MONTGOMERY
& ASSOCIATES
Water Resource Consultants

www.elmontgomery.com

1550 East Prince Road
Tucson, AZ 85719

TEL 520-881-4912
FAX 520-881-1609

PERÚ CHILE COLORADO ARIZONA

TECHNICAL MEMORANDUM

DATE: **May 10, 2013** **PROJECT: 605.77**

TO: **Greg Ghidotti**
RESOLUTION COPPER MINING, LLC

FROM: **Mark Cross, P.G. and Janis Blainer-Fleming**
MONTGOMERY & ASSOCIATES

SUBJECT: **PHASE II HYDROGEOLOGIC FIELD INVESTIGATIONS, NEAR WEST TAILINGS SITE, PINAL COUNTY, ARIZONA**

In accordance with arrangements with Mr. Greg Ghidotti, Resolution Copper Mining, LLC (RCM), this technical memorandum has been prepared to summarize results of the Phase II field investigations of the Near West site, conducted in support of RCM's ongoing prefeasibility studies for storage of RCM mine tailings. The Near West site is shown on **Figure 1** and includes two areas, one centered on Happy Camp Canyon, and the other located between Roblas Canyon on the west and Potts Canyon on the east.

The purpose of Phase II investigations was to conduct electrical resistivity surveys to assess the potential occurrence of shallow groundwater at the Near West site. The resistivity surveys were conducted by HydroGeophysics, Inc. (HGI) from mid-February to early March 2013. Resistivity survey locations are shown on **Figure 1**; the HGI report is given in **Appendix A**.

The Phase II surveys were conducted concurrently with Phase I field investigations, which included confirmatory geologic mapping, documenting discharge and water quality for reported springs, and testing methods for conducting infiltration tests on bedrock surfaces (Montgomery & Associates [M&A], 2013b). Results from the Phase I and II investigations provide data for further characterizing hydrogeologic conditions and planning Phase III field investigations involving subsurface exploration drilling and hydrologic testing.

SUMMARY

BACKGROUND

Previous investigations for the Near West site have included a preliminary hydrogeologic assessment, which involved compiling, reviewing, and summarizing published hydrogeologic data, and assessing hydrogeologic conditions and water uses in the vicinity of the Near West site (M&A, 2012); and Phase I field investigations which involved field mapping, surveying of springs, and pilot infiltration testing (M&A, 2013b). In addition, a groundwater level monitoring round in the Superior basin was conducted by RCM in 2012 as part of the Queen Creek Corridor Survey, which provided additional useful information for the Near West site. Results of these previous investigations indicated the following hydrogeologic features:

- The site is underlain by unconsolidated to weakly consolidated Quaternary alluvium on the floors of and immediately adjacent to canyons and washes, widespread weakly to well lithified Tertiary conglomerate and sandstone, weakly to well lithified extrusive Tertiary volcanic rocks, well lithified Paleozoic sedimentary rocks, well lithified younger Precambrian sedimentary and igneous rocks, and well lithified older Precambrian schist. The Quaternary alluvial deposits are relatively thin and confined to the drainages. The Tertiary sedimentary and volcanic rocks crop out across most of the site, while Paleozoic and Precambrian rock units crop out along the northern, western, and southern margins of the site.

- Results of Phase I investigations indicated that with the exception of Quaternary alluvium, permeability for all geologic units at the site would be very small except where fractured. Fracturing of rock units was most evident along and adjacent to mapped faults in the northern part of the proposed west option tailings facility **(Figure 1)**. However, some evidence of fracturing was also observed in rock units in the western and southwestern parts of the west option tailings facility. Results of pilot infiltration testing conducted on exposed bedrock surface during Phase I investigations confirmed that hydraulic conductivity for the bedrock units tested is very small.

- Three springs occur in the vicinity of the Near West site, including Happy Camp, Benson, and Bear Tank Canyon Springs. Discharge was observed at Happy Camp and Bear Tank Canyon Springs, but not at Benson Spring. Happy Camp and Bear Tank Canyon Springs occur within the Tertiary conglomerate. Benson Spring occurs near the contact between the Tertiary conglomerate and the Pinal Schist.

- Of the numerous wells monitored for the Queen Creek Corridor Survey, four occur in the immediate vicinity of the Near West site. Depth to groundwater level at the Rice Water Well, located within the east option tailings facility footprint, was 16.7 meters (m) below land surface (bls) (54.7 feet [ft] bls) in September 2012. Depth to groundwater level measured in the other three wells, which are outside the tailings footprints, ranged from

3.2 to 16.9 m bls (10.5 to 55.5 ft bls) in September 2012 (M&A, 2013a). Based on contours of groundwater level prepared for the Queen Creek Corridor Study, direction of groundwater movement at the Near West site is generally from northeast to southwest.

RESULTS

Results of the resistivity surveys, combined with results from previous investigations at the Near West site, indicate the following:

- Results of resistivity surveys do not indicate the occurrence of a phreatic surface or water table within the upper 50 to 100 m of the subsurface, which is consistent with the general observation that permeability for all geologic units at the site (with the exception of Quaternary alluvium along ephemeral stream channels) would be very small except where fractured.

- Fracturing of rock units was most evident along and adjacent to mapped faults in the northern part of the proposed west option tailings facility, with some evidence of fracturing in rock units in the western and southwestern parts of the proposed tailings facility. In these areas, shallow groundwater conditions could occur.

- Where fractured, the rock units provide for local collection and storage of groundwater, and movement of groundwater from recharge areas to discharge areas. However, the extent of these fracture networks may be limited, such that groundwater systems are relatively localized and not integrated into a regional groundwater flow system.

- Discharge at springs surveyed during the Phase I investigations indicate the following with respect to the groundwater flow system:

    - Happy Camp Spring occurs in the Gila Conglomerate along the alignment of Roblas Canyon Fault. It is possible that Roblas Canyon Fault extends through the vicinity of Happy Camp Spring, resulting in fracturing of older rocks such as the volcanic tuff and underlying diabase, and possibly the Gila Conglomerate. Local discontinuities in the Gila Conglomerate may provide a pathway for upward movement of groundwater to land surface; however, results of resistivity surveys do not confirm this.

    - Bear Tank Canyon Spring occurs in the Gila Conglomerate. Although fracturing of the Gila Conglomerate is not apparent in the vicinity of the spring, a lineament extending west-northwest from the spring was identified from Google Earth images and aerial photography. It is possible that this feature represents a discontinuity in the Gila Conglomerate and a pathway for upward movement of groundwater to land surface; however, results of resistivity surveys do not confirm this.

  - Benson Spring occurs in the Gila Conglomerate near the contact with Pinal Schist. Little fracturing was observed in the Pinal Schist compared to other rock units in the study area, and the Pinal Schist may act as a barrier to groundwater movement. Although Benson Spring was not flowing at the time of the Phase I survey, it is assumed to flow seasonally, and may reflect groundwater moving through fracture zones in younger rocks that may be forced upward to land surface at or near the contact with the Pinal Schist.

- Results of the Phase II resistivity surveys, combined with results Phase I investigations, indicate the following with respect to implications for tailings storage at the Near West site:

  - Most areas of the Near West site are underlain by rocks of very small permeability, which would limit tailings water seepage and potential for migration of tailings water.

  - Localized fracture networks of larger permeability occur in some areas, and would act to collect, store, and transmit groundwater. In areas where these fracture networks intersect land surface, potential for tailings water seepage and migration in the subsurface could be larger.

  - Tailings water seepage into these fracture networks would act to increase hydraulic head, which could cause increased discharge from existing seeps or springs outside of the tailings facility and/or potentially cause development of new springs or seeps.

  - Where fractured rock units are in contact with the Pinal Schist south of the proposed west option tailings facility, the Pinal Schist likely acts as a barrier to groundwater movement, and groundwater may be forced upward to land surface at or near the contact with the Pinal Schist.

BACKGROUND

The Near West site encompasses an area of approximately 12 square miles west-northwest from Superior, Arizona. The site is shown on **Figure 1** and includes all or parts of sec. 22, 23, 24, 25, 26, 27, 34, 35, and 36, T. 1 S., R. 11 E., all or parts of sec. 19, 21, 27, 28, 29, 30, 31, 32, 33, and 34, T. 1 S., R. 12 E., part of sec. 1, T. 2 S., R. 11 E., and parts of sec. 5 and 6, T. 2 S., R. 12 E., in Pinal County, Arizona. The Near West site is located on land managed by the U.S. Forest Service, Tonto National Forest (TNF).

PRELIMINARY HYDROGEOLOGIC ASSESSMENT

A preliminary hydrogeologic assessment was conducted in 2012 and involved compiling, reviewing, and summarizing published hydrogeologic data, and assessing hydrogeologic conditions and water uses in the vicinity of the Near West site (M&A, 2012). The following hydrogeologic units (in descending order) were inferred to occur in the subsurface in the vicinity of the Near West site:

- A thin veneer of unconsolidated active Quaternary alluvium and weakly consolidated older Quaternary alluvium on and adjacent to the floors of canyons and washes

- Tertiary conglomerate, sandstone, and volcanic rocks of relatively low permeability, except where fractured, which are exposed across most of the site

- Paleozoic sedimentary rocks including carbonates, siltstone, shale, and quartzite of relatively low permeability, except along bedding planes and where fractured, which are exposed in the western part of the site and underlies younger units in the remainder of the site

- Younger Precambrian sedimentary and igneous rocks including quartzite, shale, limestone, and diabase of low permeability, except along bedding planes and where fractured, which are exposed in the northeastern, western and southwestern parts of the site and underlies younger units in the remainder of the site

- Older Precambrian crystalline metamorphic rocks (Pinal Schist) of low permeability, except along relict bedding surfaces and where fractured, which is exposed in the northern, southern, and southwestern parts of the site and underlies younger units in the remainder of the site

QUEEN CREEK CORRIDOR SURVEY

Water levels were measured at selected wells in Superior Basin by RCM during the period May to September 2012 as part of the Queen Creek Corridor Survey (M&A, 2013a). Two stock wells (Rice Water Well and Noble Windmill) are located within the tailings footprints of the Near West site (**Figure 1**). A groundwater level of 16.7 m bls (54.7 ft bls) was measured at the Rice Water Well, but the Noble Windmill has no sounder access. The Rice Water Well is collared in Gila Conglomerate, but construction details are unavailable. In September 2012, groundwater levels were also measured at three wells outside the tailings footprints but within the area shown on **Figure 1**. The wells are summarized in **Table 1** and shown on **Figure 1**.

TABLE 1. WELLS AND GROUNDWATER LEVELS IN IMMEDIATE VICINITY OF NEAR WEST SITE

CADASTRAL LOCATION	WELL NAME	DEPTH TO GROUNDWATER LEVEL (m [ft] bls)[a]	GROUNDWATER LEVEL ELEVATION (m [ft], amsl)[b]
(D-1-11) 22 ad	Roblas Windmill	3.2 (10.5)	703 (2,305)
(D-1-12) 16db	Cottonwood Well	10.9 (35.7)	847 (2,778)
(D-1-12) 19cb	Noble Windmill	NA	NA
(D-1-12) 31dd	Rice Water Well	16.7 (54.7)	739 (2,426)
(D-2-11) 01cda	Herron Ranch House	16.9 (55.5)	704 (2,310)

[a] m (ft) bls = meters (feet) below land surface
[b] m (ft) amsl = meters (feet) above mean sea level
NA = Not Accessible

For the three wells outside the tailings footprints, depth to groundwater level ranged from 3.2 to 16.9 m bls (10.5 to 55.5 ft bls). The only well for which there is construction information is the Herron Ranch House well which is 121.9 m (400 ft) deep, with perforated casing from 61.0 to 121.9 m bls (200 to 400 ft bls). The driller's log for the well indicates the well is completed in fractured volcanics. The other four wells are likely shallow and completed in alluvium and shallow bedrock units.

A groundwater level contour map was prepared for the Queen Creek Corridor Survey to assess regional patterns of groundwater movement (M&A, 2013a). The elevation contours are based on water level measurements in wells and elevations of mapped springs. Groundwater was inferred to move from recharge areas in the topographically higher portions of the Superior Basin toward Queen Creek (generally northeast to southwest in Near West area). Because data used to prepare the regional contour map are very sparse, contours were interpolated over large areas, and are not considered reliable for inferring occurrence of groundwater or groundwater level at a specific location. However, the contours suggest that in areas where rocks are fractured, groundwater may occur at relatively small depths.

PHASE I HYDROGEOLOGIC INVESTIGATIONS

The Phase I hydrogeologic investigations for the Near West site were conducted during the period from February 11 through March 5, 2013 (concurrently with the Phase II resistivity surveys). The Phase I program included confirmatory geologic mapping along selected traverses, documenting four reported springs, collecting water samples at two of the springs, and testing methods for conducting infiltration tests on bedrock surfaces (M&A, 2013b). Results from Phase I indicated that:

- Geologic mapping by Arizona Geological Survey (AZGS) appears to be generally accurate with some relatively minor exceptions at a local scale. Small-scale features were not always mapped locally, and small inconsistencies were noted along some of the traverses. Near the southwest corner of the proposed tailing facility, faulting was observed to be more complex than shown on the published geologic map.

- With the exception of Quaternary alluvium along ephemeral stream channels, permeability for all geologic units at the site would be very small except where fractured. Fracturing of rock units was most evident along and adjacent to mapped faults in the northern part of the proposed tailings facility. However, some evidence of fracturing was also observed in rock units in the western and southwestern parts of the proposed tailings facility.

- Three springs occur in the vicinity of the Near West site, including Happy Camp, Benson, and Bear Tank Canyon Springs. Discharge was observed at Happy Camp and Bear Tank Canyon Springs, but not at Benson Spring. Happy Camp and Bear Tank Canyon Springs occur within the Tertiary conglomerate. Benson Spring occurs near the contact between the Tertiary conglomerate and the Pinal Schist. A feature mapped as Perlite Spring was inspected. Three apparent surface water impoundments occur in the vicinity of the perlite quarries in the northern part of the site, but are not believed to be springs. Samples were collected for laboratory chemical analyses from Happy Camp and Bear Tank Canyon Springs.

- Results of pilot infiltration testing indicate that the “bottomless bucket” method provided an appropriate means for measuring infiltration rates and field-saturated hydraulic conductivity (Ksat) of exposed bedrock surfaces. The generally very small Ksat values determined by these pilot tests are consistent with the general magnitude of Ksat values that would be expected for these bedrock units.

PHASE II HYDROGEOLOGIC INVESTIGATIONS

The objective of the Phase II hydrogeologic investigations was to assess the occurrence of shallow groundwater at the Near West site by conducting surface resistivity surveys at selected locations. The resistivity surveys were conducted by HGI. A "pilot" resistivity survey was conducted during the period February 12 through 15 to assess occurrence of groundwater in the immediate vicinity of Happy Camp Spring and Bear Tank Canyon Springs. A "full-scale" survey was conducted at six additional locations during the period February 22 through March 3, 2013. Methods and results of the pilot and full-scale surveys are documented in the report prepared by HGI **(Appendix A)** and summarized below. Resistivity survey locations are shown on **Figure 1**.

METHODOLOGY

Resistivity data were obtained along a total of sixteen resistivity lines at eight locations. At each location, data were obtained along two 500-m long orthogonal resistivity lines **(Figure 1)**. An initial pilot resistivity survey was conducted at Happy Camp Spring (Area A1) and Bear Tank Canyon Spring (Area A2). Results from the pilot survey were used to select locations for a subsequent "full-scale" survey, which included Areas B, E, F, G, M, and N. The maximum depth of investigation of the resistivity surveys was in the range of approximately 50 to 100 m at the center of the resistivity lines, decreasing outward toward the ends of the lines. Resistivity data were supplemented by Induced Polarization (IP) data at locations A1 and N. Details on geophysical theory, data acquisition logistics and equipment, and data processing are given in the HGI report **(Appendix A)**.

RESULTS OF RESISTIVITY AND IP SURVEYS

Areas A1 (Gila Conglomerate at/near Bear Tank Canyon Spring) and G (Gila Conglomerate northwest of Bear Tank Canyon Spring)

Area A1 is centered at Bear Tank Canyon Spring and Area G is centered about 0.35 kilometers (km) north-northeast from the spring **(Figure 1)**. Only the Gila Conglomerate (Tcg) is exposed in these areas. Differences in resistivity between Areas A1 and G are minor, and appear to be related chiefly to differences in lithologic characteristics of Gila Conglomerate rather than differences in moisture content. Results from the four resistivity lines in areas A1 and G indicate that:

- the occurrence of a near-surface zone of higher resistivity, approximately 5 m thick, interpreted to be a relatively dry, sandy material
- Deeper zones of variable resistivity, interpreted to be related to differences in composition and size of clasts within the Gila Conglomerate
- No obvious indicators of groundwater occurrence

Areas A2 (Happy Camp Spring) and B (north of Happy Camp Spring)

Area A2 is centered at Happy Camp Spring and Area B is centered about 0.32 km north from Happy Camp Spring **(Figure 1)**. Four geologic units are exposed in these areas: Quaternary undivided surficial deposits (Qs) along the floor of Happy Camp Canyon, Tertiary Gila Conglomerate (Tcg) underlying the alluvium and exposed to the east, poorly welded volcanic tuff (Tt) exposed west of the alluvium, and younger Precambrian diabase (Yd) exposed west of the tuff.

Differences in resistivity between Areas A2 and B appear to be related chiefly to differences in depth and clay content for geologic units, with only minor indications of possible differences in moisture content. Slightly conductive material was identified at the location of Happy Camp Spring on line A2-2, which may reflect occurrence of groundwater. Localized more conductive near-surface zones were identified on line A2-1 that could represent localized occurrence of groundwater or increased moisture content from infiltration of surface runoff. However, these possible indications of increased moisture content at or near Happy Camp Spring are minor compared to differences attributed to depth and clay content for geologic units.

Results from the four resistivity lines and two IP lines in areas A2 and B indicate:

- the occurrence of a near-surface zone of higher resistivity, approximately 5 m thick, interpreted to be a relatively dry sandy material

- a deeper highly conductive zone, representing the Tertiary volcanic tuff (Tt) that crops out to the west and dips to the southeast beneath the Gila Conglomerate

    - The IP survey indicates that the tuff also has high electrical chargeability, which suggests that the high electrical conductivity is associated with presence of clay minerals, and does not necessarily indicate the presence of groundwater.

    - The presence of clay minerals in the tuff could result from weathering, which could be enhanced due to infiltration and downward movement of surface runoff along fractures in the tuff. In addition, it is hypothesized that clay minerals from weathering of the diabase could be entrained in surface runoff that infiltrates the tuff, partially filling some pore space with clay particles.

- a deeper more resistive zone, interpreted to be the diabase that crops out west of the tuff, dips to the southeast, and underlies the tuff

Area N (Gila Conglomerate on ridge east of Rice Water Canyon

Area N is located on a ridge east of Rice Water Canyon **(Figure 1)**. Only the Gila Conglomerate (Tcg) is exposed in this area. Results from the two resistivity lines and one IP line in Area N indicate that materials are relatively resistive in the upper 60 m, and slightly more conductive below 60 m.

- IP results suggest that the slightly higher conductivity below 60 m is due to higher clay content, either in the Gila Conglomerate or possibly due to presence of a higher conductivity unit such as the tuff below 60 m.

- IP results show some contrasts in chargeability above 60 m related to clay content, which may correspond to coarse-grained channel deposits of small clay content and finer-grained overbank deposits with larger clay content.

Area E (older Quaternary alluvium and south edge of Gila Conglomerate)

Area E is located in the southeast part of the study area, east of Rice Water Canyon approximately 1 km north of Queen Creek **(Figure 1)**. Three geologic units are exposed in this area: Older Quaternary alluvium (Qoa), Tertiary Gila Conglomerate (Tcg), and Tertiary sandstone (Tss). Results from the two resistivity lines in Area E indicate:

- The Gila Conglomerate more conductive than the older alluvium, and is more conductive than the Gila Conglomerate in Area N to the north; the higher conductivity may be due to groundwater and/or higher clay content

- Materials in the south part of Area E are more resistive, which may correspond to sandstone units buried beneath older alluvium and cropping out nearby

- Presence of groundwater is not readily apparent

Area F (Gila Conglomerate south of Tertiary volcanic rocks)

Area F is located in the central part of the study area **(Figure 1)**. Gila Conglomerate (Tcg) is exposed in the area, and Tertiary felsic lava flow rocks (Tfp) are exposed northeast from this area. Results from the two resistivity lines in Area F indicate:

- The Gila Conglomerate has similar conductivity to the conglomerate in Area N

- A deeper resistive zone is interpreted to correspond to the felsic lava flow rocks, which crop out northeast of Area F and interpreted to underlie the Gila Conglomerate in Area F

Area M (western edge of Gila Conglomerate)

Area M is located in the west part of the study area **(Figure 1)**. Only the Gila Conglomerate is exposed in this area. A stratigraphically and structurally complex assemblage of older Tertiary, Paleozoic, and younger Precambrian rocks is exposed on the northwest boundary of this area. Results from the two resistivity lines in Area M indicate:

- A thin veneer of high resistivity sandy soil
- Gila Conglomerate with higher conductivity than conglomerate in Areas F and G
- Slightly conductive materials near center of survey lines, with more resistive material away from center
- No obvious indicators of groundwater

SUMMARY OF RESULTS

Results of resistivity and IP surveys are summarized as follows:

- A thin veneer of resistive material, about 5 to 6 m thick, occurs at the surface at all sites, and is interpreted to be a relatively dry sandy material
- The Gila Conglomerate exhibits a range of electrical resistivity
    - Low resistivity could be either larger clay content as indicated by IP results, or occurrence of groundwater, but no definitive groundwater signatures were identified
    - High resistivity could be due to larger clasts
    - Conductivity is higher in Areas E and M than in Areas F, G, and N
- The most conductive material identified in the resistivity surveys is the poorly welded tuff (Tt) on the west side of Happy Camp Spring, which suggests a higher clay content and/or water content in the tuff. Induced polarization data suggest a higher clay content in the tuff compared to the diabase or conglomerate. The higher clay content could result from breakdown of the tuff due to weathering, which could be enhanced due to infiltration and downward movement of surface runoff along fractures. In addition, it is hypothesized that clay minerals from weathering of the diabase could be entrained in surface runoff that infiltrates the tuff, partially filling some pore space with clay particles.

DISCUSSION OF RESULTS

Results of resistivity surveys indicate substantial variations in electrical resistivity of geologic units in the shallow subsurface, which can reflect variations in clay content and/or moisture content. For the two sites at which an IP survey was also conducted (Areas A2 and N), zones that exhibited high electrical conductivity also exhibited high chargeability, which is associated with high clay content. These results suggest that higher electrical conductivity is chiefly an indication of increased clay content, at least in Areas A2 and N.

HGI did not identify any definitive groundwater signatures in the resistivity data for any of the areas surveyed. However, some possible indications of groundwater (or at least increased moisture content), were identified by HGI in the survey data for Area A2 centered at Happy Camp Spring. Along line A2-2 which trends northwest-southeast through Happy Camp Spring, HGI noted that the slightly higher conductivity near the spring could reflect occurrence of groundwater. HGI also noted that near surface conductive material north of Happy Camp Spring along north-south section A2-1 (where the line crosses stream channel alluvium) could represent increased moisture content from infiltration of surface runoff. The conductivity is smaller south of the spring where the resistivity line crosses Gila Conglomerate.

Conceptual Model for Groundwater Flow System

Results of resistivity surveys do not indicate the occurrence of a phreatic surface or water table within the upper 50 to 100 m of the subsurface. These results are consistent with the general observation that permeability for all geologic units at the site (with the exception of Quaternary alluvium along ephemeral stream channels) would be very small except where fractured. Fracturing of rock units was most evident along and adjacent to mapped faults in the northern part of the proposed west option tailings facility, with some evidence of fracturing in rock units in the western and southwestern parts of the proposed tailings facility. In these areas, shallow groundwater conditions could occur.

Where fractured, the rock units provide for local collection and storage of groundwater, and movement of groundwater from recharge areas to discharge areas. However, the extent of these fracture networks may be limited, such that groundwater systems are relatively localized and not integrated into a regional groundwater flow system. Faulting has resulted in the groundwater system being highly compartmentalized in some areas, further limiting integration of local groundwater systems into a regional groundwater system.

The small but measurable rates of groundwater discharge at Happy Camp and Bear Tank Canyon Springs at the time of the surveys in Winter of 2013 (M&A, 2013b) indicate the following with respect to the groundwater flow system(s):

- Happy Camp Spring occurs in the Gila Conglomerate along the alignment of Roblas Canyon Fault. It is possible that Roblas Canyon Fault extends through the vicinity of Happy Camp Spring, resulting in fracturing of older rocks such as the volcanic tuff and underlying diabase, and possibly the Gila Conglomerate. The tuff and diabase may be sufficiently fractured to store and transmit groundwater, and local discontinuities in the Gila Conglomerate may provide pathways for upward movement of groundwater to land surface at the spring; however, results of resistivity surveys do not confirm this.

- Bear Tank Canyon Spring occurs in the Gila Conglomerate. Although fracturing of the Gila Conglomerate is not apparent in the vicinity of the spring, a linear topographic feature (lineament) extending west-northwest from the spring was identified from Google Earth images and aerial photography. This lineament is shown on **Figure 2**. It is possible that this feature represents a discontinuity in the Gila Conglomerate and a pathway for upward movement of groundwater to land surface; however, results of resistivity surveys do not confirm this.

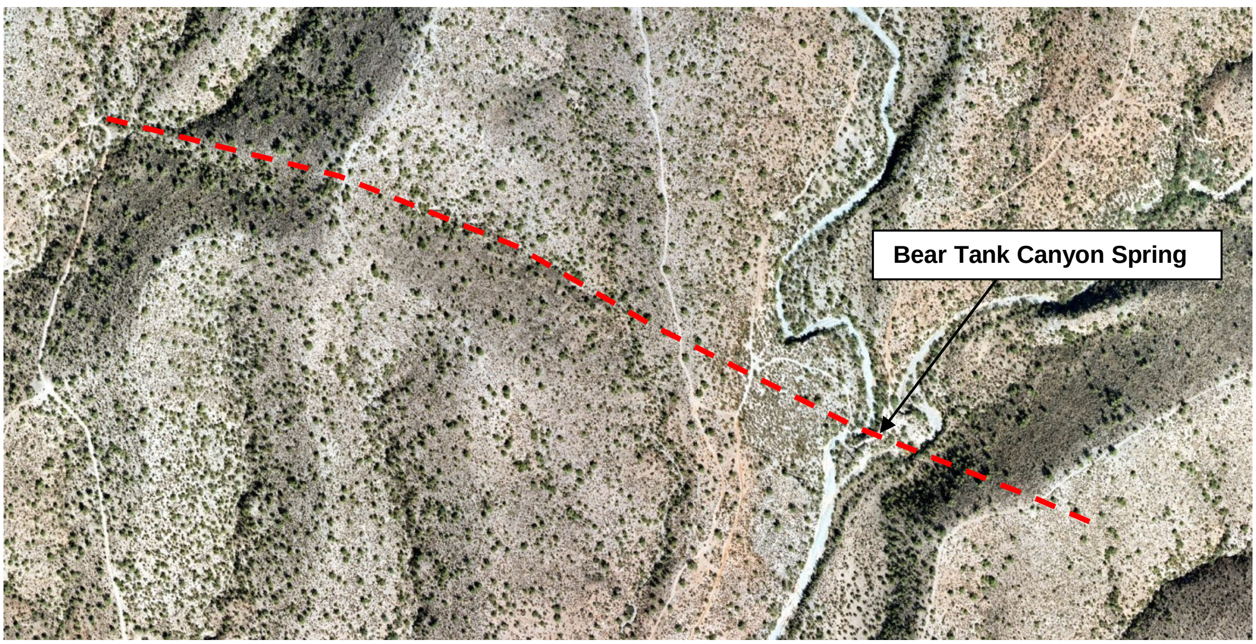

Figure 2. Bear Tank Canyon Spring and linear feature to the west-northwest

Benson Spring was not flowing at the time of the Phase I spring survey, but is assumed to flow seasonally. Benson Spring occurs in the Gila Conglomerate near the contact with Pinal Schist. Little fracturing was observed in the Pinal Schist compared to other rock units in the study area, and the Pinal Schist may act as a barrier to groundwater movement. Benson Spring, when flow occurs, may result from groundwater moving through fracture zones in younger rocks that is forced upward to land surface at or near the contact with the Pinal Schist.

Implications for Tailings Storage

Results of the Phase II resistivity surveys, combined with results Phase I investigations, indicate that most areas of the Near West site are underlain by rocks of very small permeability, which would limit tailings water seepage and potential for migration of tailings water. However, results also indicate the occurrence of localized fracture networks of larger permeability that act to collect, store, and transmit groundwater. In areas where these fracture networks intersect land surface, potential for tailings water seepage and migration in the subsurface could be larger. Tailings water seepage into these fracture networks would act to increase hydraulic head, which could cause increased discharge from existing seeps or springs outside of the tailings facility and/or potentially cause development of new springs or seeps. Where fractured rock units are in contact with the Pinal Schist south of the proposed west option tailings facility, the Pinal Schist likely acts as a barrier to groundwater movement, and groundwater may be forced upward to land surface at or near the contact with the Pinal Schist.

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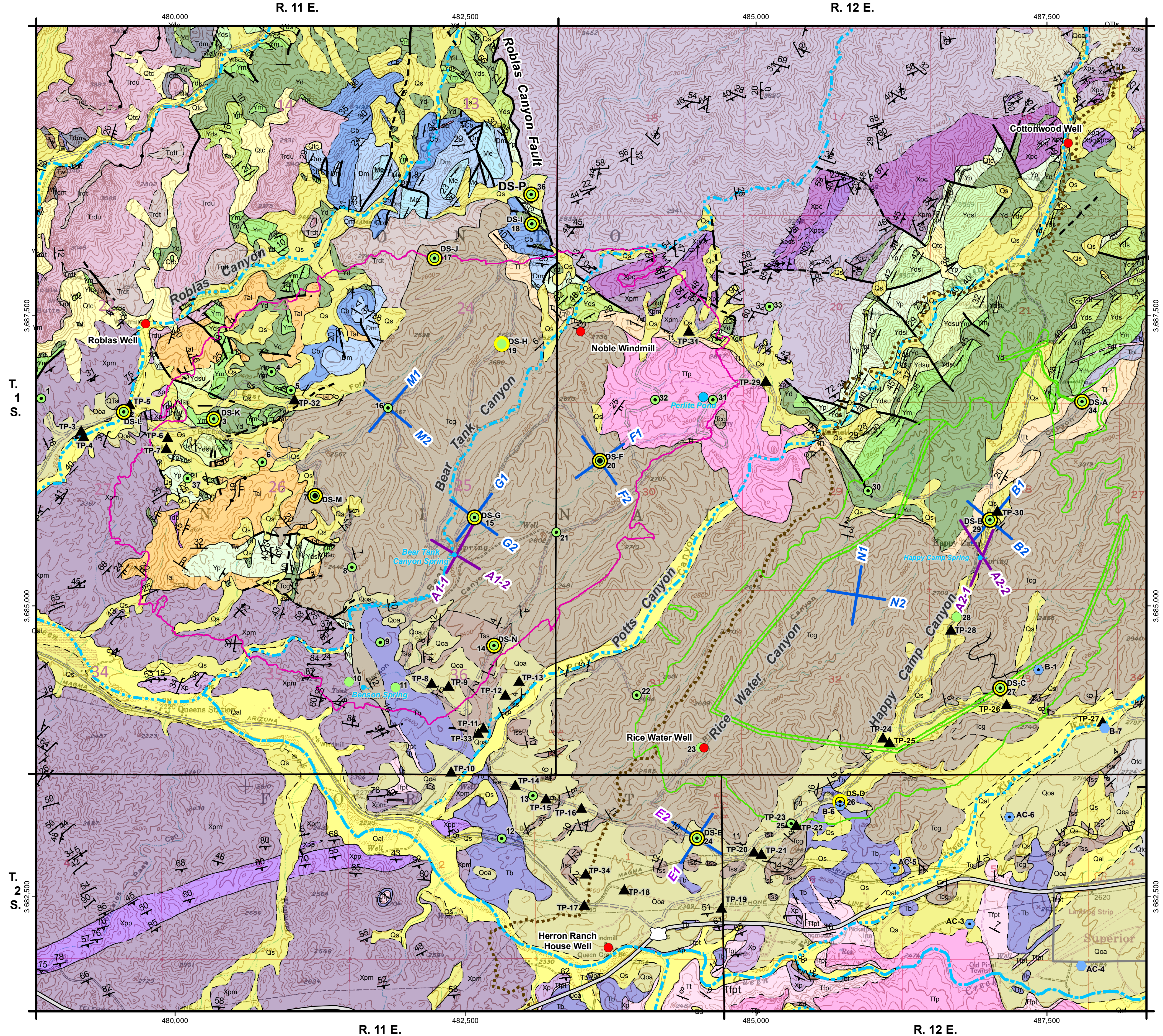

EXPLANATION

Footprint of Potential Tailings Facility West Option
Footprint of Potential Tailings Facility East Option
Pilot Resistivity Line
Full-Scale Resistivity Line
Proposed Hydrologic Drill Site
Proposed Geotechnical Drill Site
Proposed Test Trench
Well
Exploration Hole
Spring
Pond

Geologic Structural Features

Felsic Dike
Fault
Fault - approximate
Fault - concealed

Contact

Contact
Contact - approximate
Contact - inferred
Marker Horizon
Contact Between Pinal Schist Clast-rich Congomerate Below and Dripping Spring Quartzite Clast-rich Conglomerate Above

FOLIATION; strike and dip

Broken and wavy lines may be used to indicate approximate measurements or curviplanar foliation in conjunction with any symbol

Primary foliation

BEDDING

upright, vertical, overturned, irregular, approximate
dots on strike line indicate facing direction based on primary features

FLOW FOLIATION

flow banding in lavas or hypabyssal intrusions, eutaxitic foliation in welded tuffs; igneous flow foliation in plutons

Tetonic foliations

Generic foliation

Compositional banding, > 1 cm-scale

Banding formed by transposed bedding
Banding of uncertain or metamorphic origin

Compositional banding, < 1 cm-scale

Banding of metamorphic origin
Schistosity, continuous cleavage
Disjunct cleavage (fracture cleavage)
Disjunct cleavage parallel to bedding

Superimposed Fabrics symbols as above, double dip tics indicate that fabric is superimposed

Axial surface to small-scale crenulation
Disjunct cleavage
Compositional layering <1cm thick, formed by transposition of thin compositional layering
Similar to above, but fabric is very planar; quartz veins mostly transposed to concordant lenses

LINEAR FEATURES; trend and plunge

MINOR FOLD HINGE, showing plunge direction

upright, symmetrical fold
cascade fold
asymmetrical fold showing vergence ('S' or 'Z')

LINEATIONS

Mineral lineation in L-tectonites

APPARENT DIP

Trace of bedding on cliffs or steep slopes

GEOLOGIC UNITS

Qs Undivided Surficial Deposits (Quaternary)
Qtd Disturbed Surficial Deposits (Holocene)
Qtc Talus and Colluvium (Quaternary)
Qal Unconsolidated Alluvium (Holocene)
Qoa Old Alluvium (late Pleistocene to early Pleistocene)
QTls Older Landslide Deposits (early Quaternary to late Tertiary)
Tbl Lower Basalt (middle Tertiary)
Tdf Felsic Dikes (middle or early Tertiary or Cretaceous)
Tda Aphanitic Felsic to Intermediate Dikes (middle Tertiary)
Tdb Basaltic Dikes (middle Tertiary)

Superstition Volcanic Complex

Gila Group

Tcg Conglomerate (Miocene)
Tss Sandstone (Miocene)
Tb Basalt (middle to early Miocene)
Tt Tuff (poorly welded) (Miocene)

Picketpost Mountain Formation

Tfp Felsic Lava Flows (middle to early Miocene)
Tfpt Felsic Tuffs (middle to early Miocene)

Apache Leap Tuff

Tal Apache Leap Tuff (early Miocene)

Superstition Group

Trdu Undifferentiated Felsic Lavas (middle Miocene)
Trdt Tuffs associated with Trdu (early Miocene)
Tdm Intermediate to mafic lavas (early Miocene)

Whitetail Formation

Tw Conglomerate (Miocene to late Oligocene)
Tx Rock Avalanche Breccia (Miocene or Oligocene)

Kd Quartz Diorite of Arnett Creek (late Cretaceous)
Me Escabrosa Limestone (Mississippian)
Dm Martin Formation (Devonian)
Cb Bolsa Quartzite (Cambrian)
Yd Diabase (middle Proterozoic)
Ym Mescal Limestone (middle Proterozoic)
Yds Dripping Spring Quartzite, undivided (middle Proterozoic)
Ydsu Dripping Spring Quartzite, Upper Unit (middle Proterozoic)
Ydsl Dripping Spring Quartzite, Lower Unit (middle Proterozoic)
Yp Pioneer Formation (middle Proterozoic)
Ypt Pioneer Formation, Tuff Unit (middle Proterozoic)
Xp Pinal Schist, undivided (early Proterozoic)
Xpc Pinal Schist, Calc-silicate Facies (early Proterozoic)
Xpcs Pinal Schist, Calc-silicate and Schist Facies (early Proterozoic)
Xpm Pinal Schist, Psammite Facies (early Proterozoic)
Xpp Pinal Schist, Phyllite Facies (early Proterozoic)
Xpq Pinal Schist, Quartzite Layers (early Proterozoic)
Xps Pinal Schist, Pelitic Schist (early Proterozoic)

0 250 500 750 1,000
Meters

0 1,000 2,000 3,000 4,000
Feet

(Geology modified from Spencer and others, 1998; Spencer and Richard, 1995; and Ferguson and Trapp, 2001)

Resolution Copper Mining

RESISTIVITY SURVEY LOCATIONS NEAR WEST SITE PHASE II FIELD INVESTIGATIONS

MONTGOMERY & ASSOCIATES
Water Resource Consultants

2013

FIGURE 1

GIS-TUC\605\605.77\GeologySurveyLocs.mxd\10May2013

RPT-2013-009

ELECTRICAL RESISTIVITY CHARACTERIZATION OF THE NEAR WEST TAILINGS SITE

D. Rucker, Ph.D.
C. Baldyga
G. Noonan

2302 N. Forbes Blvd, Tucson, AZ 85745 USA

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Prepared for Resolution Copper

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Chargeability: The ability of a material to store an electrical charge (in milliseconds); a measure of capacitance

Conductivity: The ability of a material to conduct an electrical impulse (in Siemen per meter, S/m); reciprocal of resistivity.

Infrastructure: A collective grouping of subsurface structures that is likely to be adverse to resistivity data quality. Infrastructure may include foundations, concrete pads with rebar, railway lines, pipes, utilities, fences, disposal cribs, wells, or any other metallic items.

Inversion: Inversion, or inverse modeling, attempts to reconstruct subsurface features from a given set of geophysical potential measurements, and to do so in a manner that the model response fits the observations according to some measure of error.

Isopleth: A line on a map connecting points at which a given variable has a specified constant value, such as concentration

Resistance: A measure of a material's ability to resist electrical current flow, in ohms

Resistivity: A material property that is measured as its resistance to current per unit length for a uniform cross-section in Ohm-meters.

Tomography: A method of producing a three-dimensional image of a volumetric object by the observation and recording of the differences in the effects on the passage of energy impinging on that object.

1.0 INTRODUCTION

1.1 PROJECT DESCRIPTION

The geological and hydrogeological conditions of the Near West Tailings area, northwest of Superior, AZ, are highly variable. Structural features, such as deep-seated faults, as well as variability in porosity and permeability of the geological units control regional groundwater conditions. The exact conditions are only known at a few sparse locations around the site.

HGI conducted a pilot investigation using electrical in two areas (Happy Camp Spring and Bear Tank Canyon Spring) to determine whether geophysical data could be used to more fully understand the site. The survey mostly extended over the Gila conglomerate. The results of the pilot survey showed a thin veneer of soil at both sites, approximately 5-6 m thick. Some variability was shown in the conglomerate at each site, with one site exhibiting a naturally resistive conglomerate and the other significantly more conductive, which could be explained by the presence of groundwater that feeds the spring. The most conductive material was found to be the poorly welded tuff on the west side of Happy Camp Spring, which suggested a higher clay content and/or water content in the tuff. Induced polarization data suggested higher clay content in the tuff compared to the adjacent diabase or conglomerate. The higher clay content could result from breakdown of the tuff due to weathering, which could have been enhanced due to infiltration and downward movement of surface runoff along fractures. In addition, we hypothesized that clay minerals from weathering of the diabase could be entrained in surface runoff that infiltrates the tuff, partially filling some pore space with clay particles.

For the full scale implementation of electrical resistivity, HGI acquired twelve more lines within six areas, with each area containing two lines crossing perpendicular to each other. Specific areas were chosen in order to image conglomerate unaffected by springs and complex geology. In addition to electrical resistivity, induced polarization (IP) was also acquired along two lines, coincident with resistivity, to test for the presence of clayey minerals.

This report discusses the results of both the pilot and full scale surveys.

1.2 SITE LOCATION

The investigation site is located in Pinal County, northwest of the town of Superior, Arizona. Figure 1 shows the locations of the geophysical survey lines from both stages of the survey and the bedrock geology that define the site.

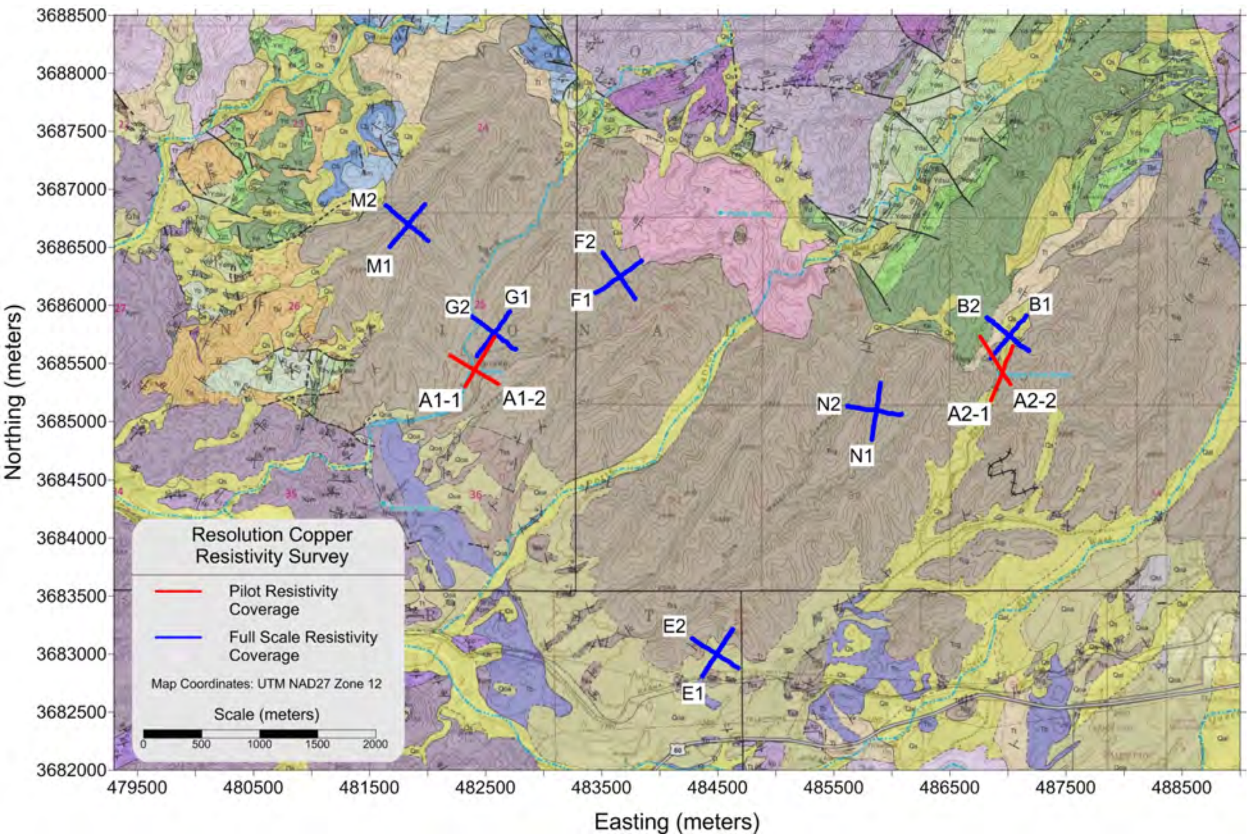
1.3 OBJECTIVE OF INVESTIGATION

The objective of the survey was to identify the occurrence of groundwater and any stratigraphic or structural features that may have the potential for controlling groundwater flow. The method of electrical resistivity was selected to take advantage of physical property contrasts that are reflective of site conditions. For example, it was expected that near surface soils on top of the bedrock would be rather resistive due to its low moisture content. The bedrock encountered in the area, such as diabase, tuff, and conglomerate, would likely have variable, yet distinct, electrical signatures. Moreover, any fluid-filled faults and fractures should show as very low resistivity in more resistive bedrock.

The induced polarization (IP) method helps differentiate rock units or features within individual rock units. The IP method measures capacitance of the ground, and clay minerals are an excellent target for the method. We expected that IP could help to differentiate fractures that are transmissive to groundwater versus those that contain clay-rich fault gouge.

Concurrent with the acquisition of data, preliminary processing was conducted to ensure that high quality data were being obtained. In the event of problems in data acquisition that could have affected data quality, the processing team would alert the field team to examine the acquisition parameters more closely (e.g., electrode coupling, noise, etc.). Final processing was conducted in the HGI office in Tucson, AZ.

Figure 1. Site Map with Geophysical Survey Locations. Geological Map from Spencer and Richards (1995)

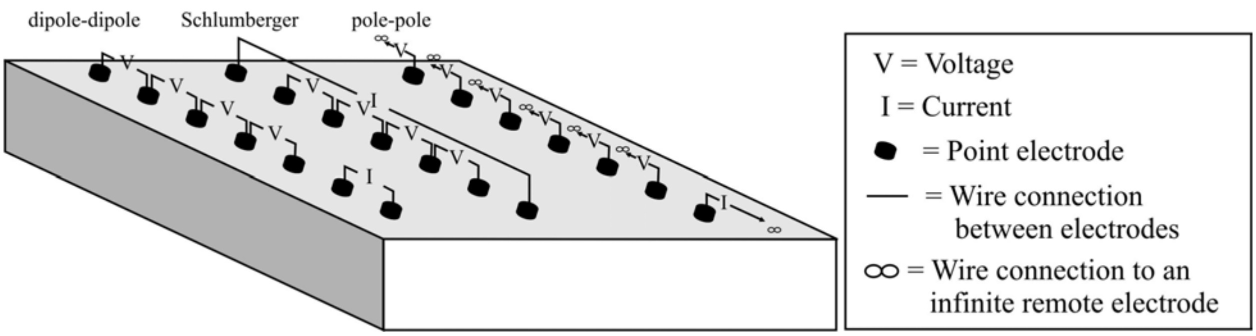


2.0 GEOPHYSICAL THEORY

Electrical resistivity is a volumetric property that describes the resistance of electrical current flow within a medium (Rucker et al., 2011; Telford et al., 1990). Direct electrical current is propagated in rocks and minerals by electronic or electrolytic means. Electronic conduction occurs in minerals where free electrons are available, such as the electrical current flow through metal. Electrolytic conduction, on the other hand, relies on the dissociation of ionic species within a pore space and is more common in the partially saturated sandy alluvium and fractured bedrock. With electrolytic conduction, the movement of electrons varies with the mobility, concentration, and the degree of dissociation of the ions. Competent rock free of fissures and fractures will have a higher resistivity compared to less competent rock.

Mechanistically, the resistivity method uses electric current (I) that is transmitted into the earth through one pair of electrodes (transmitting dipole) that are in contact with the soil. The resultant voltage potential (V) is then measured across another pair of electrodes (receiving dipole). Numerous electrodes can be deployed along a transect (which may be anywhere from feet to miles in length), or within a grid. Figure 2 shows examples of electrode layouts for surveying. The figure shows transects with a variety of array types (dipole-dipole, Schlumberger, pole-pole). A complete set of measurements occurs when each electrode (or adjacent electrode pair) passes current, while all other adjacent electrode pairs are utilized for voltage measurements. Modern equipment automatically switches the transmitting and receiving electrode pairs through a single multi-core cable connection. Rucker et al. (2009) describe in more detail the methodology for efficiently conducting an electrical resistivity survey.

Figure 2. Possible Arrays for use in Electrical Resistivity Characterization



The modern application of the resistivity method uses numerical modeling and inversion theory to estimate the electrical resistivity distribution of the subsurface given the known quantities of electrical current, measured voltage, and electrode positions. A common resistivity inverse method incorporated in commercially available codes is the regularized least squares optimization method (Sasaki, 1989; Loke, et al., 2003). The objective function within the optimization aims to minimize the difference between measured and modeled potentials (subject to certain constraints, such as the type and degree of spatial smoothing or regularization) and the optimization is conducted iteratively due to the nonlinear nature of the model that describes the potential distribution. The relationship between the subsurface resistivity (ρ) and the measured voltage is given by the following equation (from Dey and Morrison, 1979):

$$-\nabla\cdot\left[\frac{1}{\rho(x,y,z)}\nabla V(x,y,z)\right]=\left(\frac{I}{U}\right)\delta(x-x_s)\,\delta(y-y_s)\,\delta(z-z_s) \qquad (1)$$

where I is the current applied over an elemental volume U specified at a point (x_s, y_s, z_s) by the Dirac delta function.

Equation (1) is solved many times over the volume of the earth by iteratively updating the resistivity model values using either the L_2-norm smoothness-constrained least squares method, which aims to minimize the square of the misfit between the measured and modeled data (de Groot-Hedlin & Constable, 1990; Ellis & Oldenburg, 1994):

$$\left(J_i^T J_i + \lambda_i W^T W\right)\Delta r_i = J_i^T g_i - \lambda_i W^T W r_{i-1} \tag{2}$$

or the L_1-norm that minimizes the sum of the absolute value of the misfit:

$$\left(J_i^T R_d J_i + \lambda_i W^T R_m W\right)\Delta r_i = J_i^T R_d g_i - \lambda_i W^T R_m W r_{i-1} \tag{3}$$

where g is the data misfit vector containing the difference between the measured and modeled data, J is the Jacobian matrix of partial derivatives, W is a roughness filter, R_d and R_m are the weighting matrices to equate model misfit and model roughness, Δr_i is the change in model parameters for the i^{th} iteration, r_i is the model parameters for the previous iteration, and λ_i = the damping factor.

In conjunction with resistivity, IP can be acquired with the same electrode setup by measuring the voltage decay when the electrical current is shut off. The voltage decay is integrated over time (from about 200ms to 1800ms after shut off) and normalized to the maximum voltage measured prior to shut off. The data are then modeled in a similar way to resistivity, using least squares optimization with the objective to reduce the misfit between measured and modeled chargeability subject to certain data and model constraints. The chargeability is then viewed alongside the resistivity to differentiate different geologically based targets for greater understanding of the subsurface.

3.0 METHODOLOGY

3.1 SURVEY AREA AND LOGISTICS

The acquisition of electrical resistivity data involves the injection of current into the ground between two electrodes, and the measurement of electrical potential between two other electrodes, repeated for multiple combinations of the available electrodes. For the pilot investigation, a set of 84 electrodes were placed on the ground at once, using a multi-core conductor cable to switch between the transmitting and receiving electrode pairs. A roll-along method was used to extend the final line length to 500 m, using 28 electrodes per roll. Data acquisition took place February 12-15, 2013. For the full scale investigation, 168 electrodes were placed on the ground in an effort to image twice as deep compared to the pilot investigation, to a depth of 100m. Data acquisition took place between February 22 – March 3, 2013.

Tables 1 and 2 lists the details of each resistivity line.

Table 1. Pilot Investigation Electrical Resistivity Line Details

Line #	Electrode spacing (meters)	Length (meters)	Orientation	Start Position (Easting and Northing, UTM meters NAD27)	End Position (Easting and Northing, UTM meters NAD27)
A1-1	3	500	SW-NE	482323, 3685303	482573, 3685723
A1-2	3	500	NW-SE	482194, 3685568	482603, 3685326
A2-1	3	500	SW-NE	486854, 3685182	487040, 3685646
A2-2	3	500	NW-SE	486760, 3685728	487020, 3685322

Table 2. Full Scale Investigation Electrical Resistivity Line Details

Line #	Electrode spacing (meters)	Length (meters)	Orientation	Start Position (Easting and Northing, UTM meters NAD27)	End Position (Easting and Northing, UTM meters NAD27)
B1	3	500	SW-NE	486855, 3685544	487156, 3685911
B2	3	500	NW-SE	486819, 3685893	487178, 3685609
E1	3	500	SW-NE	484370, 3682815	484628, 3683213
E2	3	500	NW-SE	484277, 3683136	484677, 3682877
F1	3	500	SW-NE	483449, 3686107	483845, 3686383
F2	3	500	NW-SE	483510, 3686453	483788, 3686056
G1	3	500	SW-NE	482426, 3685560	482710, 3685943
G2	3	500	NW-SE	482385, 3685903	482761, 3685625
M1	3	500	SW-NE	481672, 3686504	481978, 3686868

M2	3	500	NW-SE	481640, 3686861	482006, 3686555
N1	3	500	S-N	485829, 3684848	485903, 3685330
N2	3	500	W-E	485615, 3685129	486076, 3685058

3.2 EQUIPMENT

Data were collected using a Supersting™ R8 multichannel electrical resistivity system (Advanced Geosciences, Inc. (AGI), Texas) and associated cables, electrodes, and battery power supply. The Supersting™ R8 meter is commonly used in surface geophysical projects and has proven itself to be reliable for long-term, continuous acquisition. The stainless steel electrodes were laid out along lines with a constant electrode spacing. Multi-electrode systems allow for automatic switching through preprogrammed combinations of four electrode measurements. A Schlumberger electrode configuration was used for the data acquisition of the lines. For further details on the electrode configuration, see Binley and Kemna (2005). In general, the Schlumberger electrode configuration provides good sensitivity to both horizontal and vertical structures, while achieving the penetration depth required for the geophysical characterization.

3.3 DATA PROCESSING

Once acquired, the data were evaluated onsite to ensure sufficient quality for processing. If the data passed the initial inspection, they were sent to HGI's Tucson office for preliminary processing for evaluation by the field geophysicist and the client. Final processing occurred after demobilization.

3.3.1 Quality Control – Onsite

Data for each survey method were given a preliminary assessment for quality control (QC) in the field to assure quality of data before progressing the survey. Following onsite QC, the data were transferred to the HGI server for storage and detailed data processing and analysis.

3.3.2 Resistivity Data Editing

The geophysical data for the resistivity survey, including measured voltage, current, measurement (repeat) error, and electrode position, were recorded digitally with the AGI SuperSting R8 resistivity meter. Each line of acquisition was recorded with a separate file name. Following field data collection, the raw resistivity data files were transmitted to the HGI server located in Tucson, Arizona. Data quality was inspected and checked for consistency with respect to adjacent line results, and then data files were saved to designated folders on the server. The server was backed up nightly and backup tapes were stored at an offsite location on a weekly and monthly basis.

Survey configuration, location, time and date, field manager, equipment used, environmental conditions, proximal infrastructure, and other useful information were recorded during data acquisition on standard HGI resistivity field forms. These forms were submitted with the raw resistivity data and were subsequently saved to the HGI Tucson server.

Raw resistivity data were imported and parsed using the HGI Pro (v 3.4.2) Software. This software provided a simple means for quality checking and preliminary assessment by using a Microsoft Excel template, which charts specific data parameters. After parsing, the raw data were evaluated for measurement noise. Those data that appeared to be extremely noisy and fell outside the normal range of accepted conditions were removed. Examples of conditions that would cause data to be removed include, negative or very low voltages, high-calculated apparent resistivity, extremely low current, and high repeat measurement error.

3.3.3 2D Resistivity Inversion

RES2DINV software (Geotomo, Inc.) was used for inverting individual lines in two dimensions. RES2DINV is a commercial resistivity inversion software package available to the public from www.geoelectrical.com. An input file was created from the edited resistivity data and inversion parameters were chosen to maximize the likelihood of convergence. It is important to note that up to this point, no resistivity data values had been manipulated or changed, such as smoothing routines or box filters. Noisy data had only been removed from the general population.

The inversion process followed a set of stages that utilized consistent inversion parameters to maintain consistency between each model. Inversion parameter choices included the starting model, the inversion routine (robust or smooth), the constraint defining the value of smoothing and various routine halting criteria that automatically determined when an inversion was complete. Convergence of the inversion was judged whether the model achieved an RMS of less than 5% within three to five iterations.

3.3.4 2D Resistivity Plotting

The inverted data were output from RES2DINV into an .XYZ data file and were then gridded and color contoured in Surfer (Golden Software, Inc.). Information such as roadways, drainages, resistivity line intersections, and other relevant line features were plotted on the resistivity section to assist in data analysis. Qualified in-house inversion experts subjected each profile to a final review.

4.0 RESULTS & INTERPRETATION

The electrical resistivity model results are presented as two-dimensional (2D) lines in Figures 3 and 4, 7 through 9, and 11 through 14. Common color contouring scales are used for all of the lines to highlight, specifically, different geological sequences and the potential influence of moisture. Electrically conductive (low resistivity) subsurface regions are represented by cool hues (purple to green) and electrically resistive regions are represented by warm hues (yellow to brown). To help emphasize particular features in each section a log scale of model resistivity is used in the profile figures. When data span multiple orders of magnitude, it is appropriate to display a log transformation.

4.1 HAPPY CAMP SPRING

The Happy Camp Spring site, also referred to as Area 2 in the pilot investigation report, is the most geologically complex site of all of the investigation areas. The initial lines from the pilot investigation were placed near the spring, but the additional lines were moved away to test the response of resistivity without the influence of a known water source. The three figures representing the spring site are grouped by parallel lines as opposed to cross lines in an effort to show a level of geological consistency through the area.

Figure 3 shows resistivity for lines running in an approximate north to south direction. The most prominent feature of the figure is the highly conductive layer in line B1. It is believed that this layer represents the tuff, which dips towards the southeast as indicated in the accompanying geological map. The tuff can be seen extending into line A2-1, which is east of line B1 so that the tuff is deeper than in line B1. Additionally, both lines also show a thin veneer of sandy soil that is relatively dry; the layer is approximately 5m thick. The resistive base of line B1 represents the older diabase, which also dips to the southeast.

In the original interpretation of line A2-1, it was thought that the low resistivity may have represented an increase in moisture or saturation from groundwater. Given the information from line B1, it is likely that the deepest feature, at about station 200m, represents the tuff. Nearer surface conductive material in the northern portion of the line could still represent increased saturation from infiltrating run-off. It also appears that the influence of moisture content in the alluvium diminishes southward in line A2-1 as the material transitions from alluvium to conglomerate and back to alluvium.

Figure 3. North-South Resistivity Lines near Happy Camp Spring

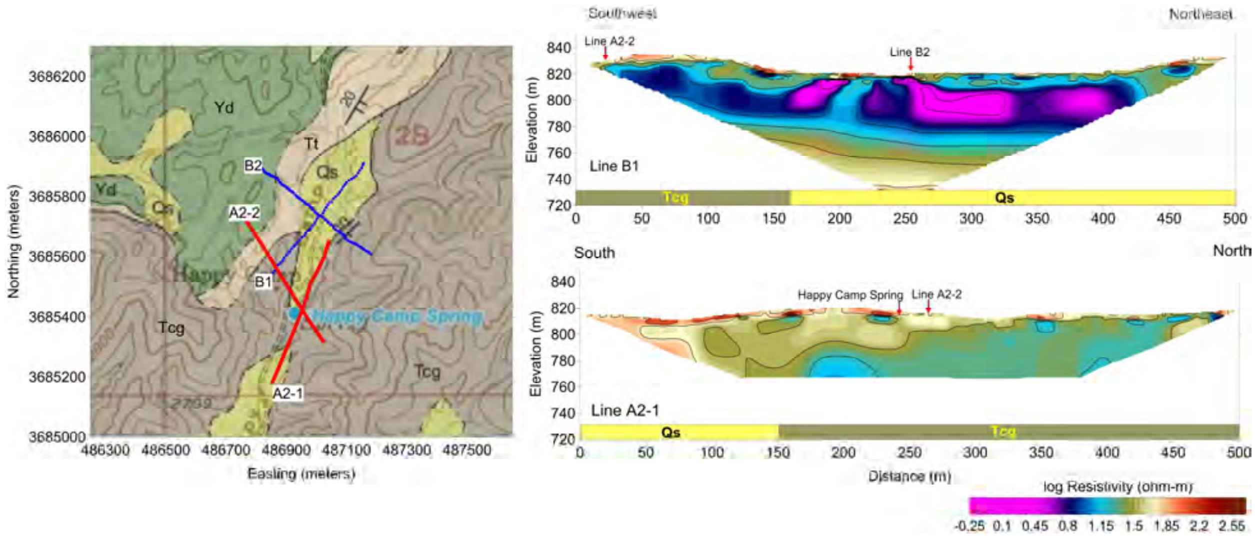
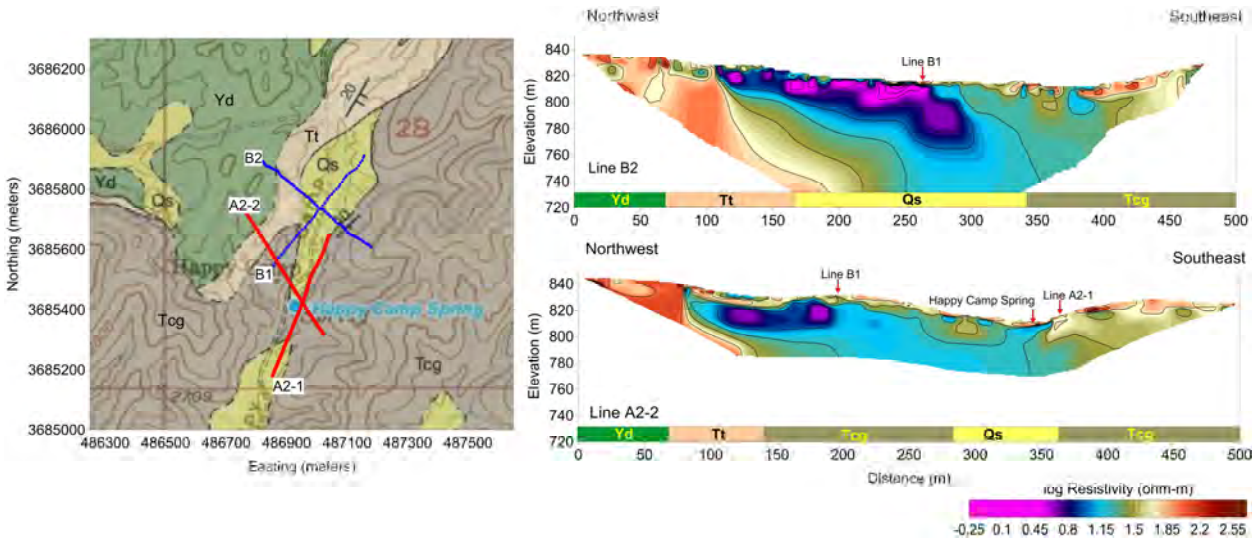


Figure 4 shows the northwest-southeast lines over the Happy Camp Spring area, where four different geological units are imaged. The two lines consistently show that the diabase towards the west is rather resistive and dipping towards the southeast. The overlying tuff is a conductive layer also dipping to the southeast. The conglomerate to the east is relatively resistive and the younger alluvium does not appear to have a specific resistivity signature. The IP data in Figure 5 shows high chargeability values east of the diabase, which most likely represents clayey material. Using Figure 5 as a further differentiator, the conductive nature of the tuff and perhaps the alluvium may be due breakdown of the tuff from weathering. In addition, it is hypothesized that clay minerals from weathering of the diabase could be entrained in surface runoff that infiltrates the tuff, partially filling some pore space with clay particles. The tuff is described as poorly welded with significant porosity and it is possible that the material could accept run-off water entrained with colloid-sized clay particles.

Figure 4. Northwest-Southeast Resistivity Lines near Happy Camp Springs



At the location of the spring in line A2-2, the material is slightly conductive which could reflect the occurrence of groundwater or infiltrating surface water.

Figure 5. Northwest-Southeast IP Lines near Happy Camp Springs

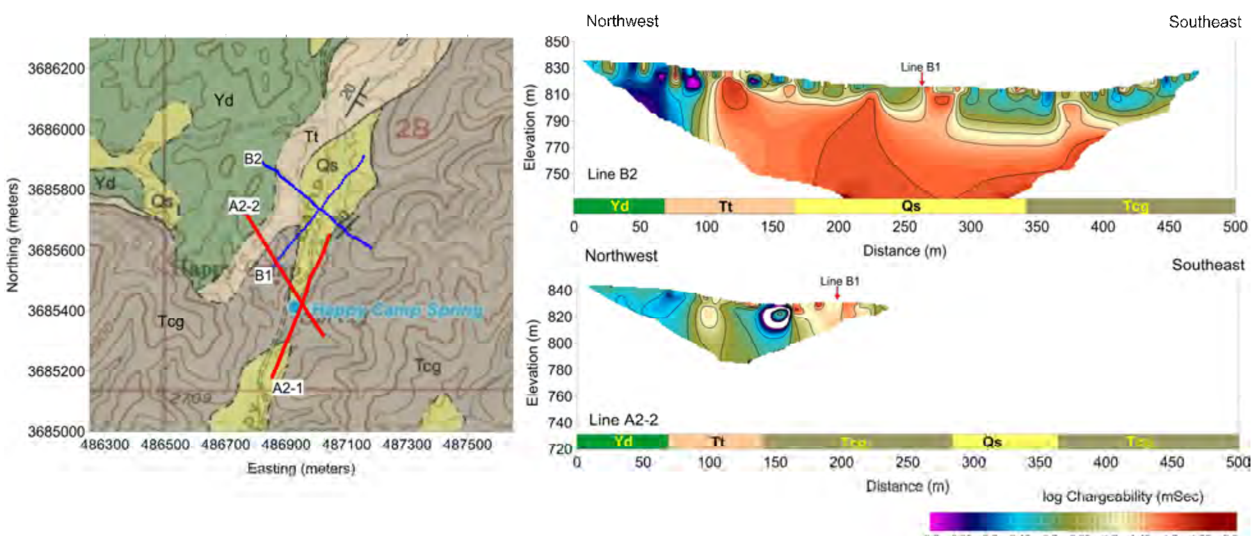
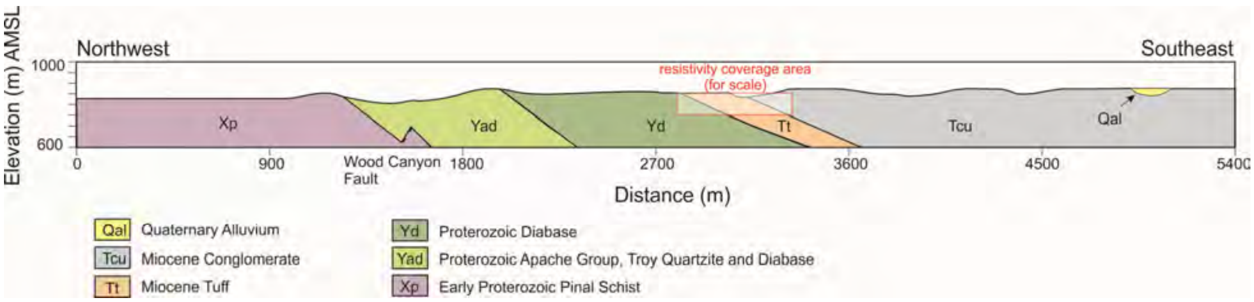


Figure 6 shows a geological cross section through the area near Happy Camp Spring. The cross section was derived from the Montgomery & Associates regional geological study and the location is shown on Figure 1 as cross section B. The regional study used the geologic map from Spencer and others (1998), which is more generalized and uses different nomenclature for geologic units than the Spencer and Richard (1995) map used for the current study. The cross section is presented with no vertical exaggeration, and the approximate location of the resistivity survey is highlighted as a red box. The figure is presented simply for reference to show subsurface relations between the diabase (Yd), the volcanic tuff (Tt) and the conglomerate (Tcu). The geophysical data and geological interpretations appear to match quite well.

Figure 6. Geological Cross Section B, near Happy Camp Spring



4.2 AREA N

The resistivity lines for Area N were placed on a ridge to the east of the Rice Water Canyon and exclusively within the Gila conglomerate. Both lines show (Figure 7) that the top 60m is resistive relative to a slightly more conductive base. Figure 8 also shows that the chargeability of line N1 is high towards the base of the line indicating that the higher conductivity is likely due to increasing clay content. The near surface resistive material, then, is likely absent of clayey material except for a few isolated vertical breaks. The shape of the features in line N1 (Figure 8) could be representative of a braided stream channel where low IP represents coarser-grained sediments deposited by the faster moving surface water and the higher IP representing the finer-grained materials with higher clay content.

Figure 7. Area N Resistivity Lines

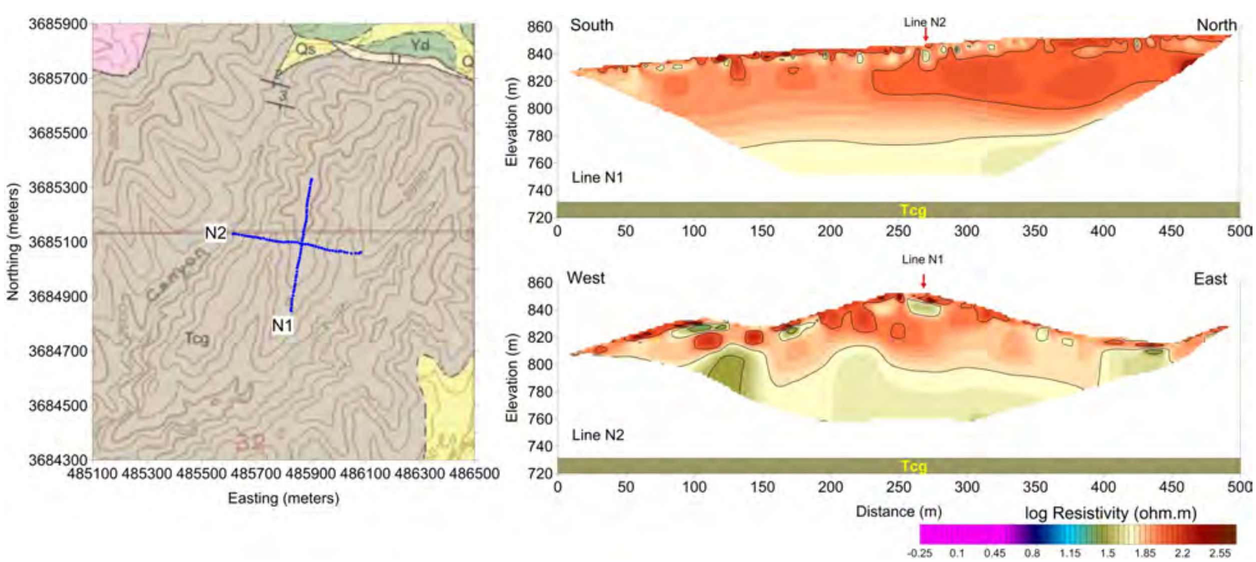
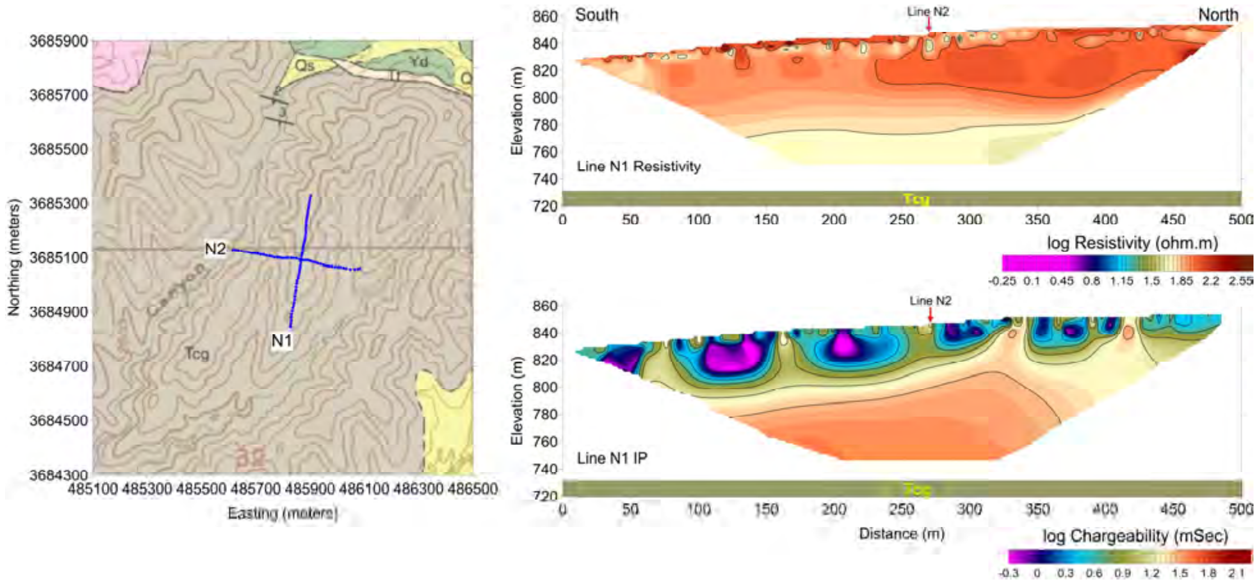


Figure 8. Area N Resistivity and IP Line for N1



4.3 AREA E

The resistivity lines of Area E were placed mostly within the older alluvium adjacent to the Gila conglomerate. Figure 9 shows that the conglomerate of Area E is more conductive than the alluvium and more conductive than the conglomerate to the north in Area N. The beginning portion of line E1 runs adjacent to sandstone outcrops and the dipping material of higher resistivity in the line could actually represent this sandstone. The direction of the dip is confirmed by the geological map. The presence of groundwater in either line is not readily apparent. The conductive nature of the conglomerate in E1 could be due to groundwater or clays. The conglomerate of E2 is less conductive.

Figure 10 shows the other geological cross section, Cross Section A, derived from the regional geological map. The regional map is from Spencer and others (1998), which is more generalized and uses different nomenclature than the more detailed Spencer and Richard (1995) map used for the current study. The cross section runs near Area E and shows mostly conglomerate. The resistivity coverage for E is highlighted in red for reference and is placed near the location of the resistivity lines.

Figure 9. Area E Resistivity

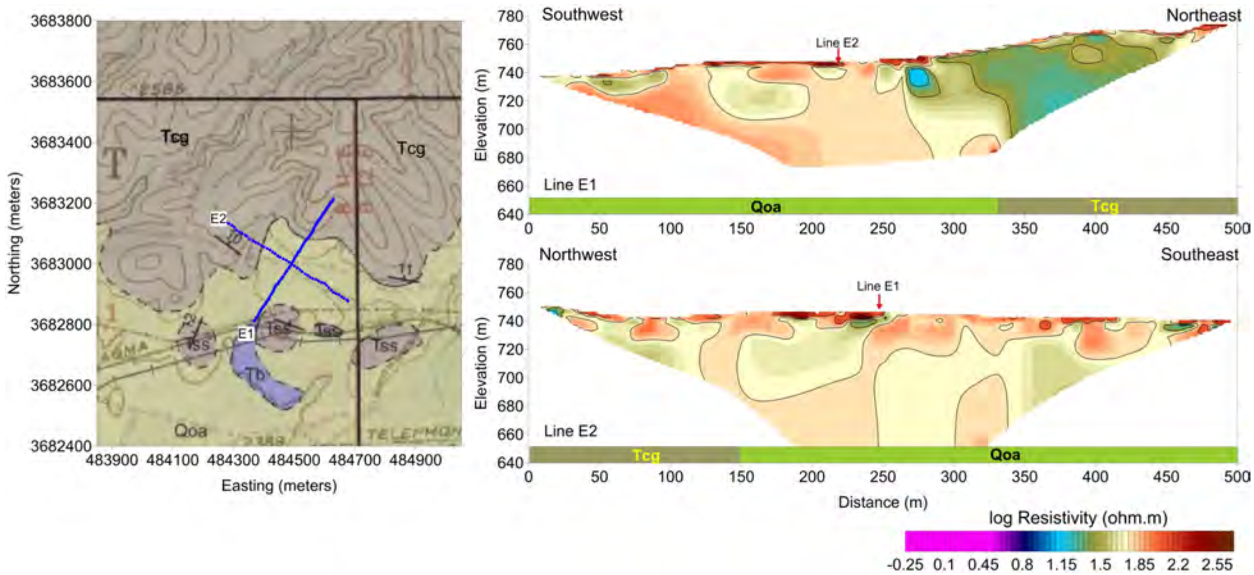
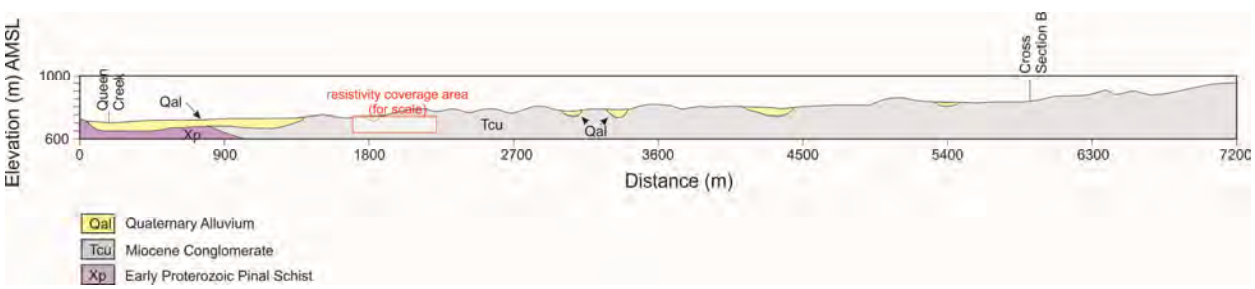


Figure 10. Geological Cross Section A, near Queen Creek



4.4 BEAR TANK CANYON SPRING AND AREA G

The resistivity lines within Area G were placed north of the Bear Tank Canyon Spring, while lines A1-1 and A1-2 from the pilot investigation were placed over the spring (Figures 11 and 12). The Gila Conglomerate comprises the entirety of the region surrounding the geophysical investigation. The resistivity data show that a thin resistive layer at the surface with an approximate thickness of 5 m. This layer is thought to represent a veneer of sandy soil that is relatively dry and can be observed in all of the lines. Beneath the near surface soil is the conglomerate with variable resistivity, with the majority of the values ranging from 45 (olive contour) to 95 (orange contour) ohm-m (log resistivity of 1.6 to 2.0 ohm-m). There are a few isolated regions of higher and lower resistivity, often showing up as spatially adjacent pairs. These pairs are likely modeling artifacts with little physical significance. The geological description of the conglomerate includes rocks that are moderately to well indurated, consisting of sub-rounded to subangular cobbles to boulders. The degree of resistivity variability of the conglomerate within all four lines could be from the relative composition and size of cobbles and boulders. Larger, more competent clasts would reduce the volume of interstitial pore space between the clasts, thus decreasing the available space for electrolyte storage. Similar to other lines, there are no obvious indicators of groundwater occurrence.

Figure 11. North-South Resistivity Lines near Bear Tank Canyon Spring

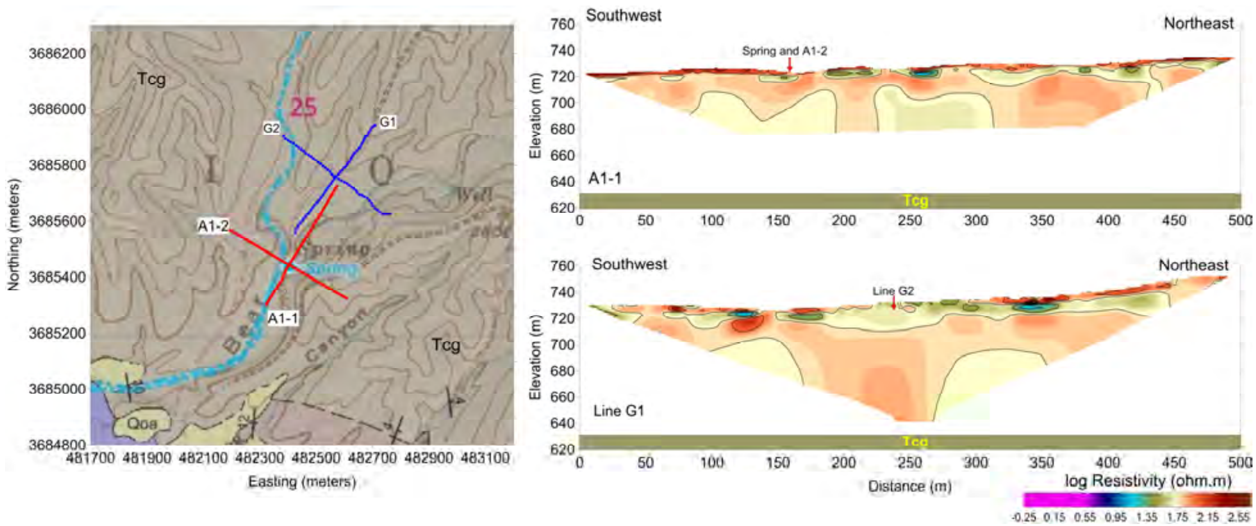
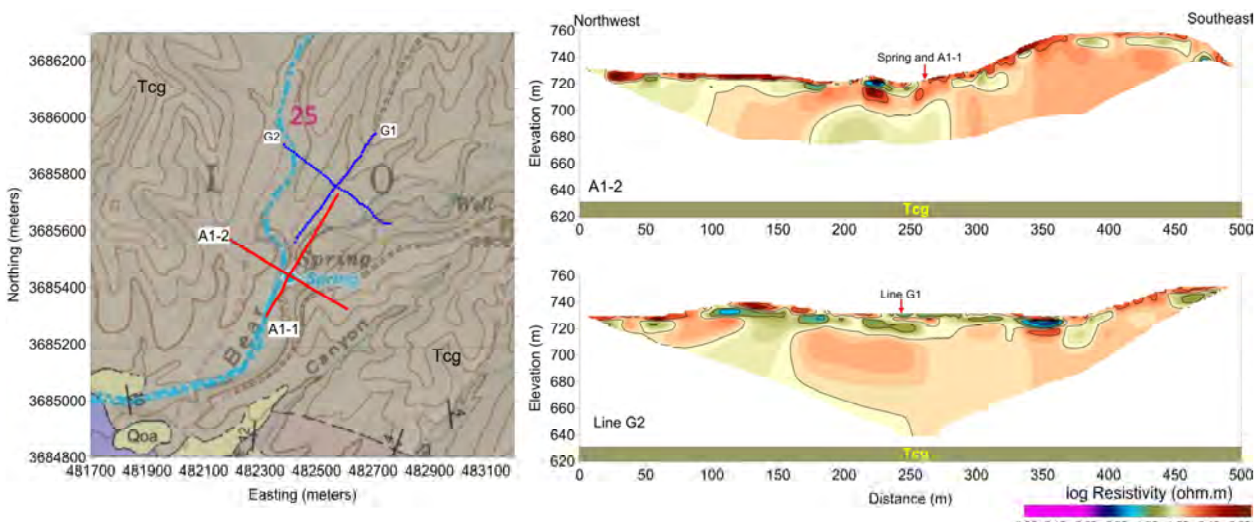


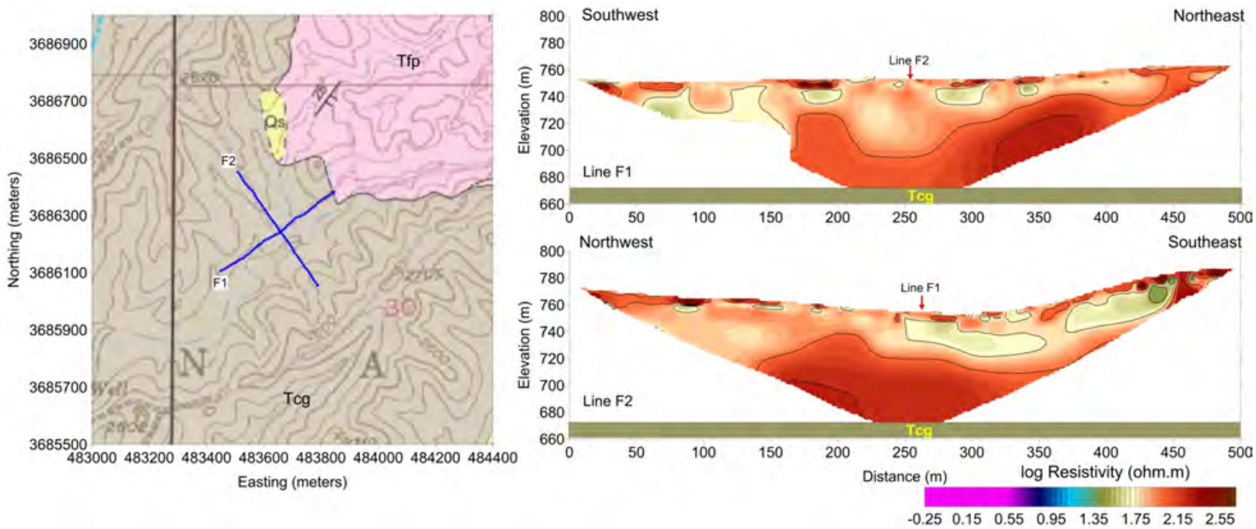
Figure 12. East-West Resistivity Lines near Bear Tank Canyon Spring



4.5 AREA F

The resistivity lines of Area F (Figure 13) were placed within the Gila Conglomerate south of the Tertiary-aged lava flows designated as Tfp on the geological map. These lava flows are described as a perlitic aphyric rhyolite. In conjunction, the resistivity data show a resistive layer of rhyolite overlain by a slightly less resistive younger conglomerate. Line F1 shows the resistive layer of rhyolite becoming deeper towards the southwest. Line F2 shows the layer in the lower half of the profile. The conglomerate is only slightly more conductive, similar to values observed around Area N.

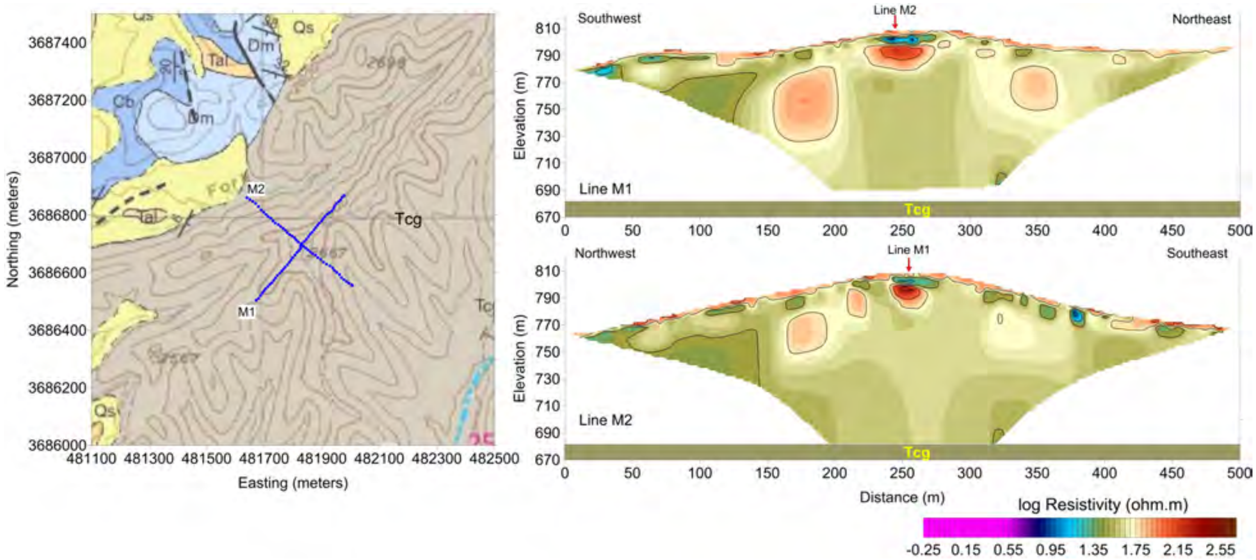
Figure 13. Area F Resistivity



4.6 AREA M

The resistivity lines of Area M were acquired at the western edge of the survey area and were limited to investigating the conglomerate. The lines were placed over a knob, with Bear Tank Canyon to the southeast. Northwest from Area M, the geology is more complex, including various older sedimentary and volcanic units and numerous mapped faults. The resistivity data reveal an interesting symmetric pattern over the knob. The data show an inner slightly conductive core with an outer ring of resistive material. The conglomerate is more conductive than that of Areas F and G nearby. Similar to other lines, there also appears to be a thin veneer of high resistivity sandy soil and no obvious indicators of groundwater conditions.

Figure 14. Area M Resistivity



5.0 CONCLUSIONS

In general, we found:

- A thin veneer of soil exists at all sites that is approximately 5-6 m thick.

- The conglomerate has wide range of resistivity values depending on location and proximity to nearby older geological units. The low resistivity could be either from an increase in clay content, as revealed by the three lines of induced polarization at Area B near Happy Camp Spring and Area N, or from the presence of groundwater. It should be noted, however, there are no definitive groundwater signatures within the section. The high resistivity conglomerate could be due to larger clasts.

- The most conductive material was found to be the poorly welded tuff exposed on the west side of Happy Camp Spring. The IP data indicate a higher clay content in the tuff compared to the diabase or conglomerate. The higher clay content could result from breakdown of the tuff due to weathering. In addition, it is hypothesized that clay minerals from weathering of the diabase could be entrained in surface runoff that infiltrates the tuff, partially filling some pore space with clay particles.

- Drilling and characterizing the core (or drill cuttings) will help differentiate the observed range in resistivity values for the conglomerate. It is recommended that after drilling is complete, the resistivity data be revisited and updated based on new information.

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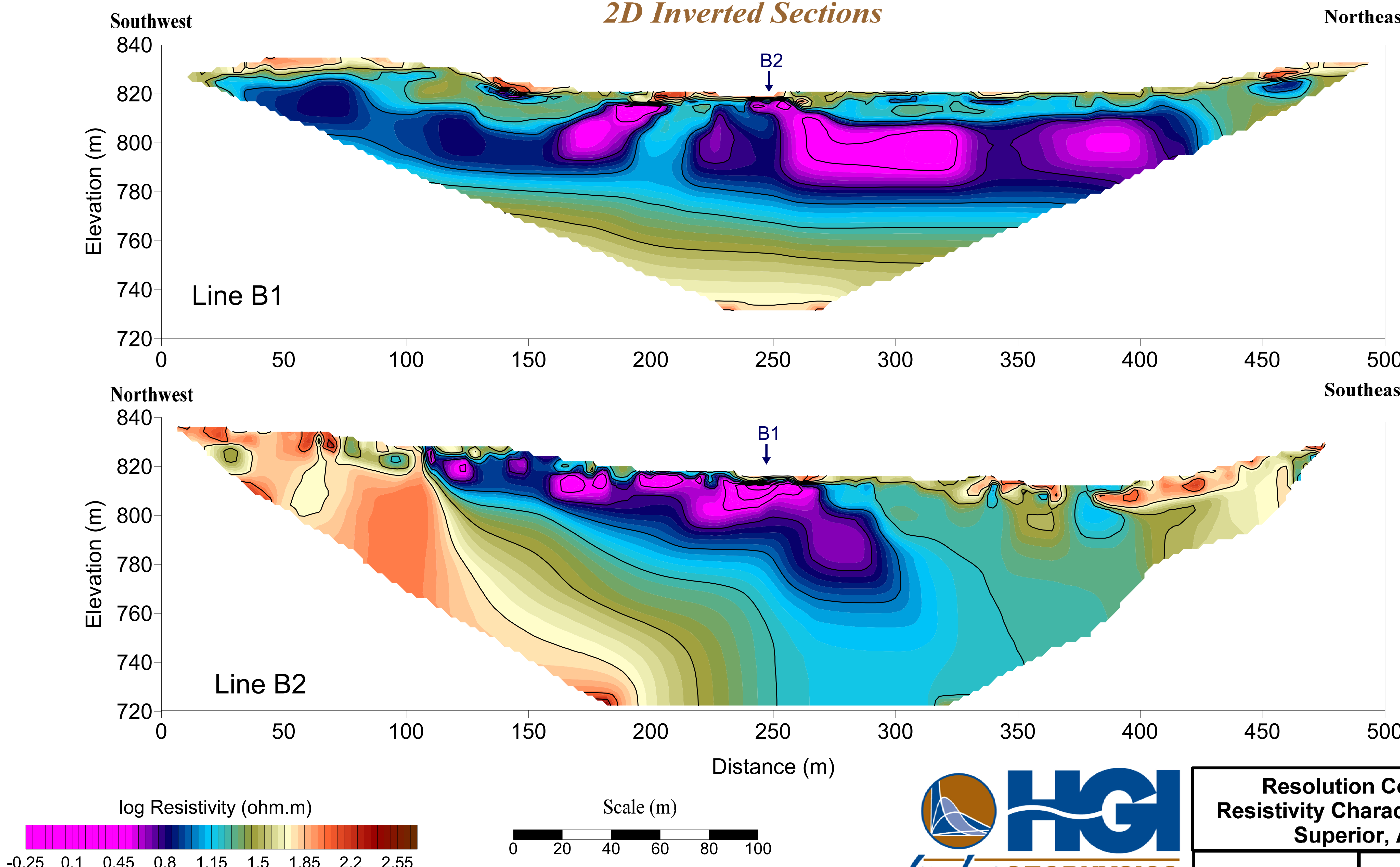
APPENDIX A

Electrical Resistivity Results - Area B

2D Inverted Sections



HGI hydroGEOPHYSICS

Resolution Copper
Resistivity Characterization
Superior, AZ

Date: April 2013

Fig.: Area B

FILES:

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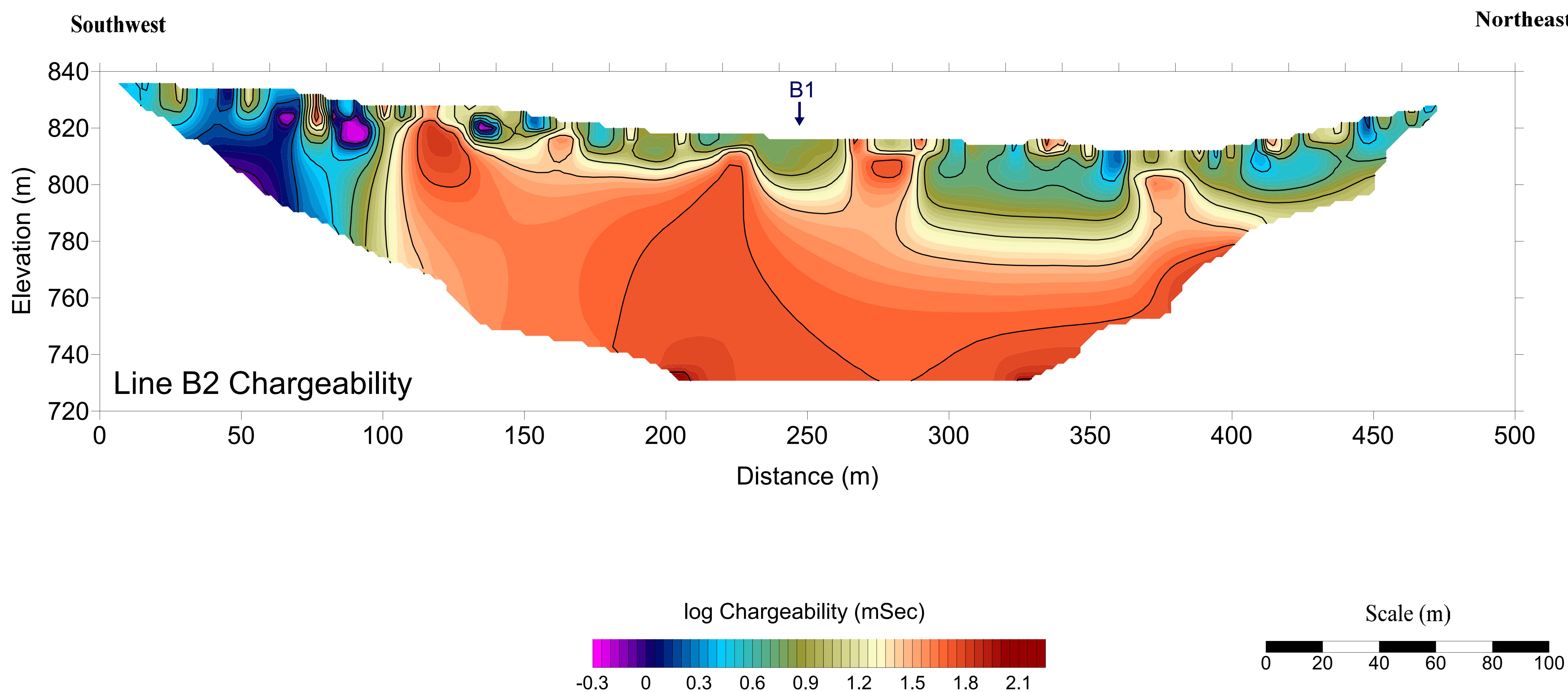
Induced Polarization Results - Line B2



hydroGEOPHYSICS

Resolution Copper
Resistivity Characterization
Superior, AZ

Date: April 2013	**Fig.: Area B - IP**

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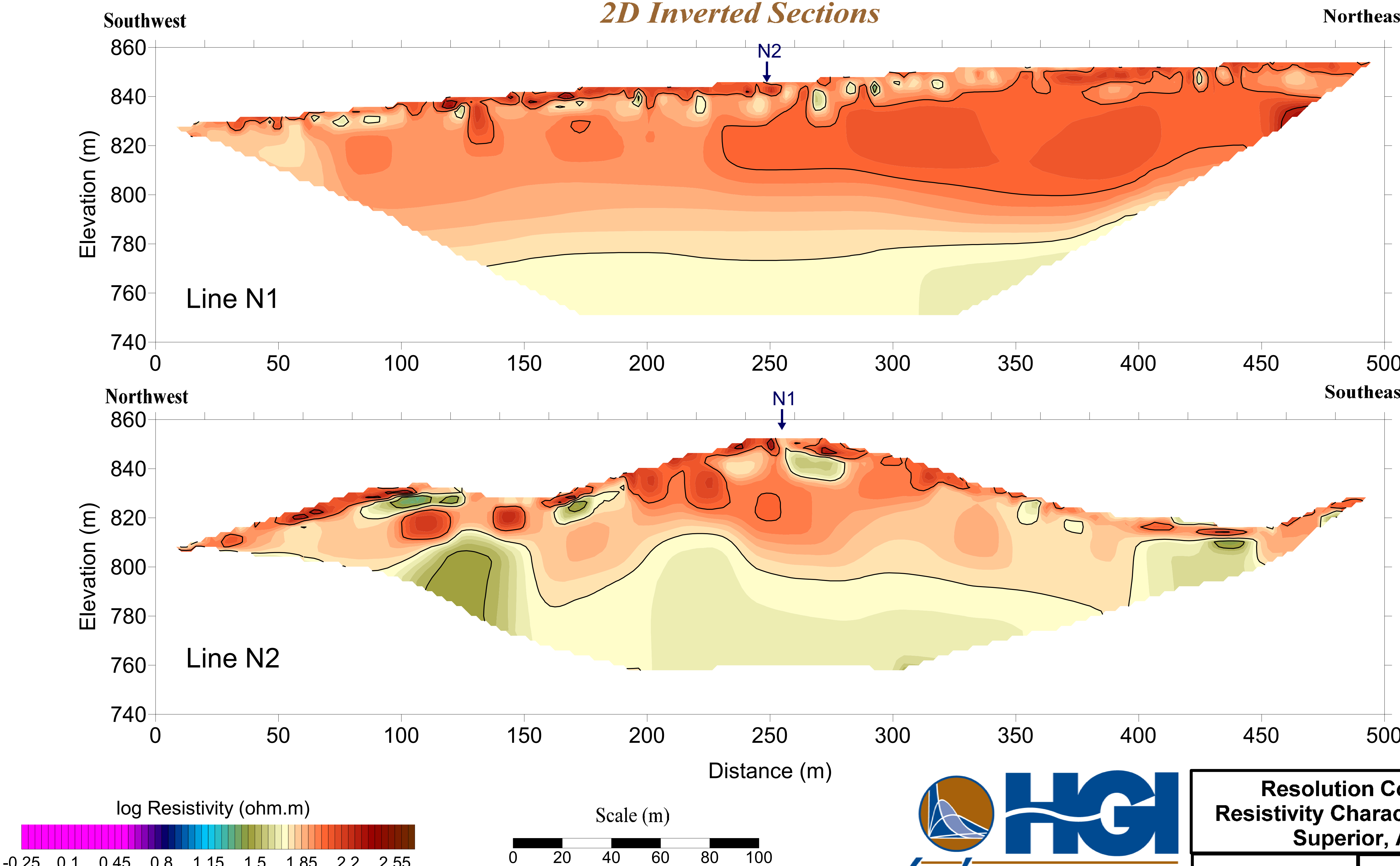
Electrical Resistivity Results - Area N

2D Inverted Sections



HGI hydroGEOPHYSICS

Resolution Copper Resistivity Characterization Superior, AZ

Date: April 2013	Fig.: Area N

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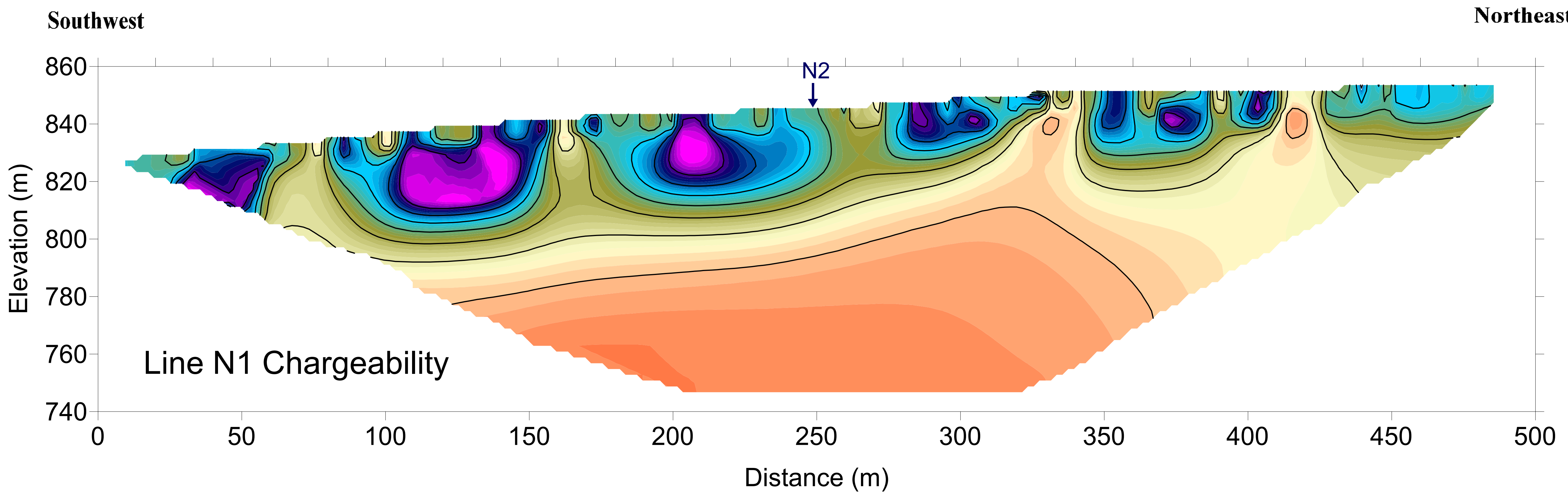
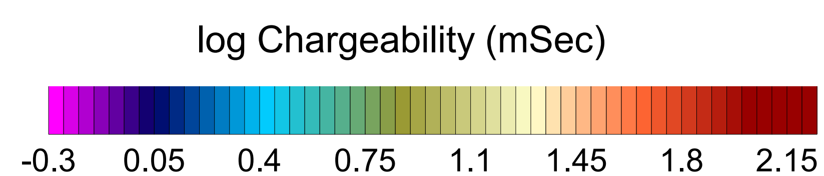
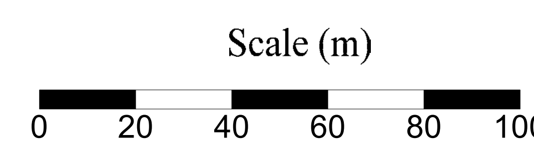
Induced Polarization Results - Line N1







Resolution Copper
Resistivity Characterization
Superior, AZ

Date: April 2013	**Fig.: Area N - IP**

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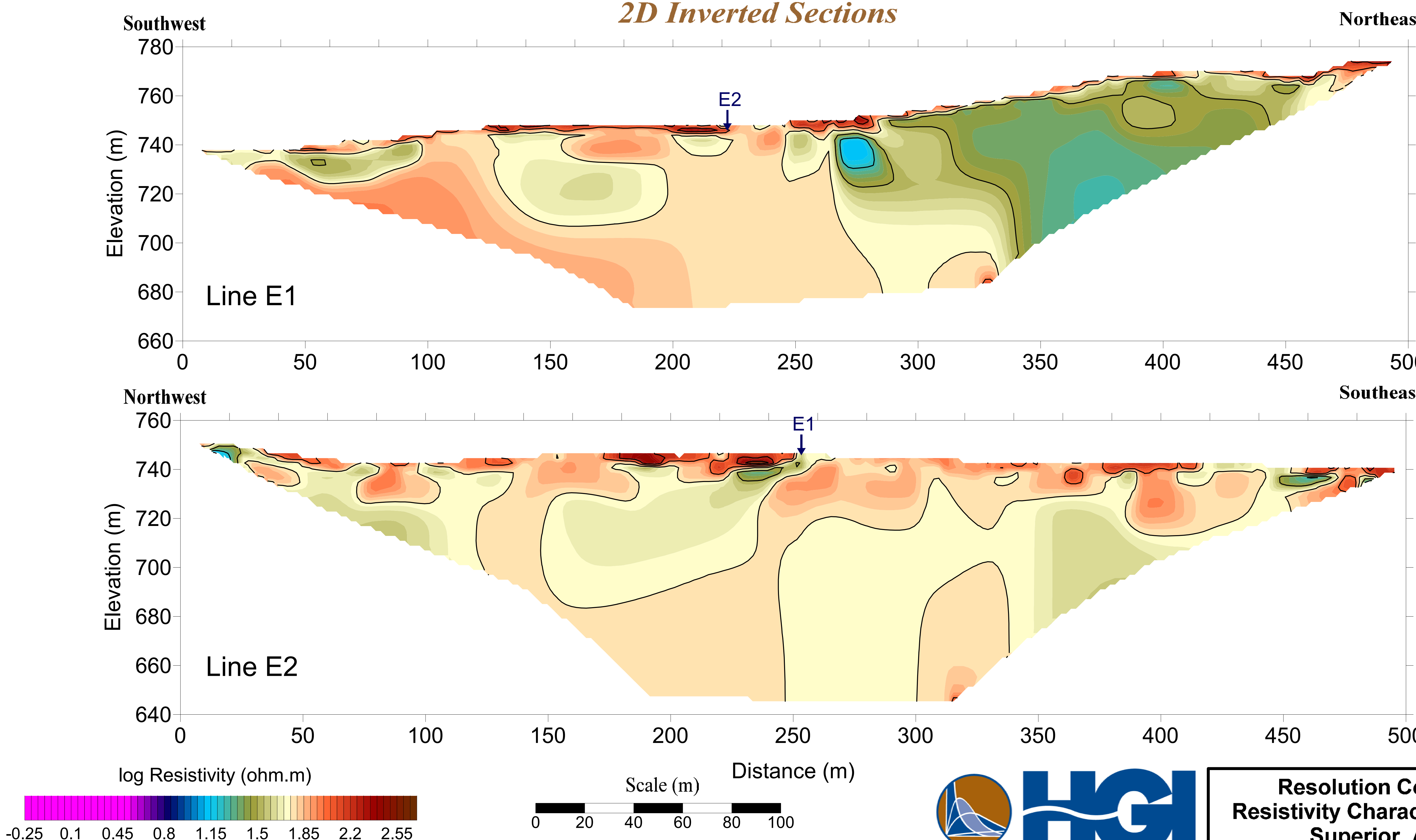
Electrical Resistivity Results - Area E
2D Inverted Sections



hydroGEOPHYSICS

Resolution Copper Resistivity Characterization Superior, AZ

Date: April 2013	**Fig.: Area E**

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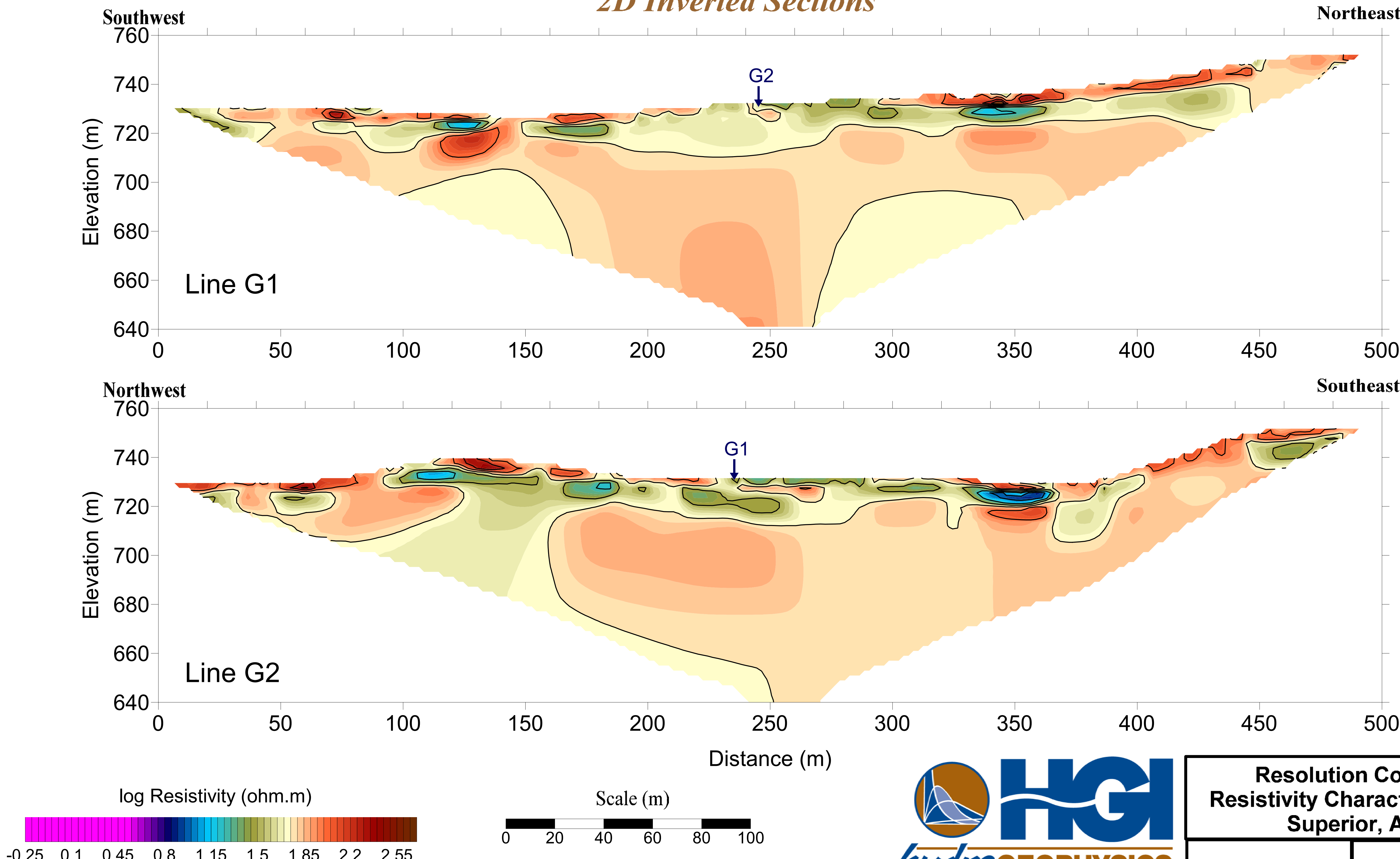
Electrical Resistivity Results - Area G

2D Inverted Sections



Resolution Copper Resistivity Characterization Superior, AZ

Date: April 2013	**Fig.: Area G**

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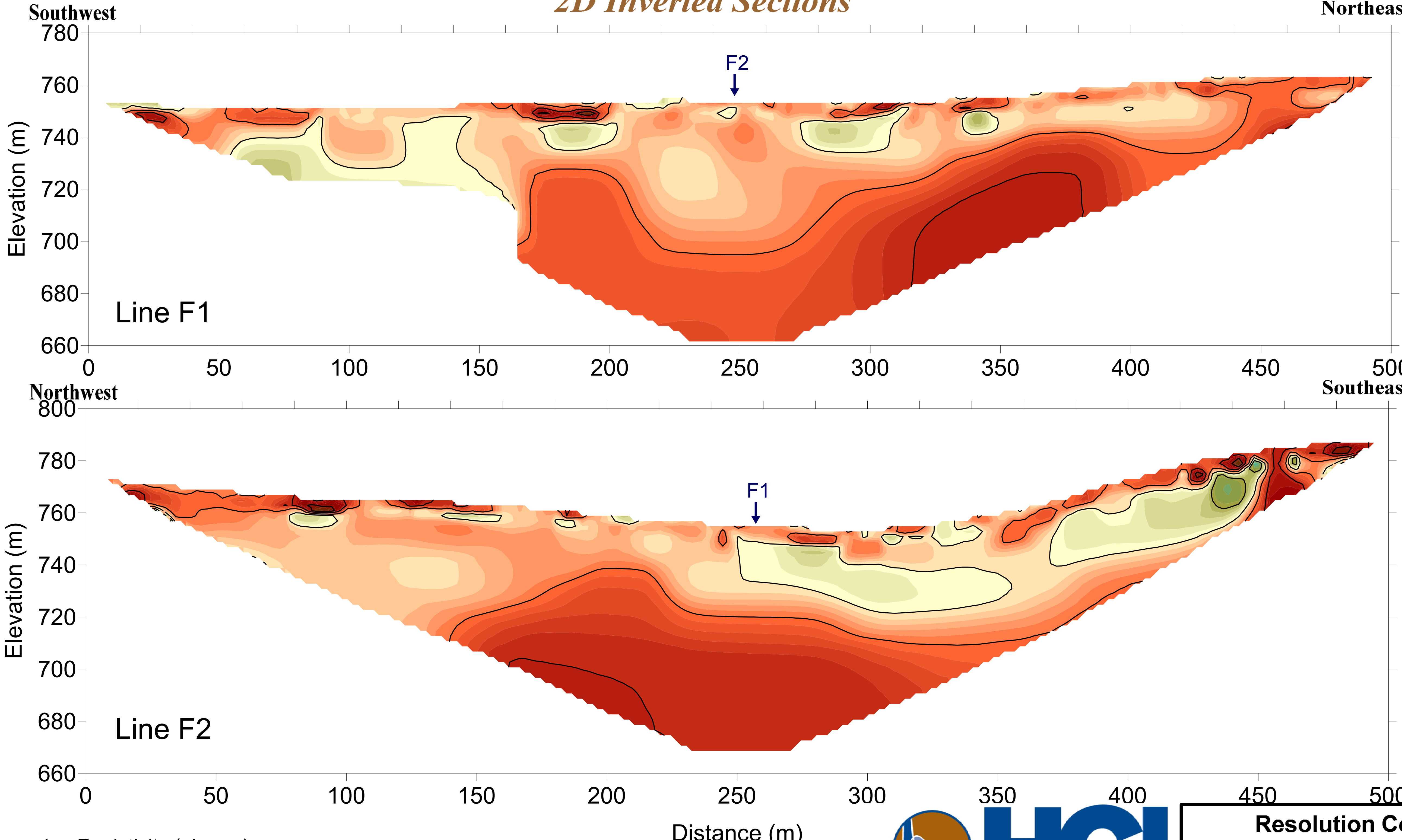
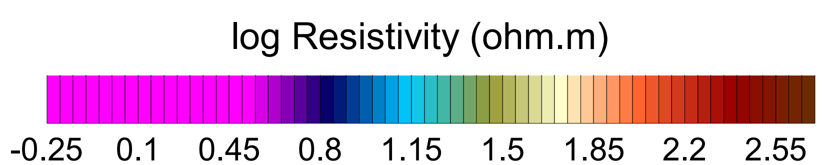
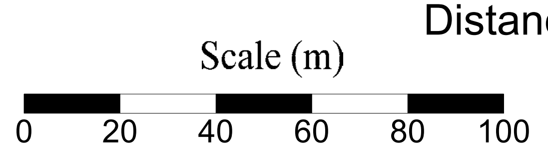
Electrical Resistivity Results - Area F

2D Inverted Sections







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Resolution Copper
Resistivity Characterization
Superior, AZ

Date: April 2013 | **Fig.: Area F**

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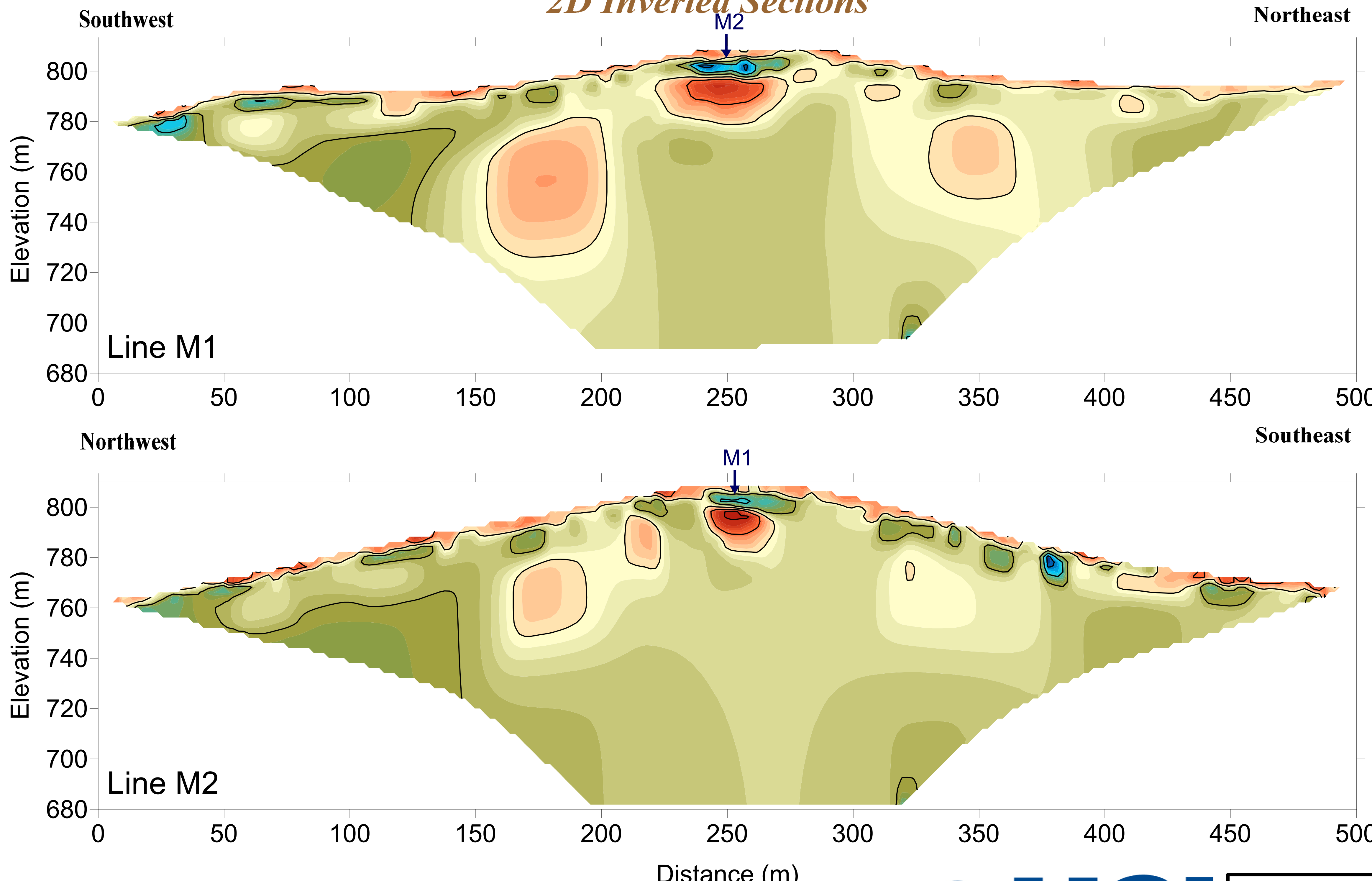
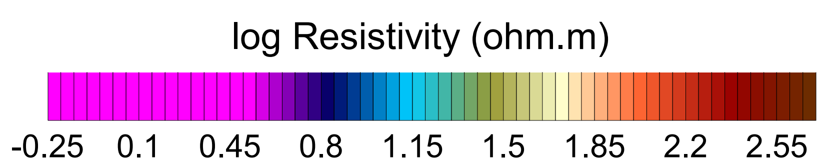
Electrical Resistivity Results - Area M

2D Inverted Sections





Scale (m)

0 20 40 60 80 100

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Resolution Copper Resistivity Characterization Superior, AZ

Date: April 2013	Fig.: Area M

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