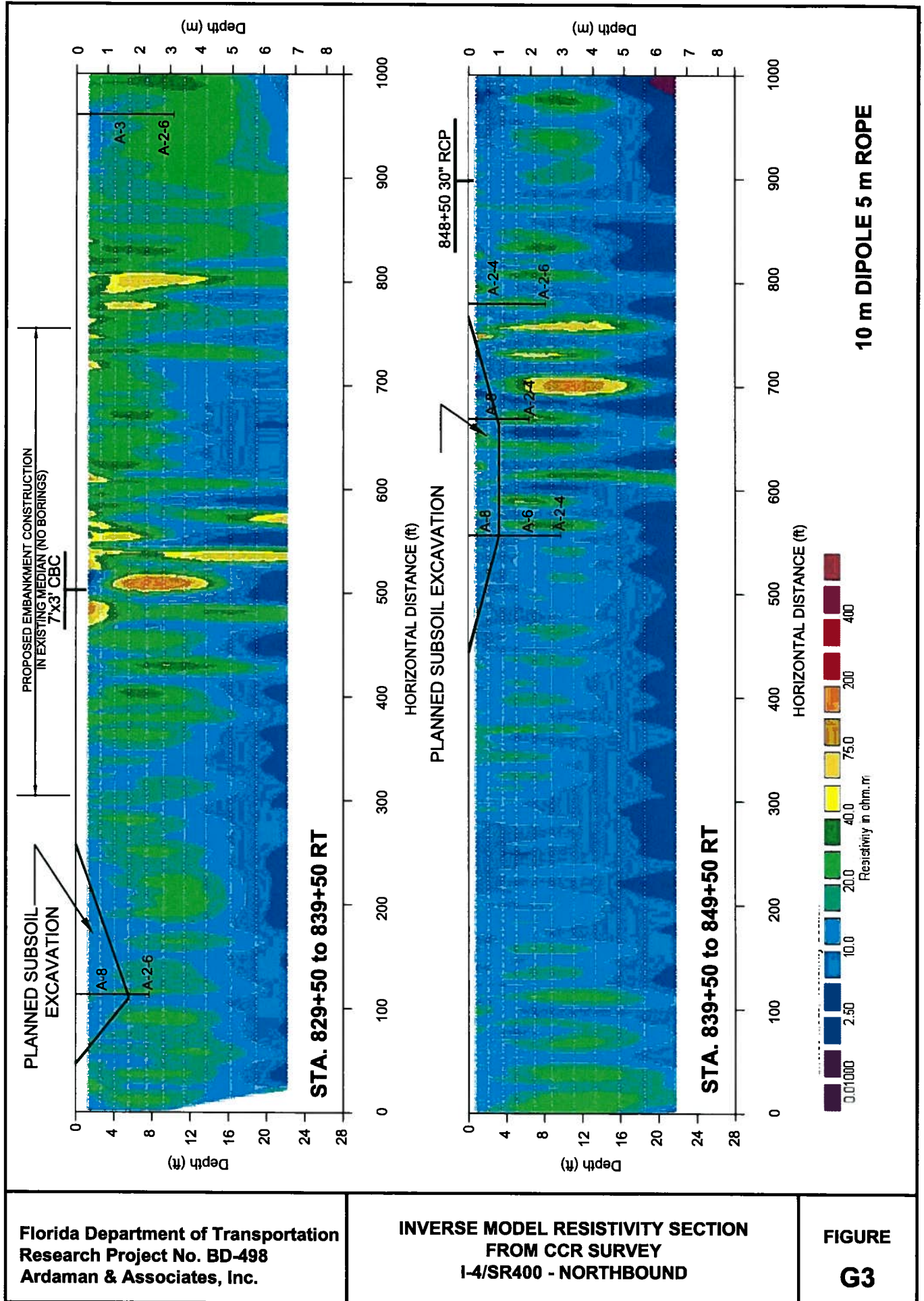
### **S.R. 400 (I-4) TEST DATA**

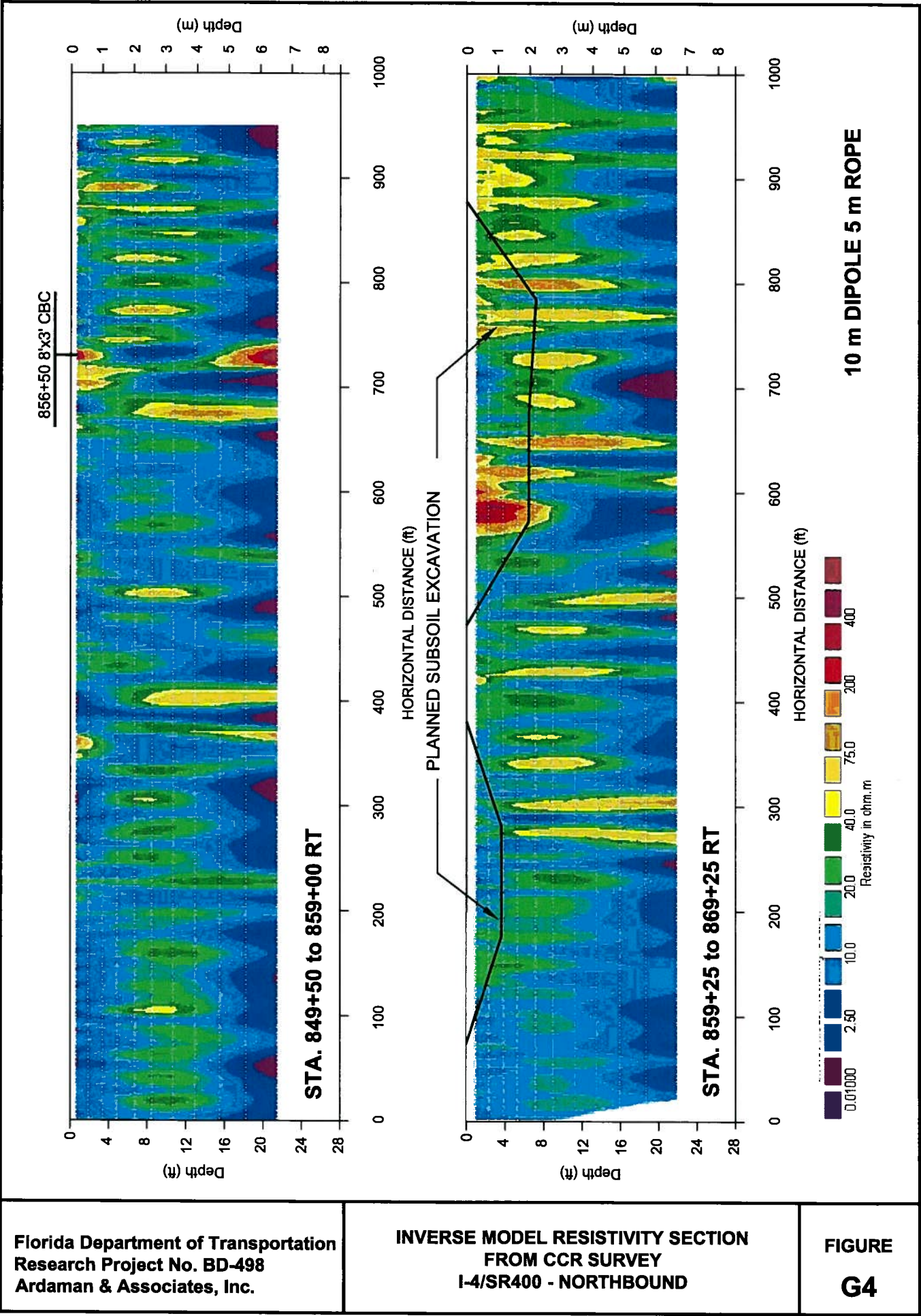






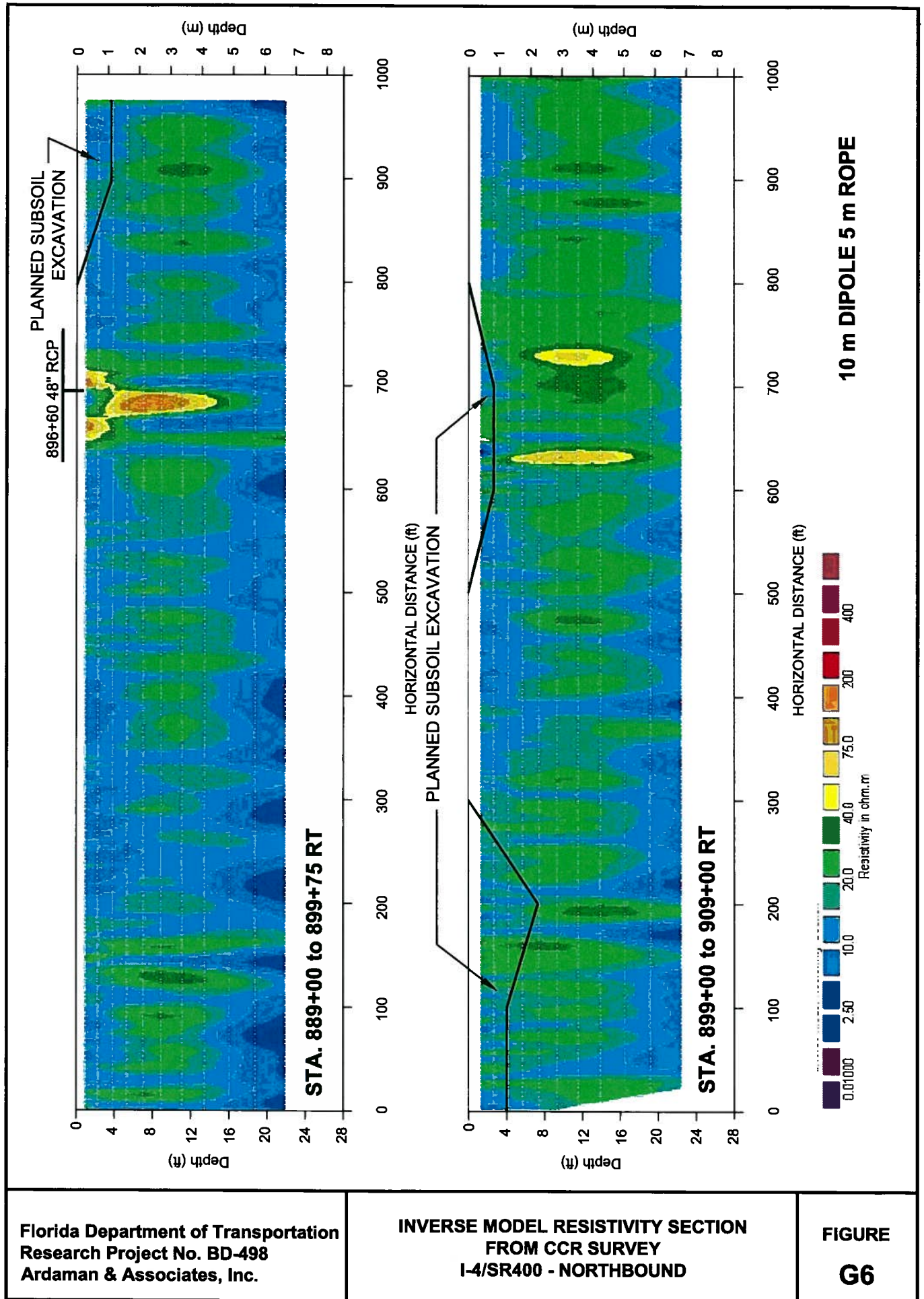




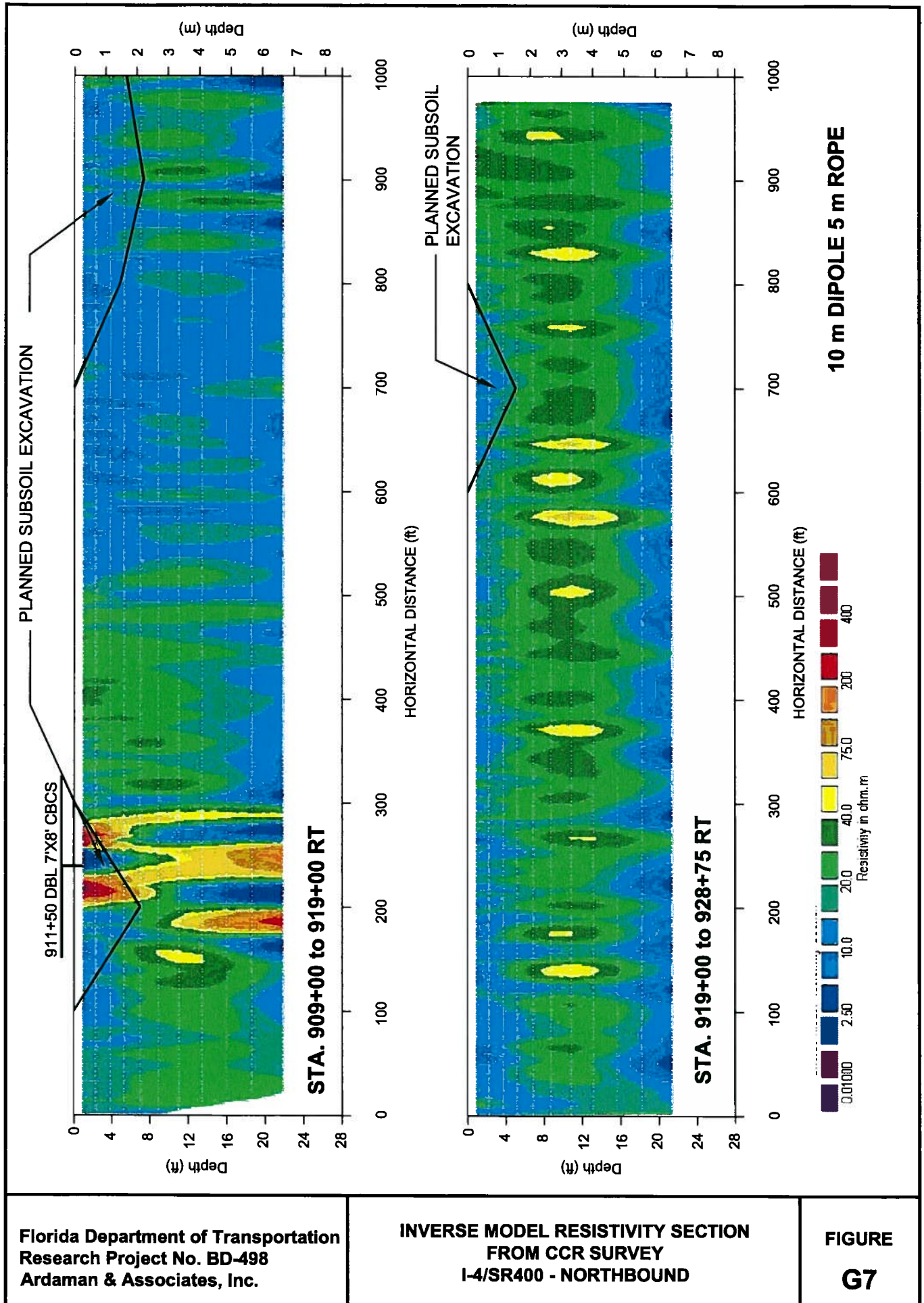


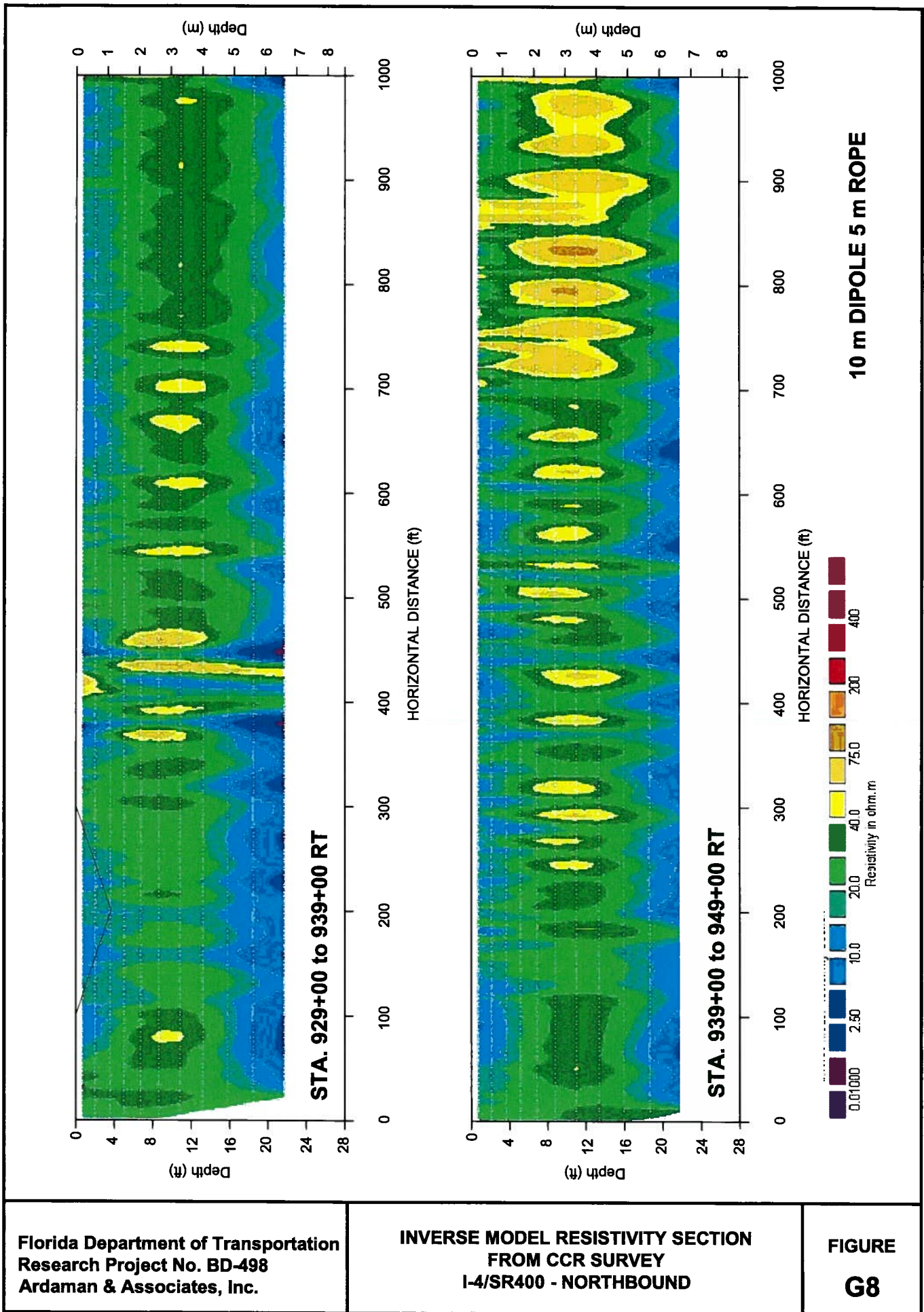




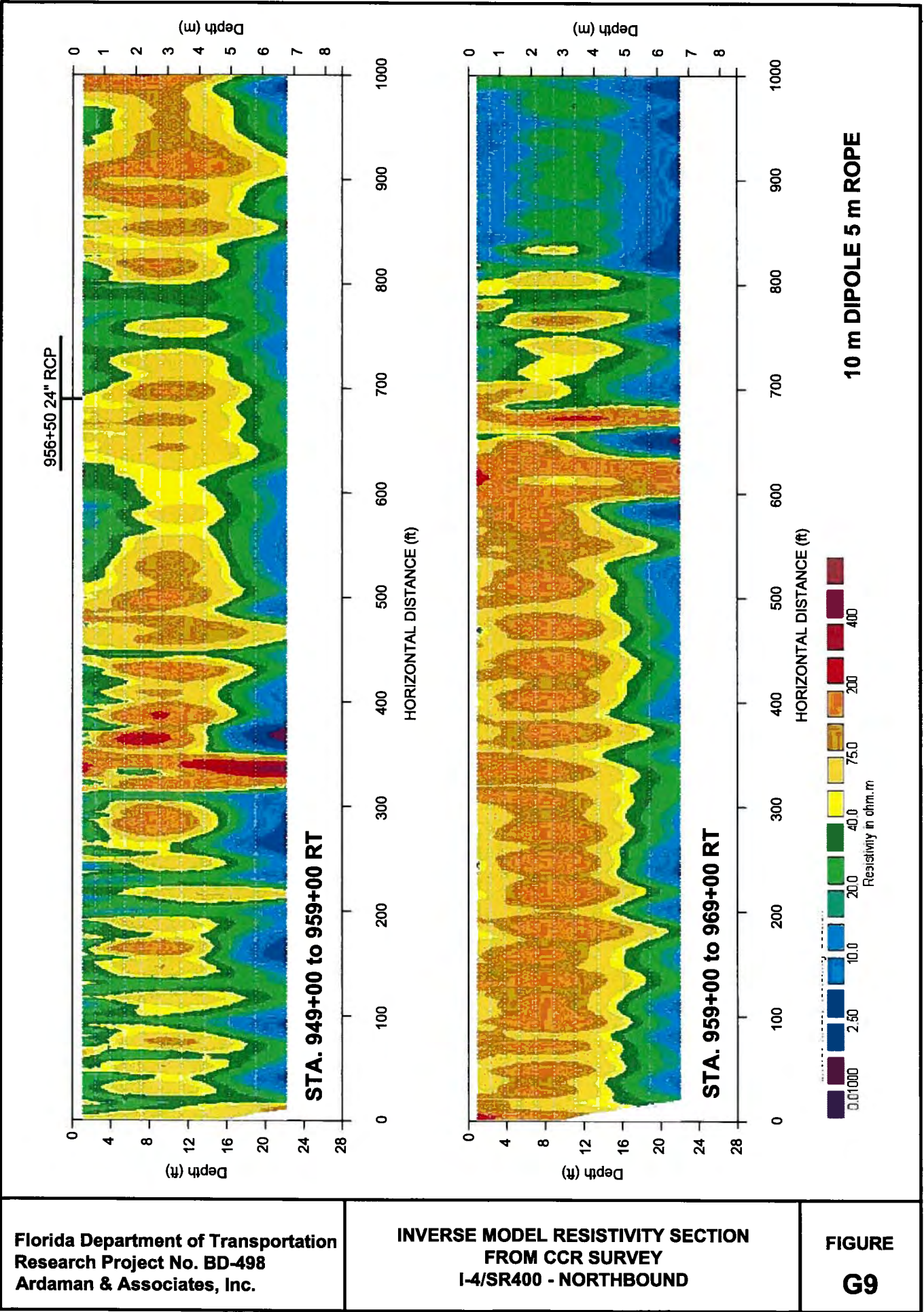










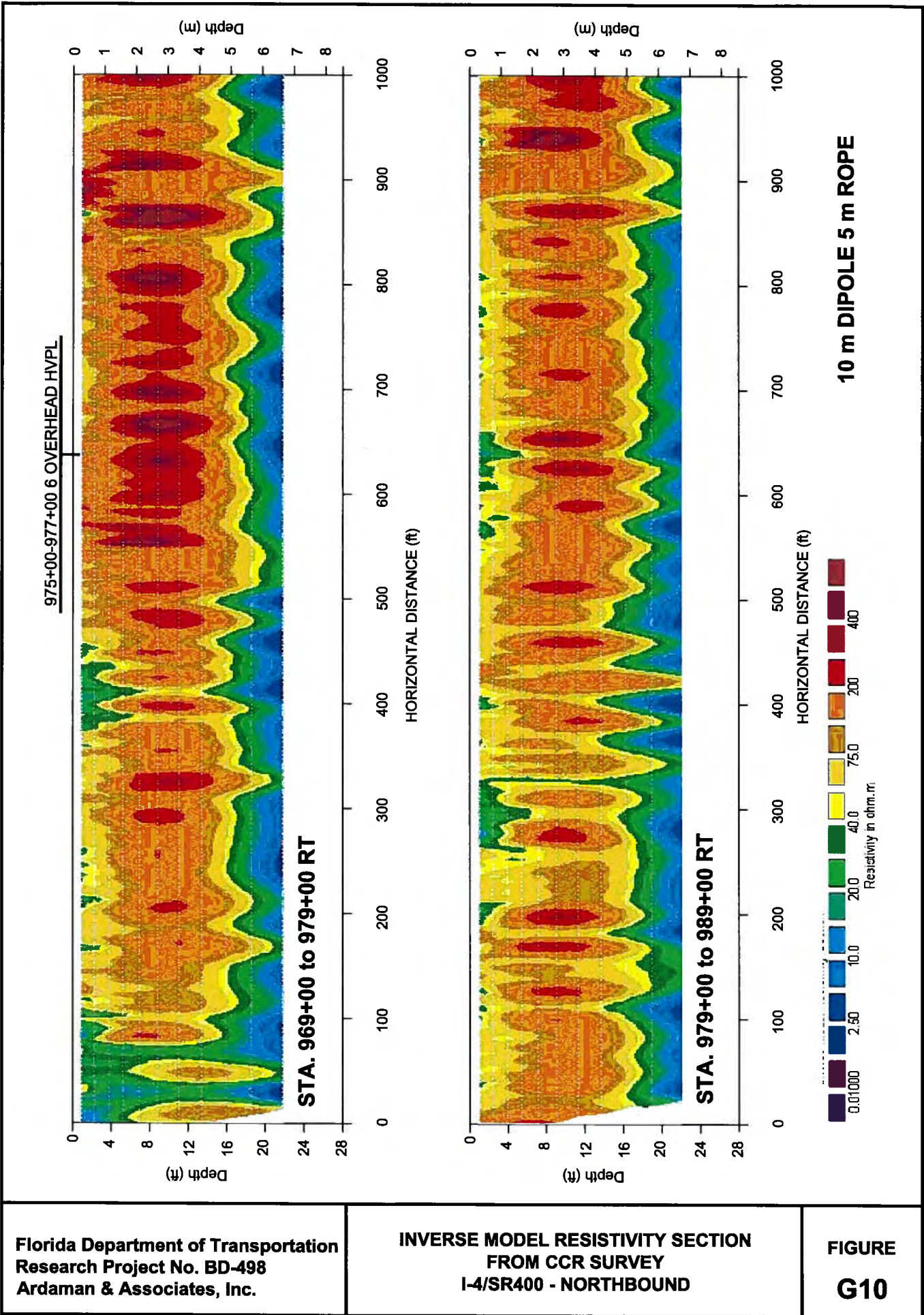


Florida Department of Transportation  
Research Project No. BD-498  
Ardaman & Associates, Inc.

INVERSE MODEL RESISTIVITY SECTION  
FROM CCR SURVEY  
I-4/SR400 - NORTHBOUND

FIGURE  
G9



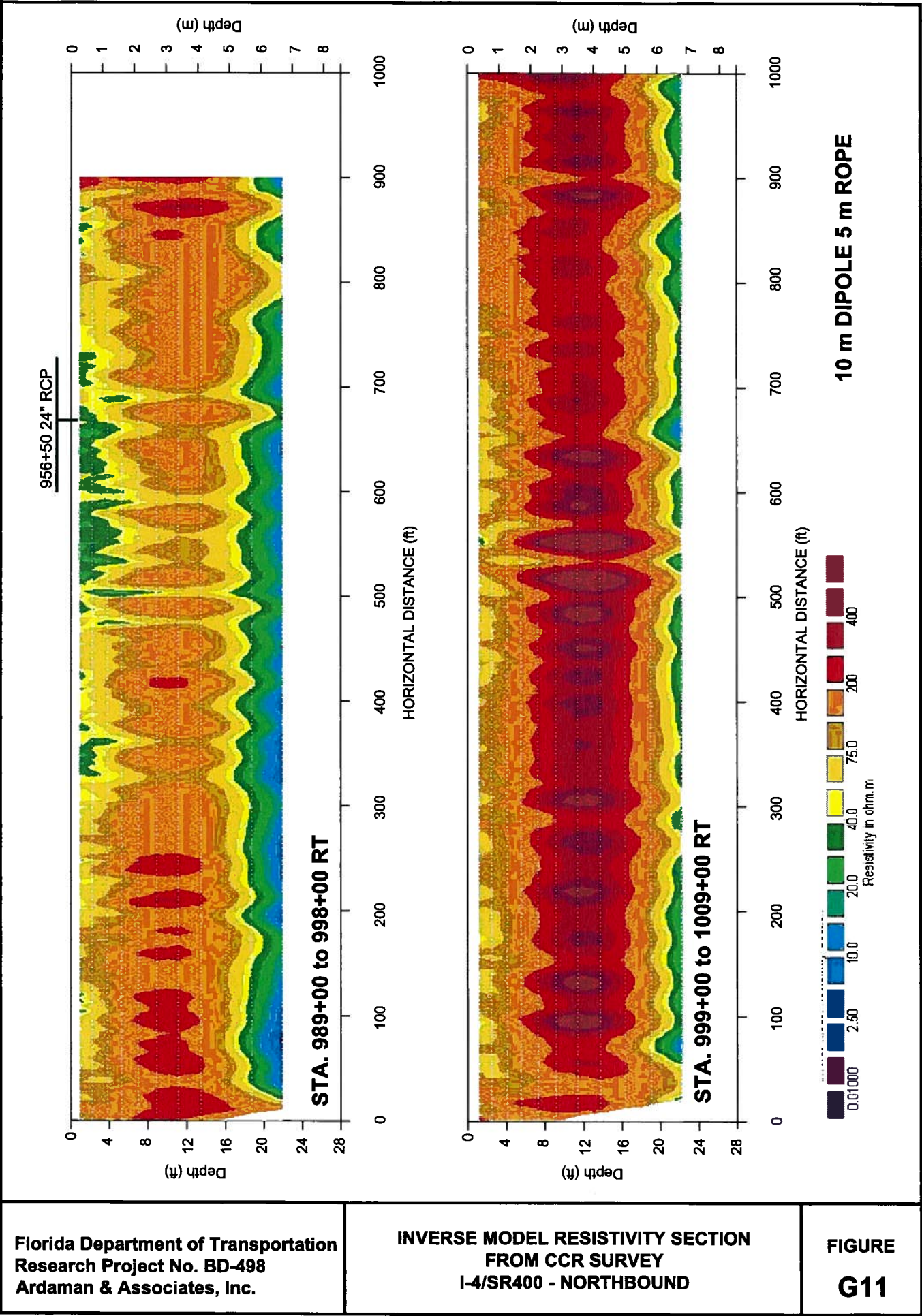


Florida Department of Transportation  
Research Project No. BD-498  
Ardaman & Associates, Inc.

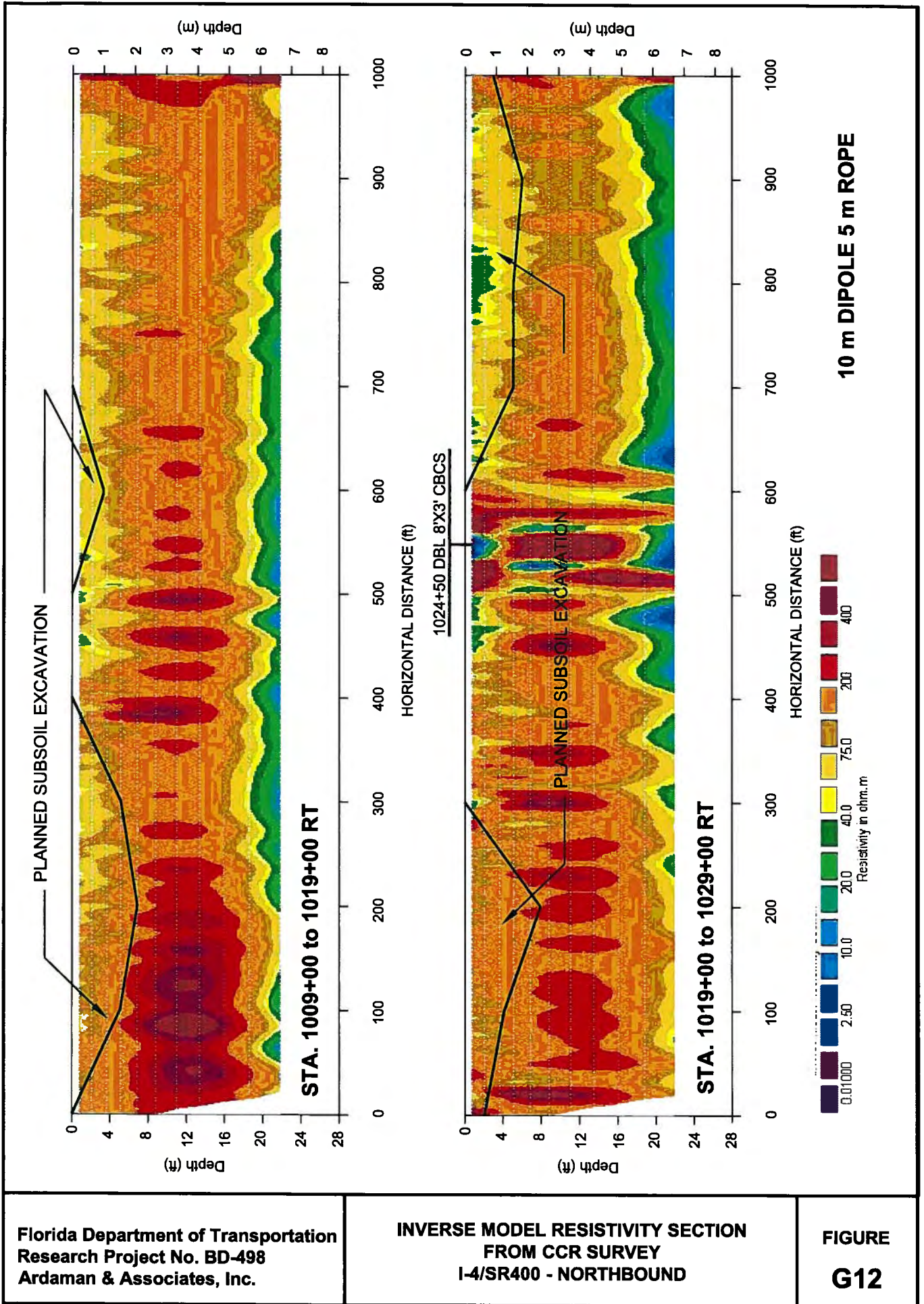
INVERSE MODEL RESISTIVITY SECTION  
FROM CCR SURVEY  
I-4/SR400 - NORTHBOUND

FIGURE  
G10

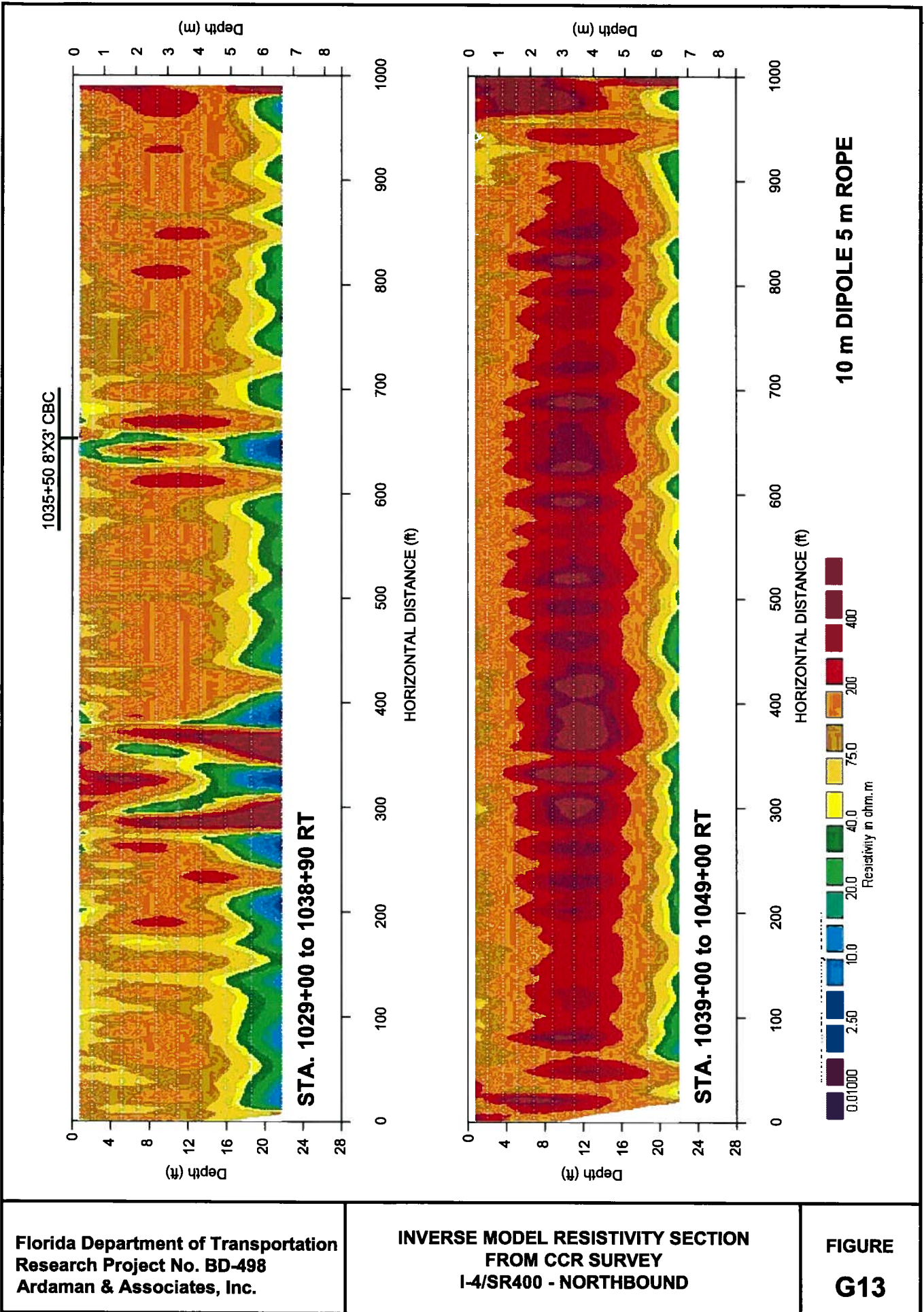


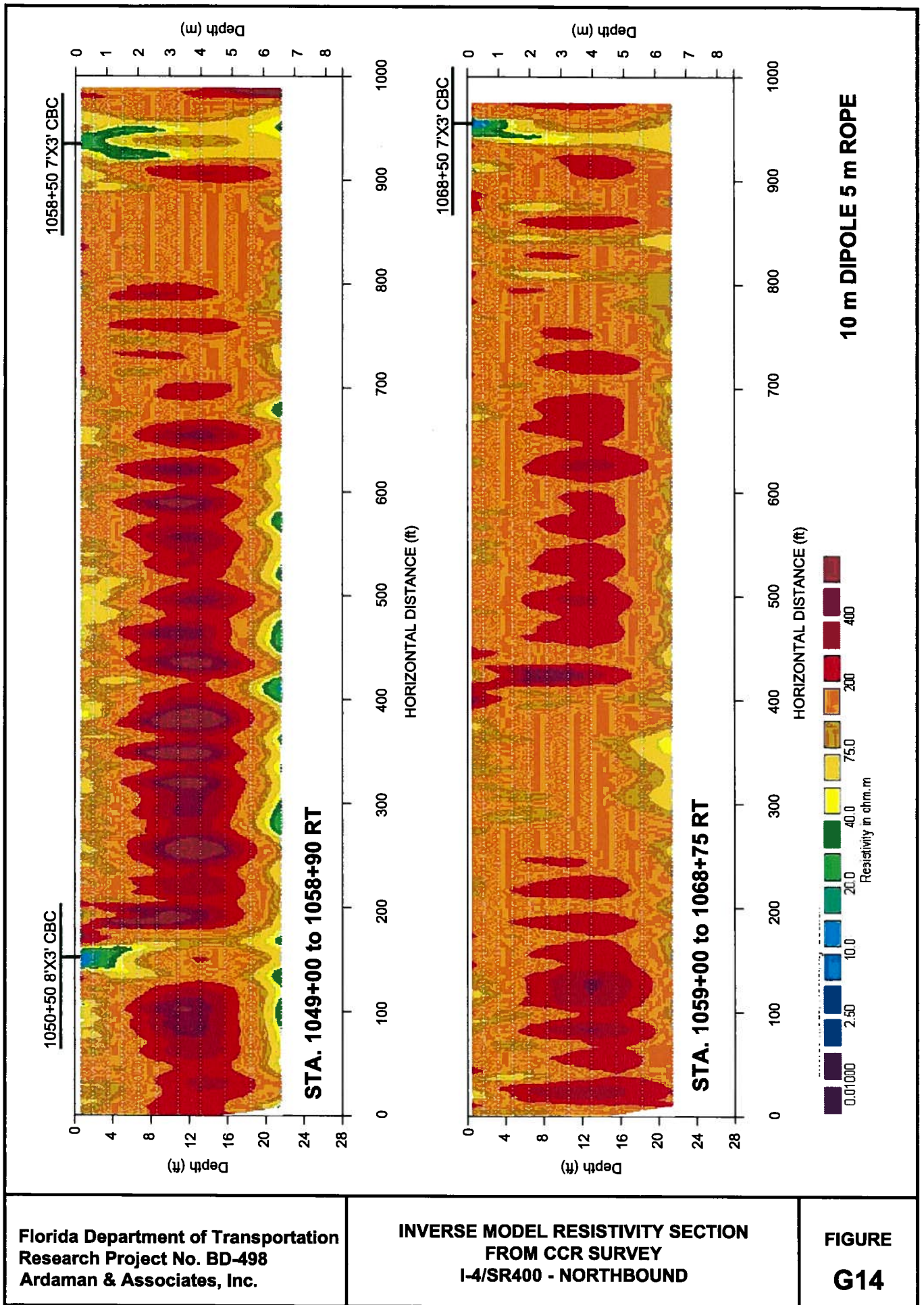




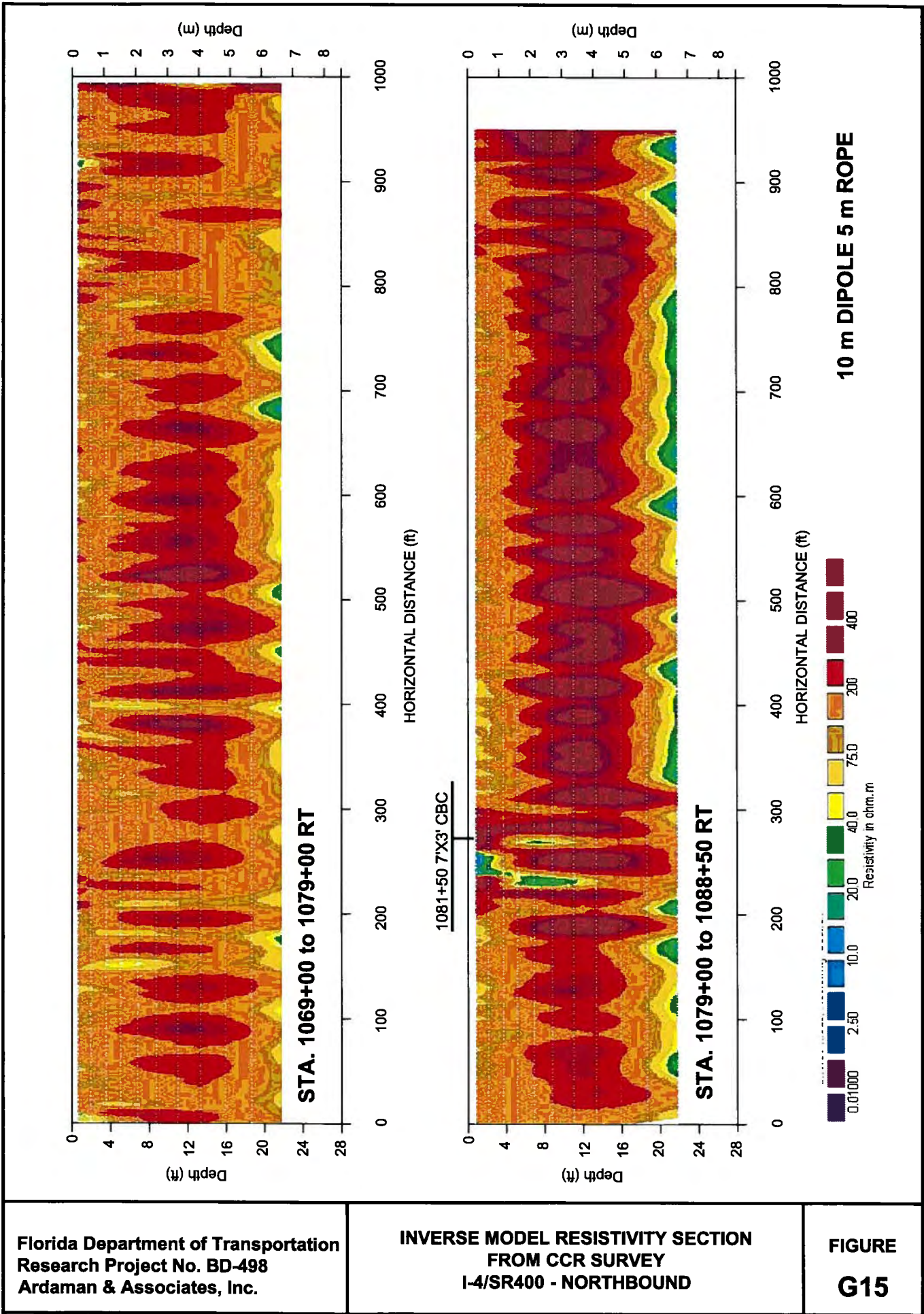




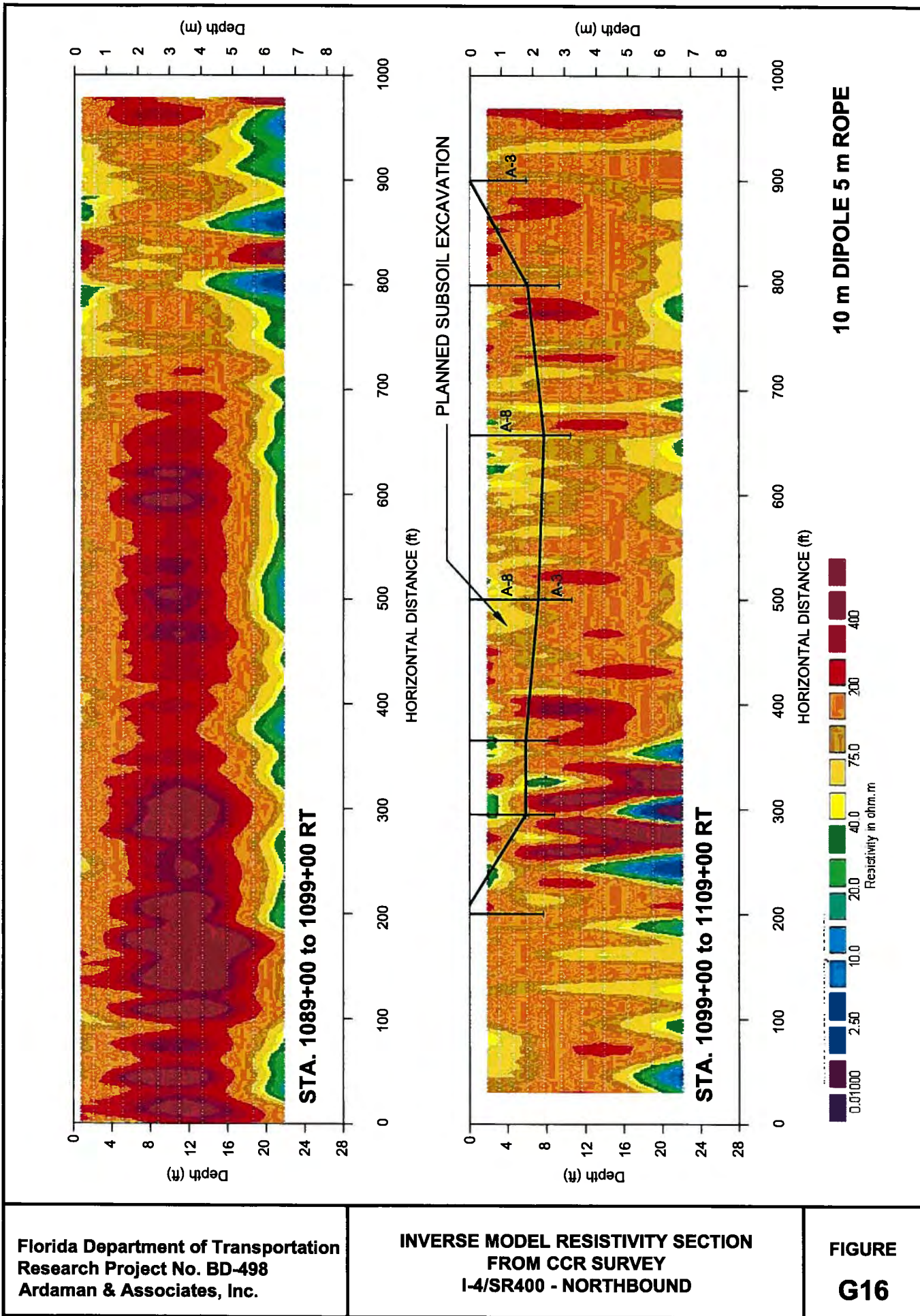








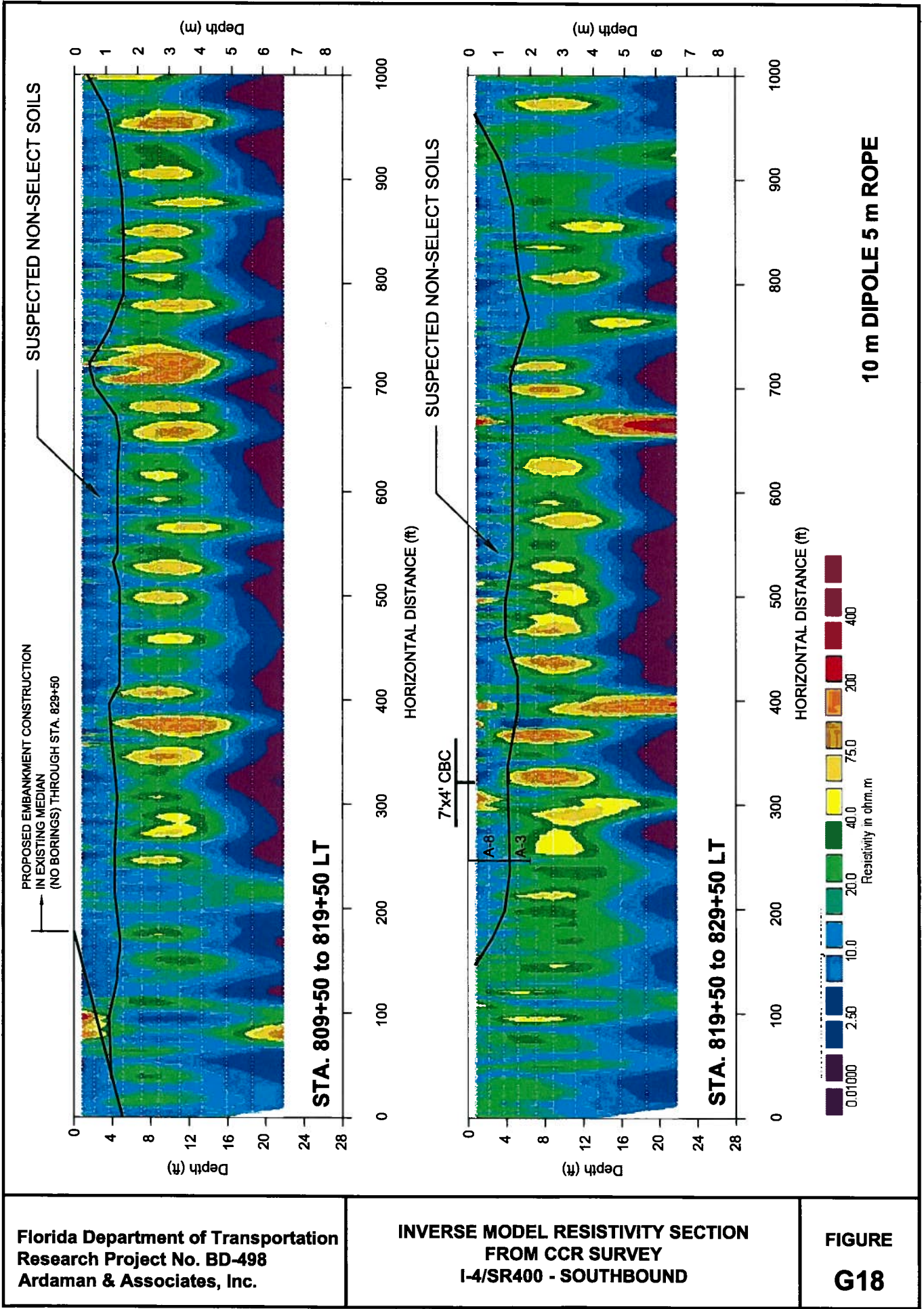


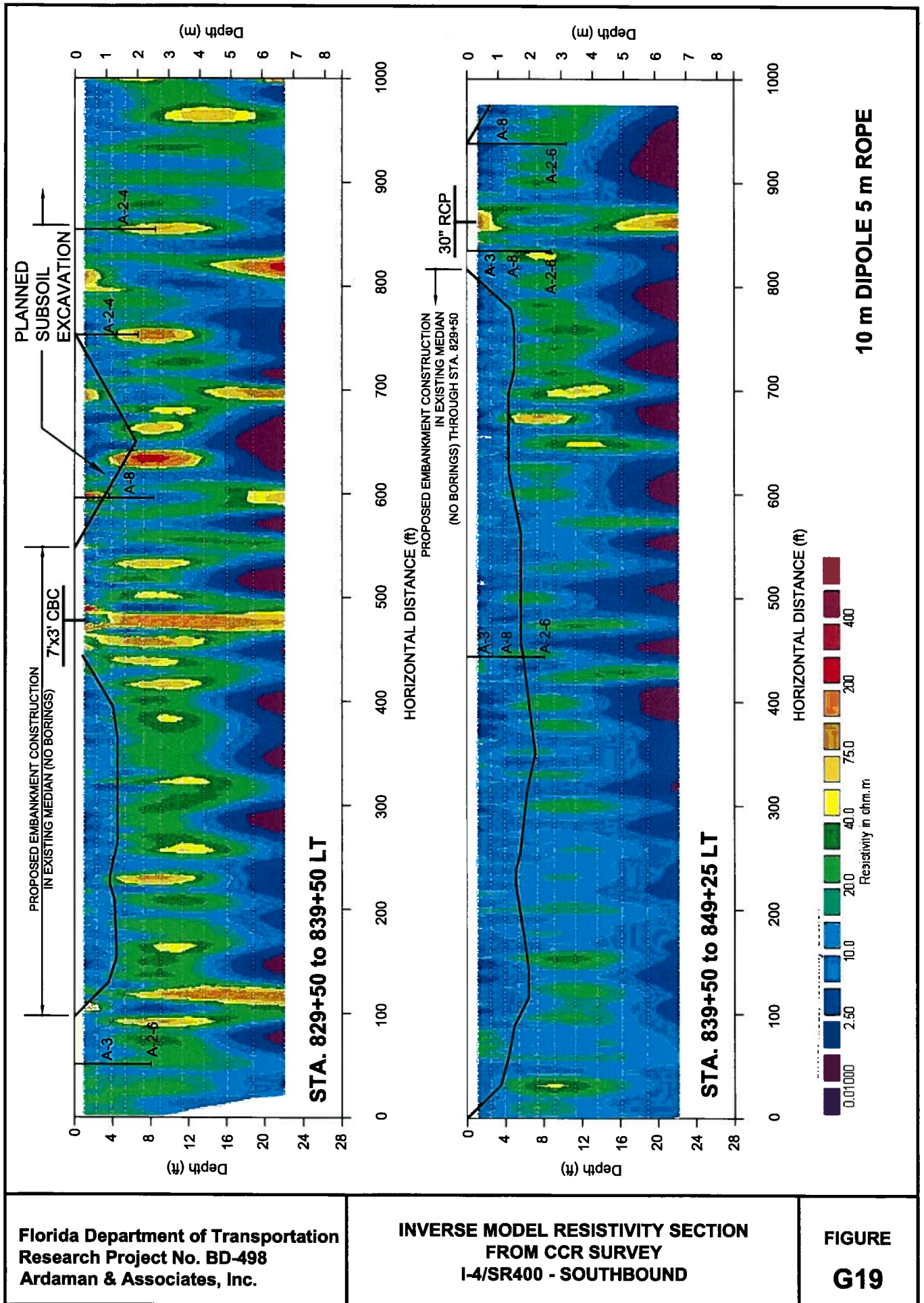




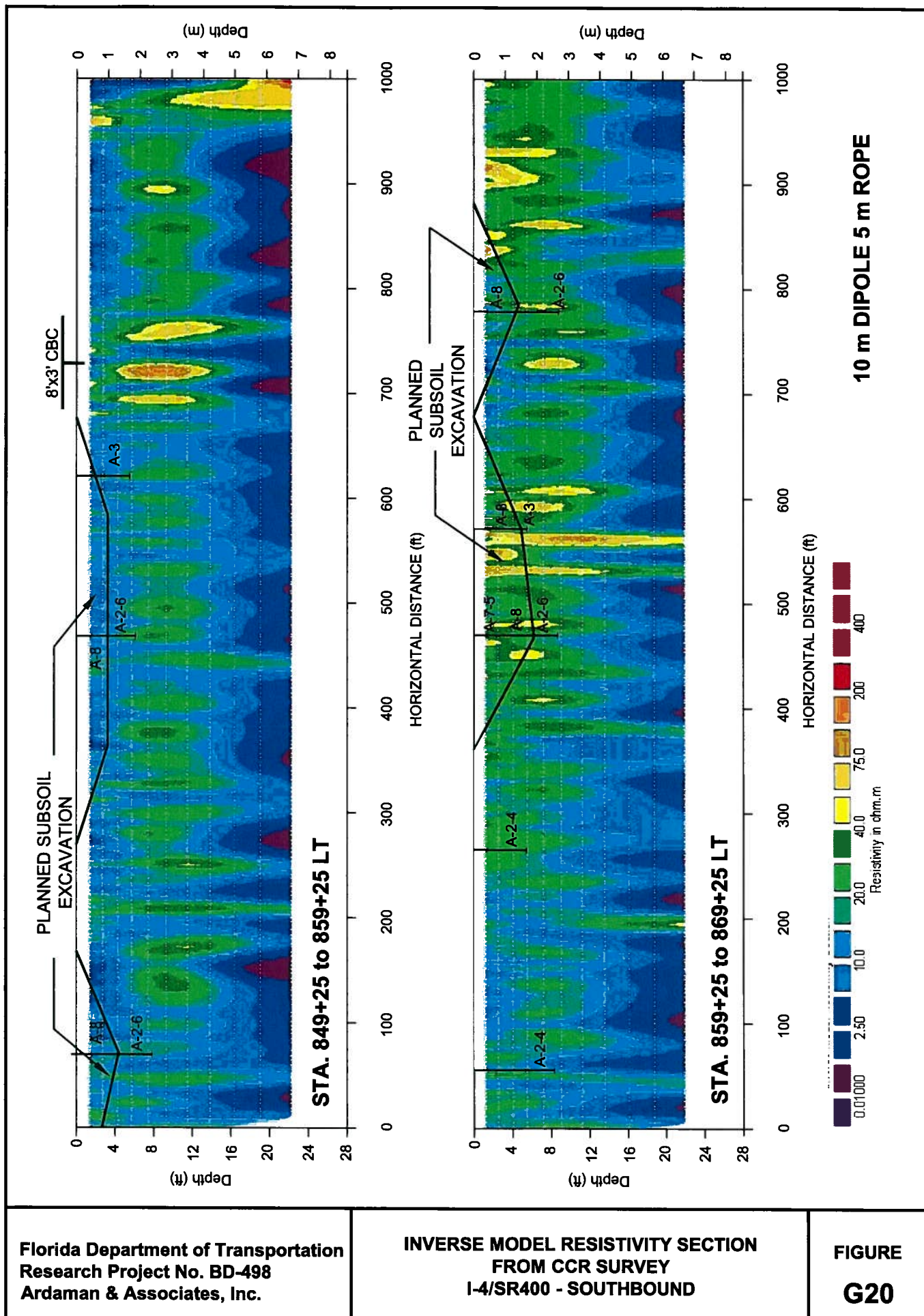




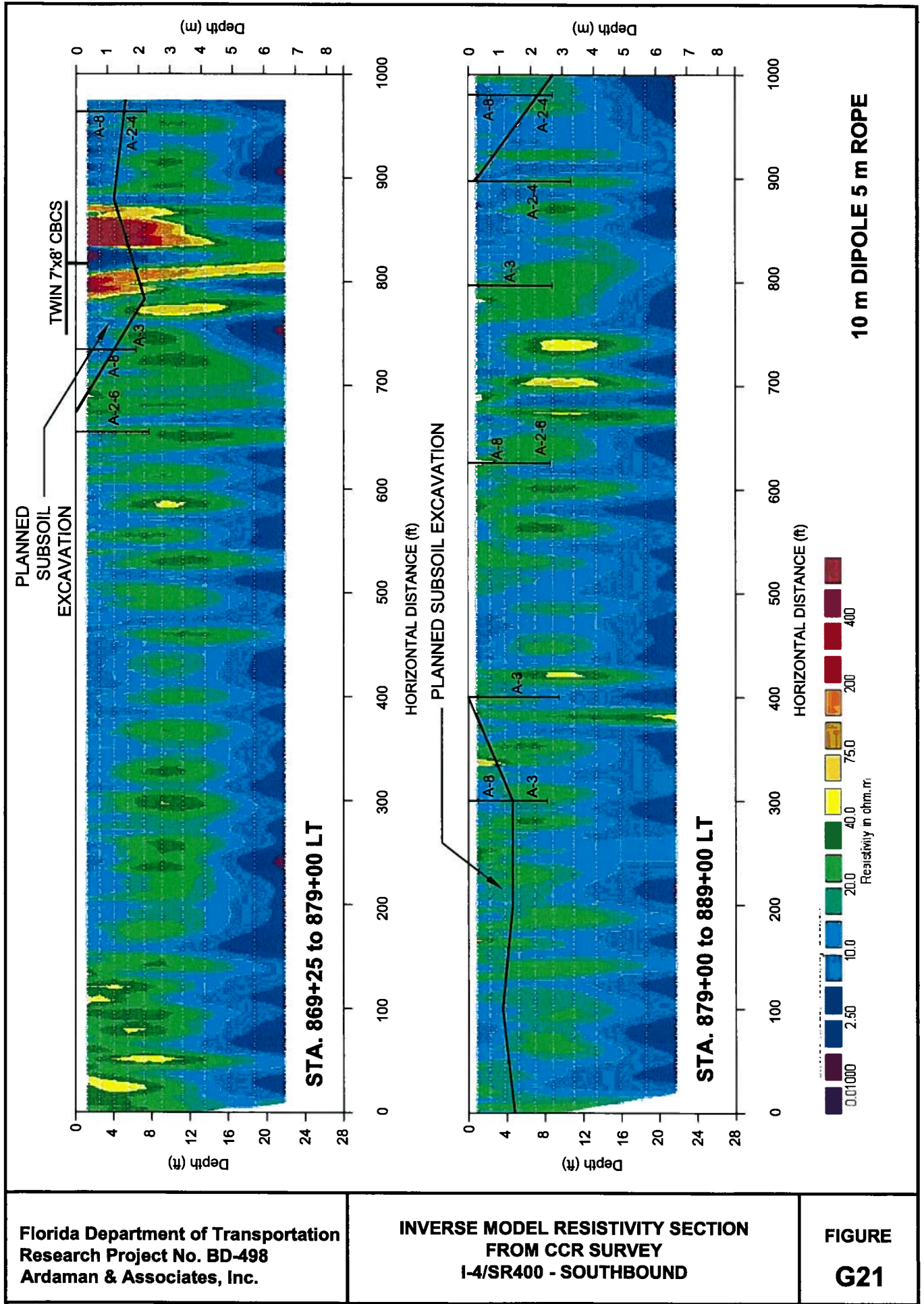


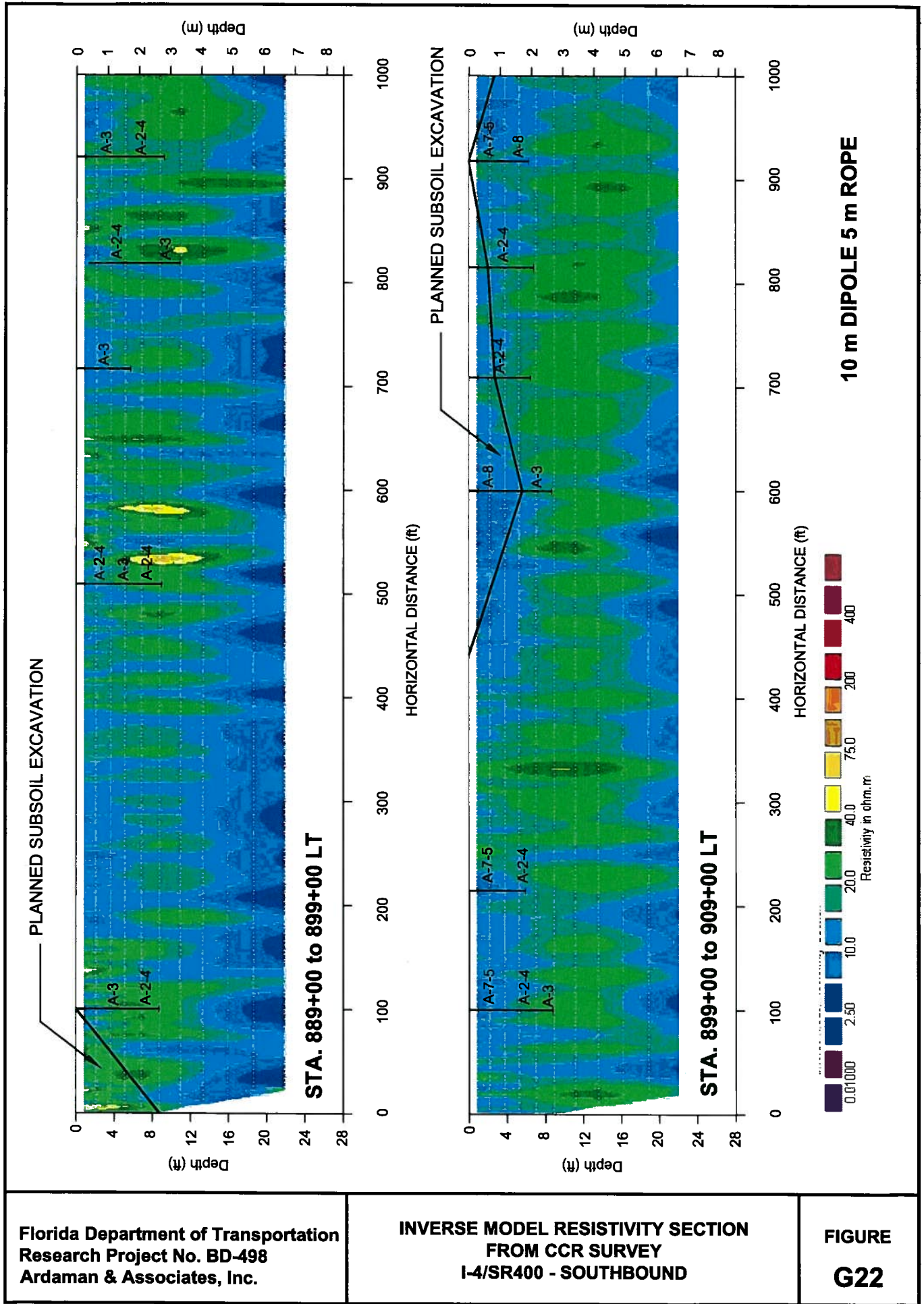




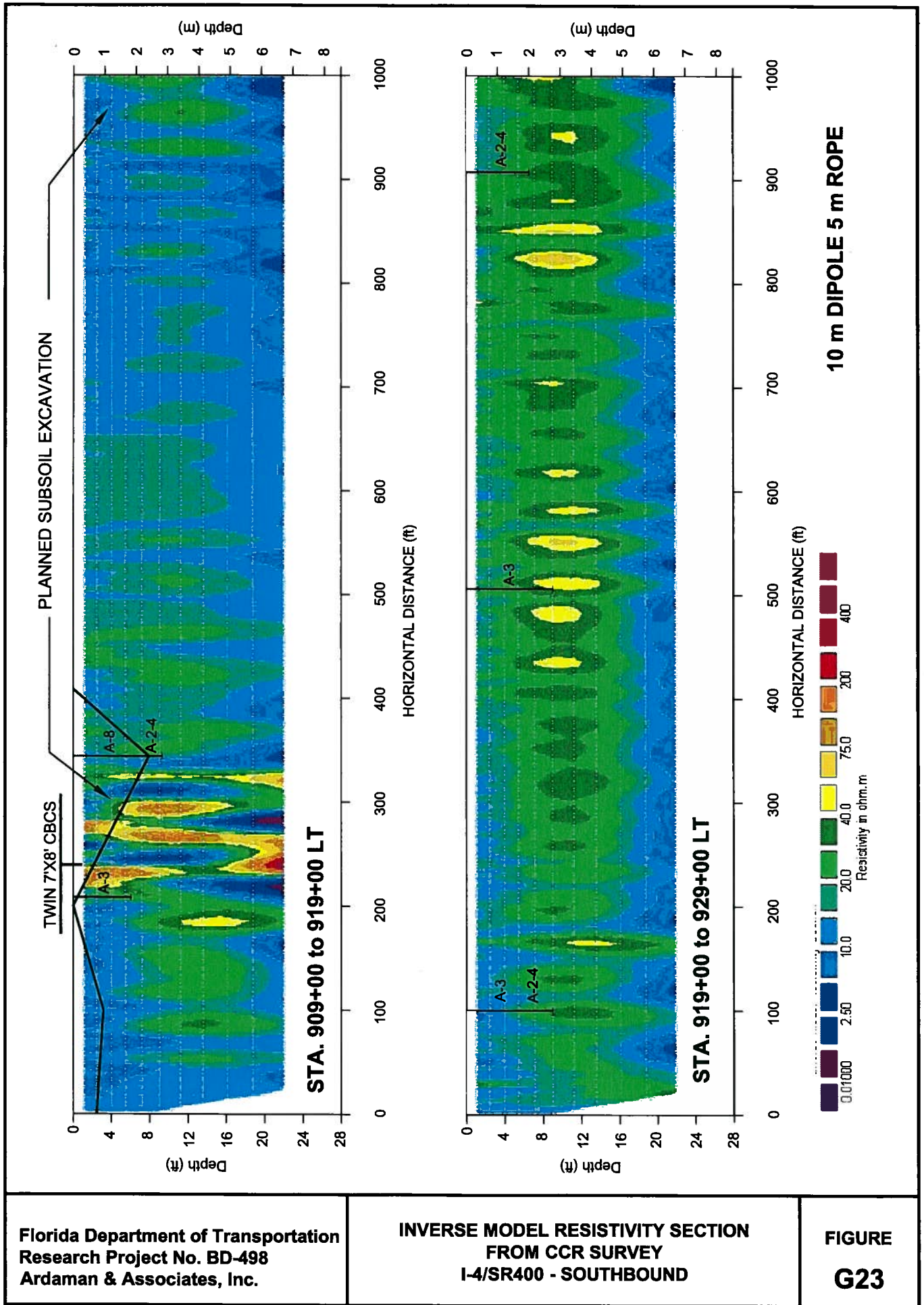




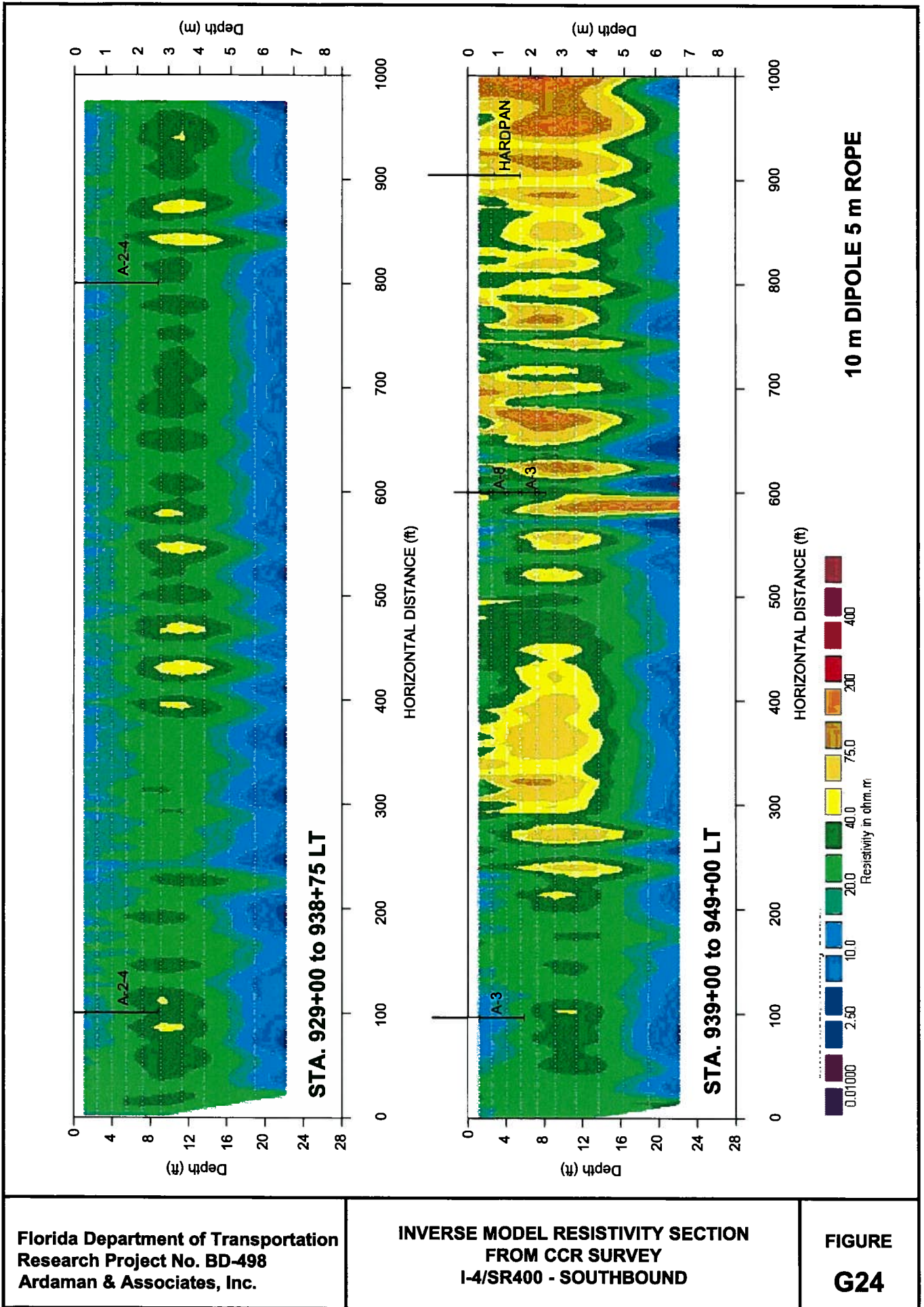


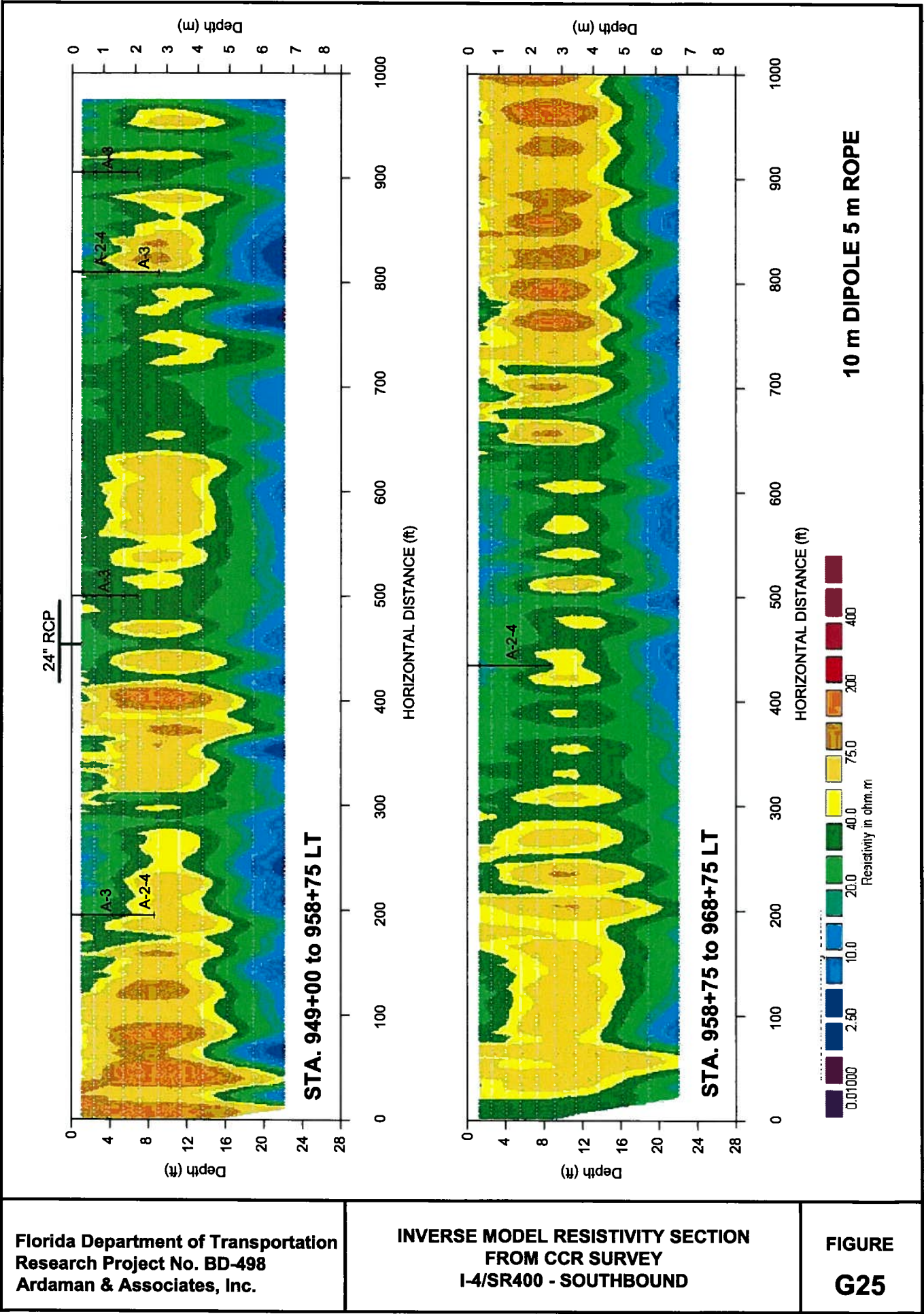








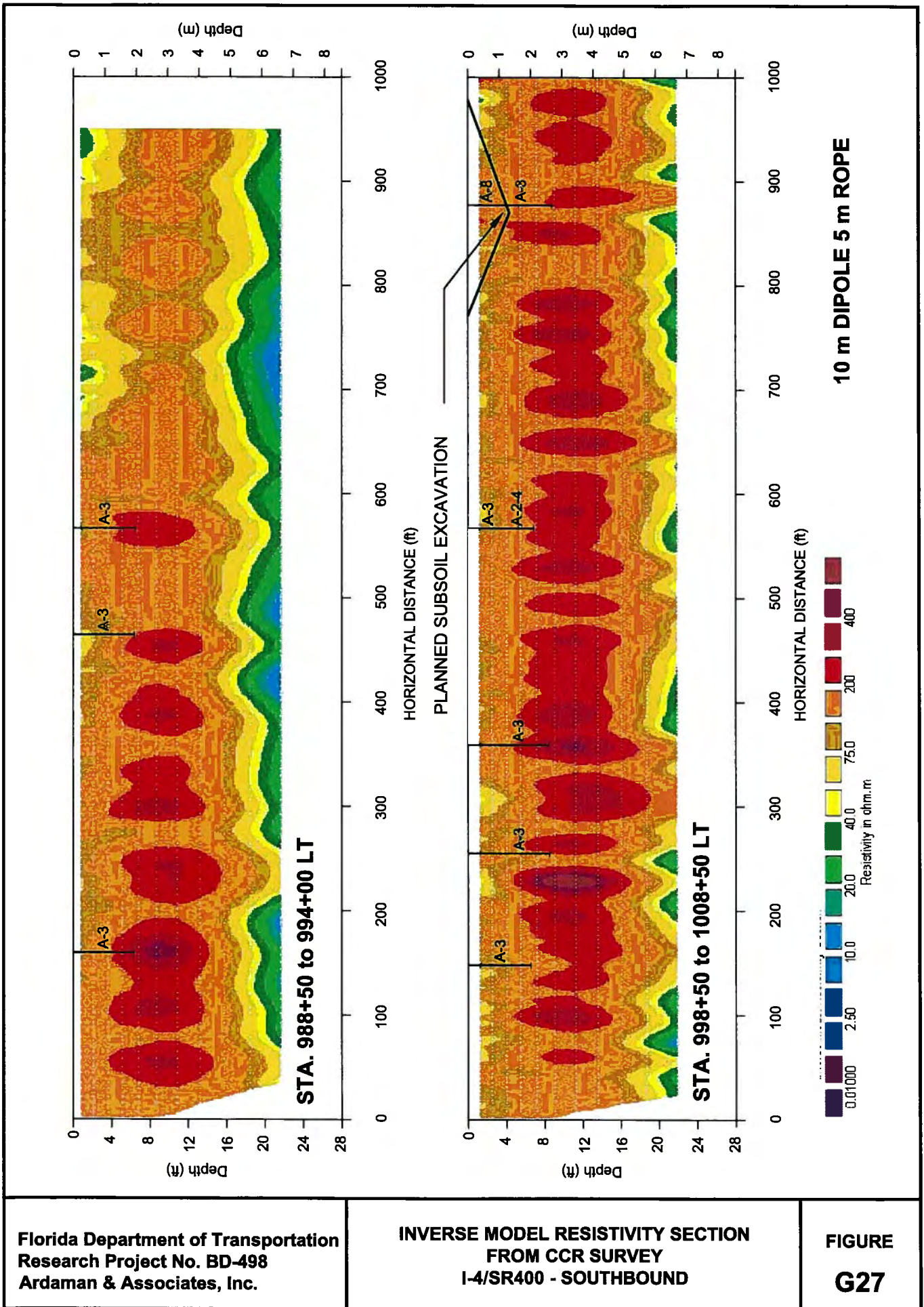




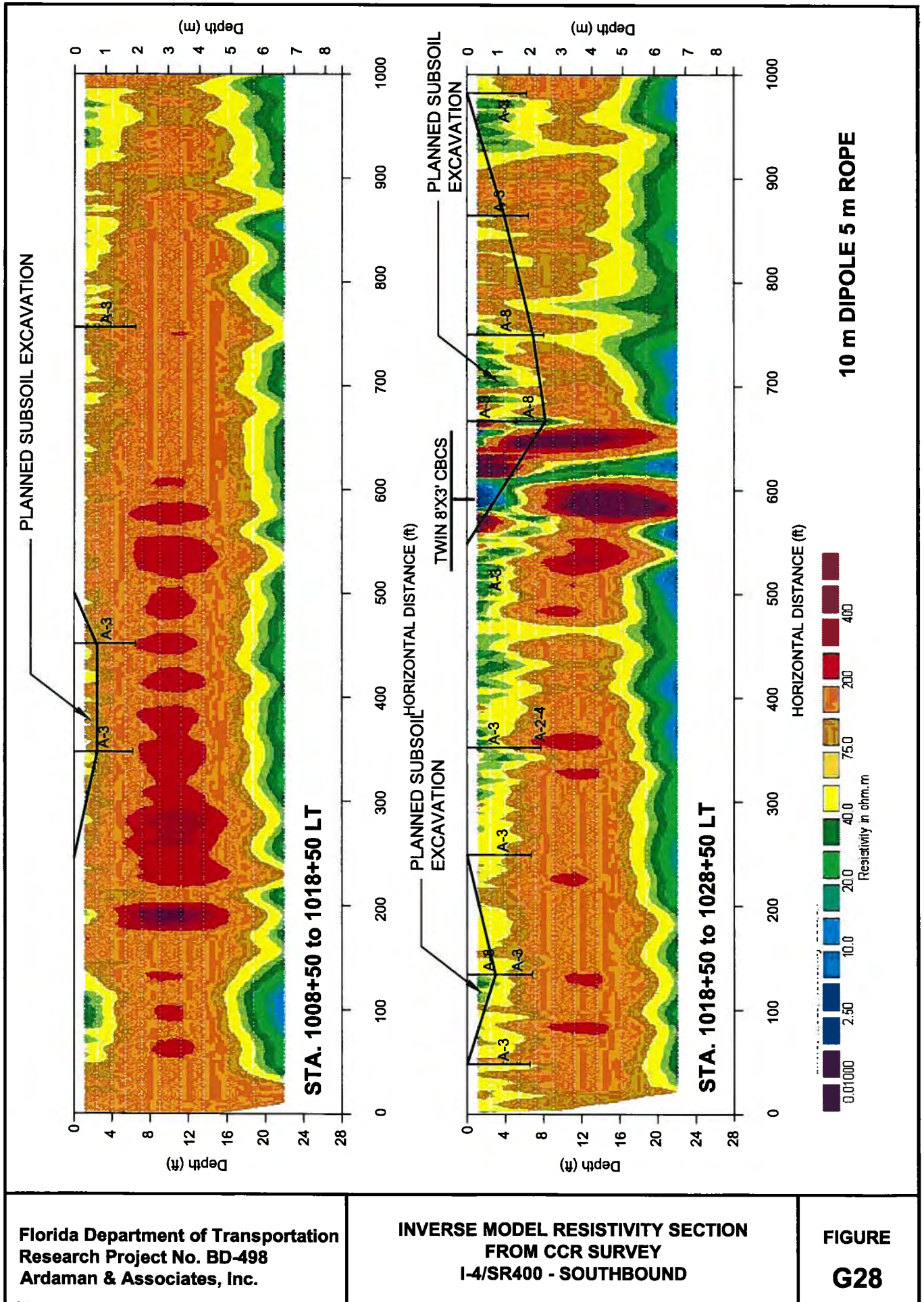




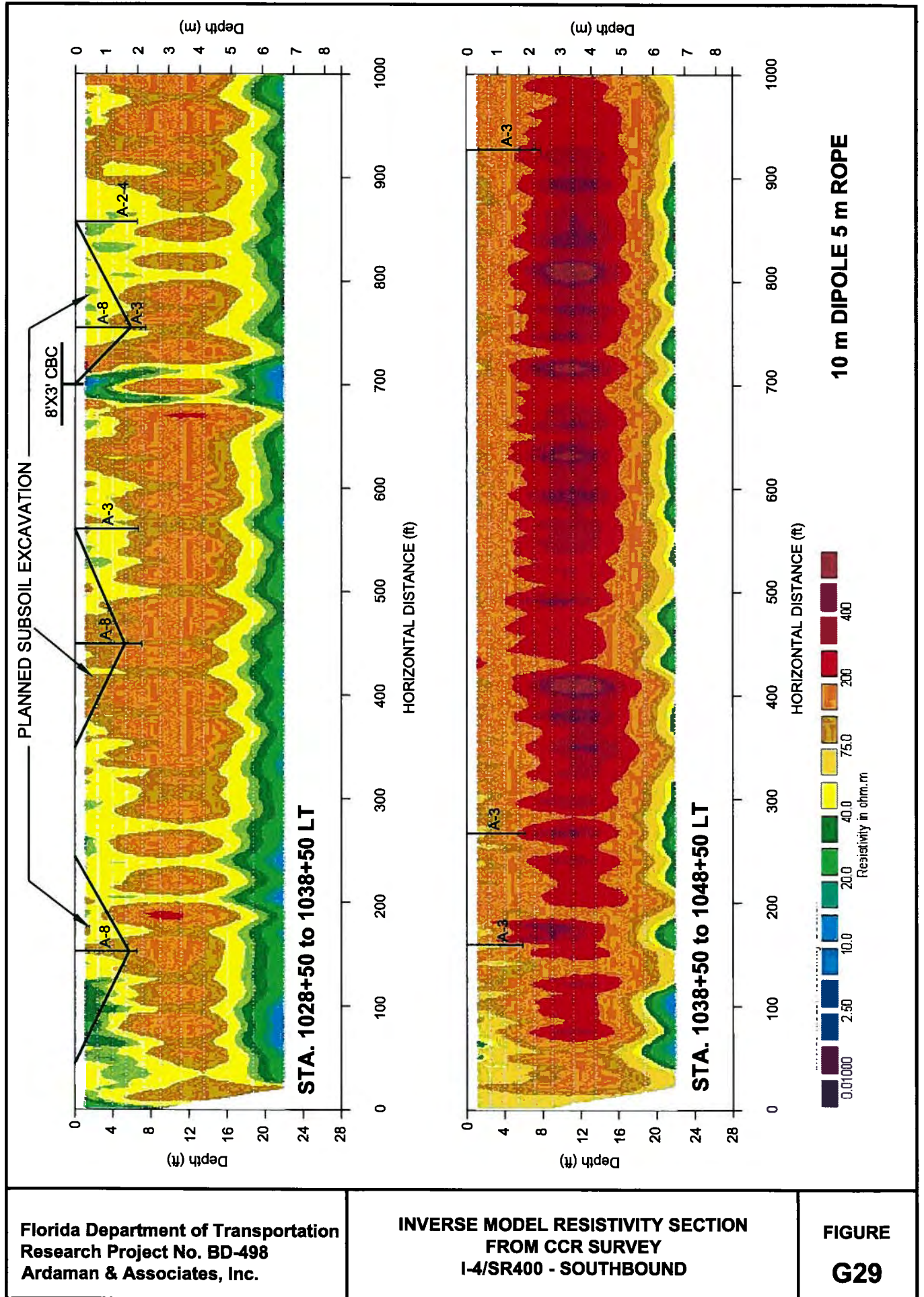




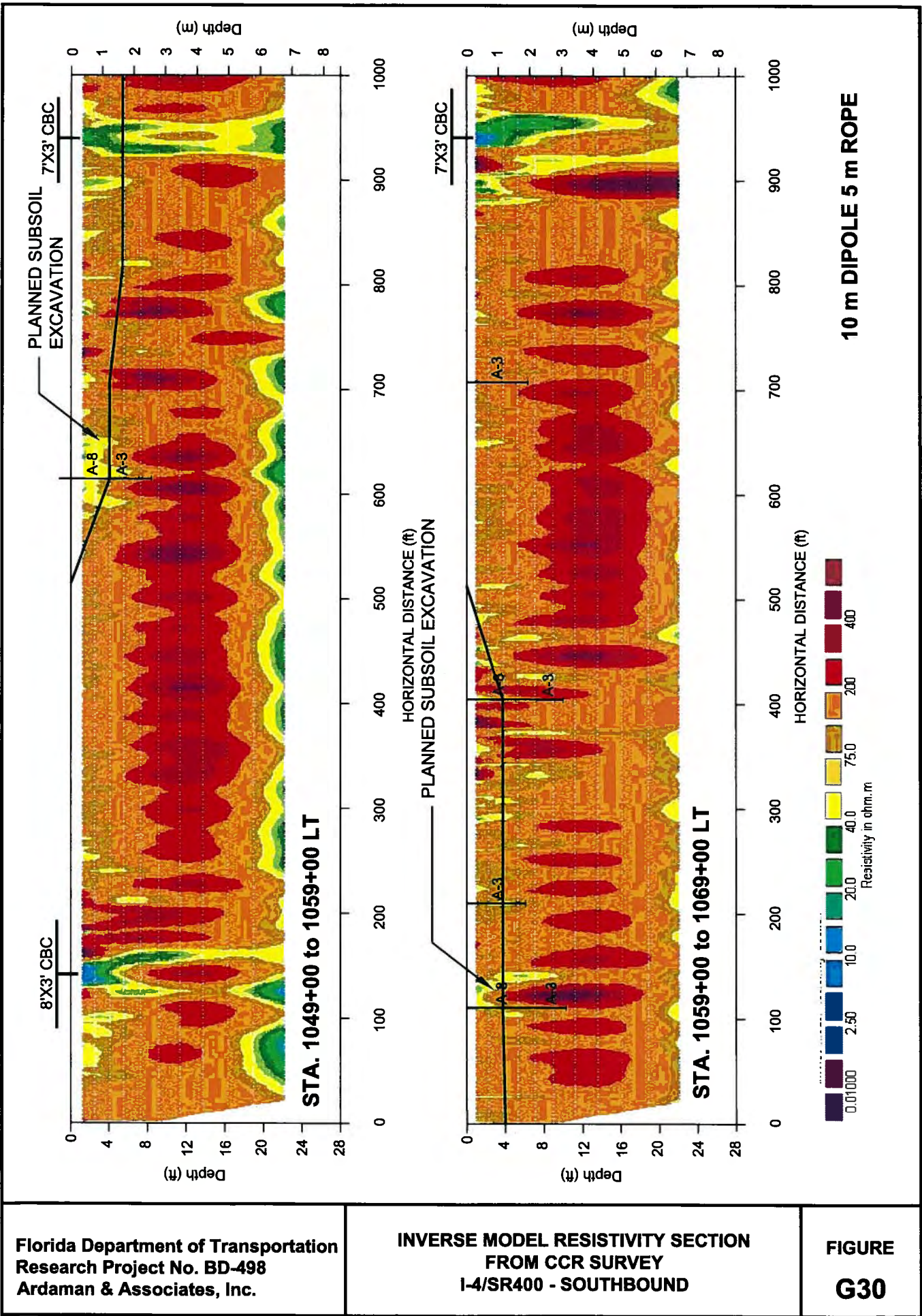














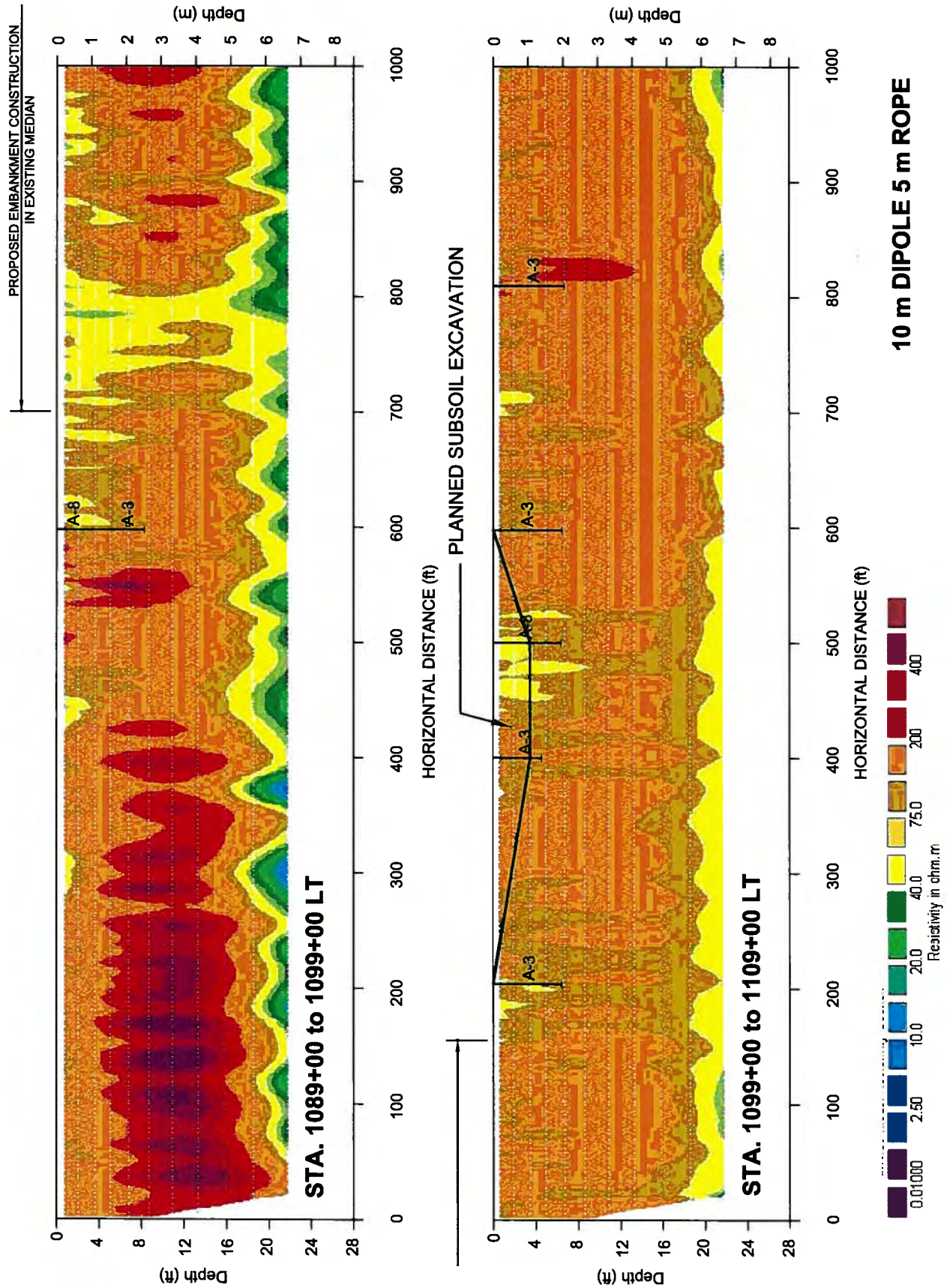




Florida Department of Transportation  
 Research Project No. BD-498  
 Ardaman & Associates, Inc.

INVERSE MODEL RESISTIVITY SECTION  
 FROM CCR SURVEY  
 I-4/SR400 - SOUTHBOUND

FIGURE  
 G32





**APPENDIX H**  
**PHOTOGRAPHS**



CCR Survey at Beauchamp Road Test Site



CCR Survey at Beauchamp Road Test Site





CCR / GPR Suvey at Glen Harwell Test Site



CCR / GPR Survey at Glen Harwell Road Test Site





**OhmMapper Transmitter Dipole**



**OhnMapper Receiver Dipoles**





**GEM-2 Conductivity Meter**



**Geonics EM-61 Conductivity Meter**





**GPR Survey at Sandlake Road Test Site**

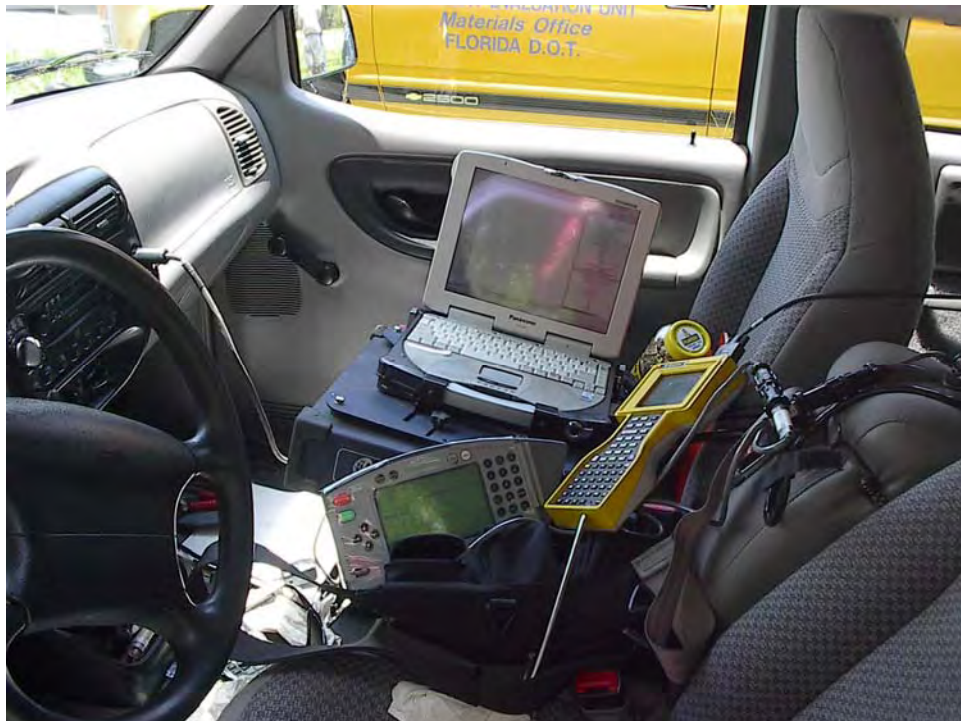


**GPR Survey at Sandlake Road Test Site**



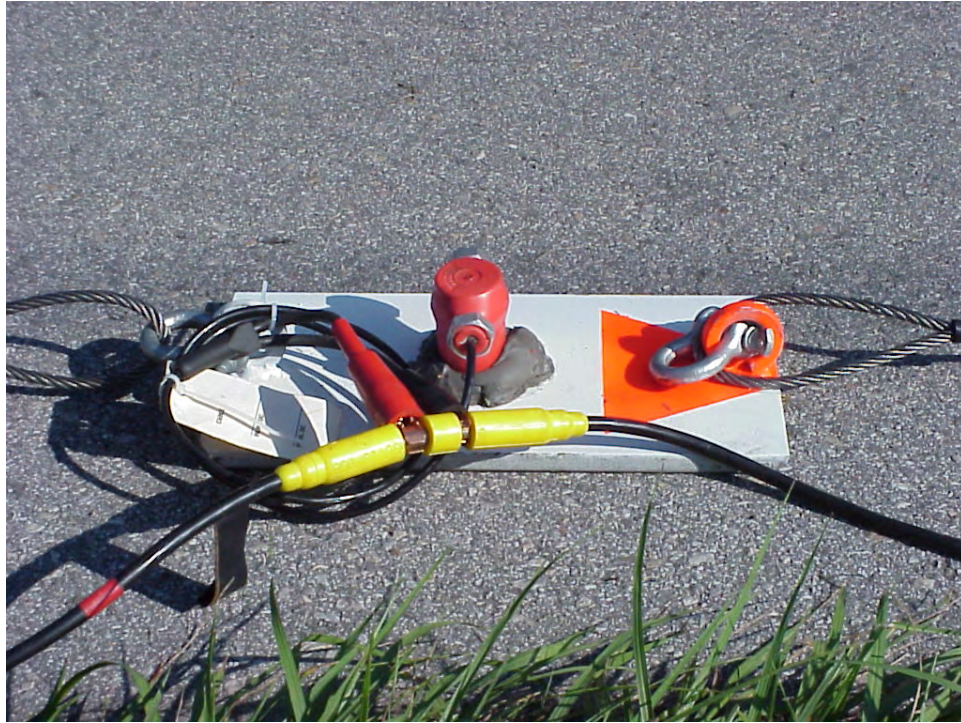


**Dual-GPR With GPS Location**



**Data Acquisition for CCR, GPR & GPS Surveys at S.R. 520**





**Plate-Mounted Geophone for MASW Testing**



**MASW Survey Shot at Glen Harwell Road Test Site**





**MASW Test Shot at Glen Harwell Road Test Site**



**MASW Data Acquisition Set-up**





**Beauchamp Road Test Site Prior to Repair**



**Beauchamp Road Test Site During Prior Repair Work**



**Pavement Repair Section at Glen Harwell Test Site**



**Leaning Power Pole at Glen Harwell Test Site**





**Typical Phosphate Strip Mining Operation**



**Line B at Phosphate Mine Test Site**