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SELF-POTENTIAL SURVEY OF THE HOT MINERAL SPA EXPLORATION AREA, CHOCOLATE MOUNTAINS AERIAL GUNNERY RANGE (CMAGR), YUMA MCAS, ARIZONA

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ABSTRACT

Self-potential (SP) geophysical surveys were conducted in the Hot Mineral Spa exploration area of Chocolate Mountains Aerial Gunnery Range (CMAGR), Yuma MCAS, Arizona in November and December 2010 by the US Navy Geothermal Program Office (GPO) and Epsilon Service Systems (ESS). Over 1200 stations at 200 foot spacing were occupied in a ~20 mi^2 region in the western piedmont of the Chocolate Mountains, upslope from known geothermal resource areas producing geothermal fluid for direct use, including the Hot Mineral Spa and Bashford Spa. The survey was conducted in two phases. Phase one identified potential anomalies and phase two focused on reproducing these previously measured anomalies for improved definition and accuracy. Two major anomalies were identified in the survey area. A negative 108-mV anomaly in the North (Anomaly A) and a negative 96-mV anomaly in the South (Anomaly B), both of which appear to be narrow, electro-kinetically produced electrical anomalies. The anomalies occur, from drilling data, in areas of known near-surface geothermal fluids. The linear trend and proposed coupling mechanism suggest that the flow of thermal fluids is structurally controlled by faults analogous to regional patterns.

INTRODUCTION

The Hot Mineral Spa Geothermal Area (HMS) is located on the western piedmont of the Chocolate Mountains. The area is an alluvial surface that slopes into the northeastern section of the highly attenuated Salton Trough. The HMS is a blind geothermal system void of surface manifestations like hot springs, fumaroles, and hydrothermal alteration. The first well was drilled by the U.S. Bureau of Reclamation in 1938, encountering moderate temperatures. The region sat idle until the early 1960's when shallow direct use production wells were drilled to support geothermal health spas, mobile home parks, and farm raised fish. The majority of producing wells in the region deliver 172^{o}F to 129^{o}F fluid from an artesian aquifer 65 to 420 feet below the surface in a 130 foot section of Holocene sands and gravels (Hunter, 1998). Outflow plumes identified during the GPO temperature gradient hole (TGH) drilling campaign at the HMS displayed similar characteristics in depth, lithology, and temperature suggesting a potential relationship.

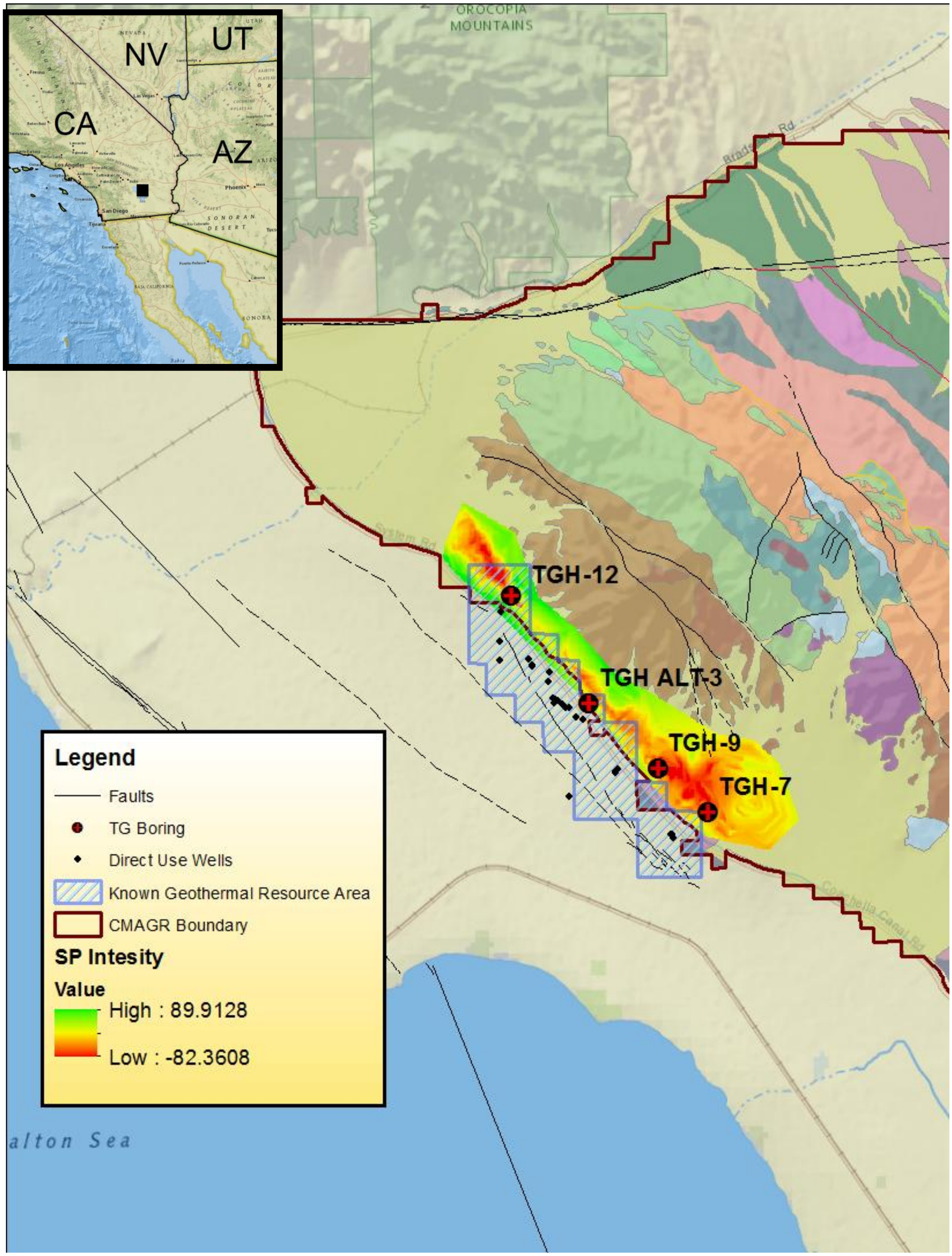

Figure 1. CMAGR Location Map including GPO temperature gradient holes.

SURVEY DESCRIPTION

From November 9th to November 16th 2010 a team of 7-8 people from the US Navy Geothermal Program Office (GPO) and Epsilon Service Systems (ESS) conducted Phase 1 of the CMAGR Hot Mineral Spa Self-Potential Survey. Phase 2 was designed and implemented to test and confirm the compelling anomalies identified in Phase 1. Phase 2 was conducted from December 16 to December 19 2010 by 4-5 people from the GPO. The survey addressed the current priority exploration area of the CMAGR with known geothermal occurrences. Historical drilling data and several shallow temperature gradient holes (TGH) drilled in early 2010 by the GPO revealed elevated groundwater temperatures in the regional subsurface. However, reversals in the temperature profile made it difficult to determine the likely source of latent upwelling geothermal fluids. The self-potential method has been identified as an effective low-cost geothermal exploration method for identifying anomalies generated from electrokinetic and thermoelectric phenomena. These phenomena, when related to geothermal fluids, are the result of ion rich fluid transportation and electrical voltages produced from temperature differences or upflow zones (Corwin and Hoover, 1979). This method has been described as very successful in identifying shallow zones of upwelling geothermal fluids at a number of known geothermal resource areas such as: Long Valley, California (Anderson and Johnson, 1976), Cerro Prieto, Mexico (Goldstein et al., 1989), East Mesa (Goldstein et al., 1989), Beowawe (Demoully and Corwin, 1980), and Newcastle (Ross et al., 1990) to name a few. The goal of this survey was to refine areas of interest for progressive exploration methods such as resistivity, magnetotellurics, seismic, and drilling.

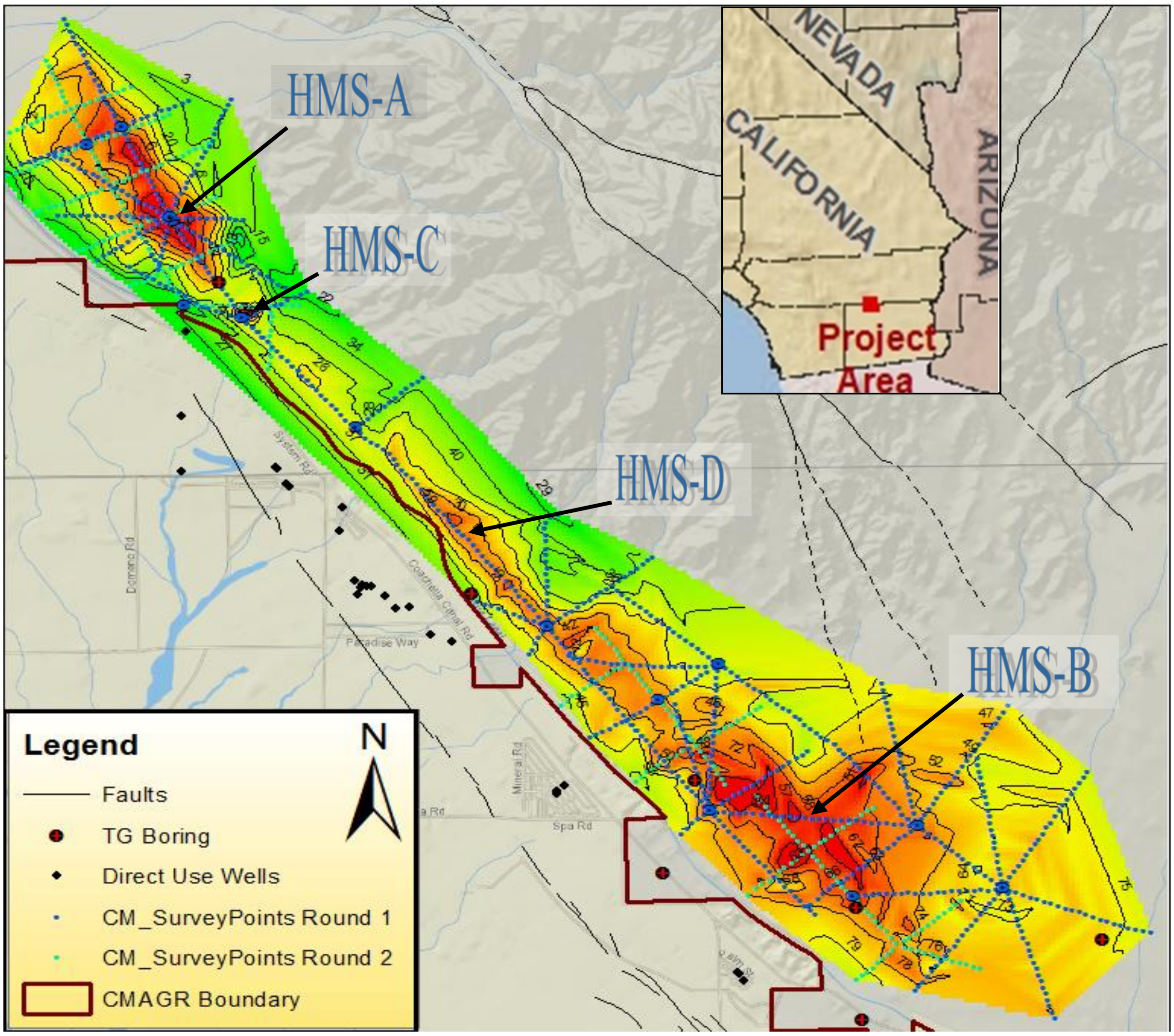

Figure 2. Location map with Phase 1 (blue dots) and Phase 2 (green dots) survey points, GPO temperature gradient holes (black/red dots), temperature gradient borings, direct use wells, and identified anomalies

METHODS

All data were collected by two four-person survey crews. Each four-person crew consisted of two people laying out the survey lines and two people collecting the self-potential (SP) data. Initial survey design was based on the "spoke" technique, which typically consists of lines being laid out in a radial pattern originating from a central stationary electrode or "base station." Stationary electrode type surveys with a single roving electrode, compared to leap-frog type surveys where there is no stationary electrodes, minimize cumulative errors that can result from intersecting profiles. We also greatly reduce the potential for compound polarization and drift error by referencing all new base stations back to the original or primary base station and monitoring the natural voltage between pots in an electrolyte bath. We also attempt to regulate the temperature of the porous pots by keeping them shaded to prevent temperature differences between pots that can cause a significant amount of voltage drift.

Line stations were marked at 200 ft spacing using a Trimble Juneau SB handheld that operates at ~3m accuracy. Lines were designed in the field using the ESRI Arcpad program installed on the Trimble unit and spacing was determined using a 200 ft length of wire. The team operating the GPS unit would clear a small 4-6" wide depression of debris, add about a cup of water, take a GPS measurement, name the site, and then flag for ease of location by the SP team. Allowing one team to work ahead gave the electrode holes ample time to allow the associated infiltration potential to completely decay and still provide enhanced electrical contact with the soil. It was observed by Ross (2009) that in a similar arid environment initial infiltration potentials after watering produced +30mV and then decreased to 0-5mV after a period of 10-30 minutes. Our survey was designed to allow for a period of 1-3 hours before an electrode measurement was taken. The voltage readings were often re-measured to verify that the infiltration potentials had completely decayed.

The survey lines were almost exclusively "cross-country" type traverses since our survey procedure equated to little more than hiking with geophysical equipment across the training ranges. Survey lines were laid out by GIS technicians from ESS and a reasonable amount of flagging was used to mark the shortest path along the line as needed. In several instances large drainages were crossed and terraces incised as much as 15 ft had to be ascended and descended with regularity. This is considered to be a potential source of error in the data since uneven topography may affect surface potential fields by distorting current flow patterns (Corwin, 1979).

SP SURVEY COMPLETION

Elevated Temperatures in TGH-7, 9, 12, and ALT-3 (Figure 1) along with known production of geothermal fluids for direct use at several nearby resorts and aquaculture developments inspired the initial survey location and design over this portion of the Hot Mineral Spa exploration area. Other enticing data includes a soil-mercury anomaly in the northern area of the survey. There are also geophysical interpretations of gravity and magnetic data previously acquired by the GPO (Bjornstad, 2011). The geophysical studies highlight potentially intersecting structures that could be related to high permeability upflow zones that are the potential source of outflow zones identified in the shallow drilling campaign.

Four anomalous features were identified from the Hot Mineral Spa SP survey based on amplitude, extent, and orientation. With careful field procedures and data processing, features such as these represent distinct variations relative to the background SP values of the survey region. These are discussed below.

HMS-A. This anomaly occurs in the far NW portion of the survey, directly SW of the Salt Creek Wash, and is defined by 8 profiles. HMS-A trends NNW ~6000 ft on the long axis and values range from -54 to -100mV with the heart of the anomaly resting under the CM007 base station on the SE portion of the entire anomaly. This dipolar self-potential anomaly has a 140mV peak to trough amplitude and 3000 ft peak to trough length. This high amplitude portion of the anomaly is about 1700 ft across on the short axis and has a similar range of -55 to -100 mV. After Phase 1 this anomaly had the potential to be a continuation of negative values cumulated in the reference base correction and was therefore heavily targeted for follow-up work in Phase 2. In Phase 2, five survey lines were run perpendicular to the long axis trend of the anomaly from new base stations. Three survey lines filled areas with little data and two survey lines were acquired close to existing lines to test the repeatability of the data. The results were encouraging. The fill-in lines did little to alter the contouring of the general shape with only minor reshaping of the contours in NW portion of the anomaly. The parallel lines reproduced the data mostly within 1-10mV with a maximum difference of 20mV. Figure 3 shows two examples of the reproducibility of the data in the second phase of the survey. Exact stations were not reoccupied, which may have induced some error in reproducing the original data. However, the data is still within an acceptable range and demonstrates that the anomaly is reproduced and is not a result of compounded errors or poor acquisition strategy.

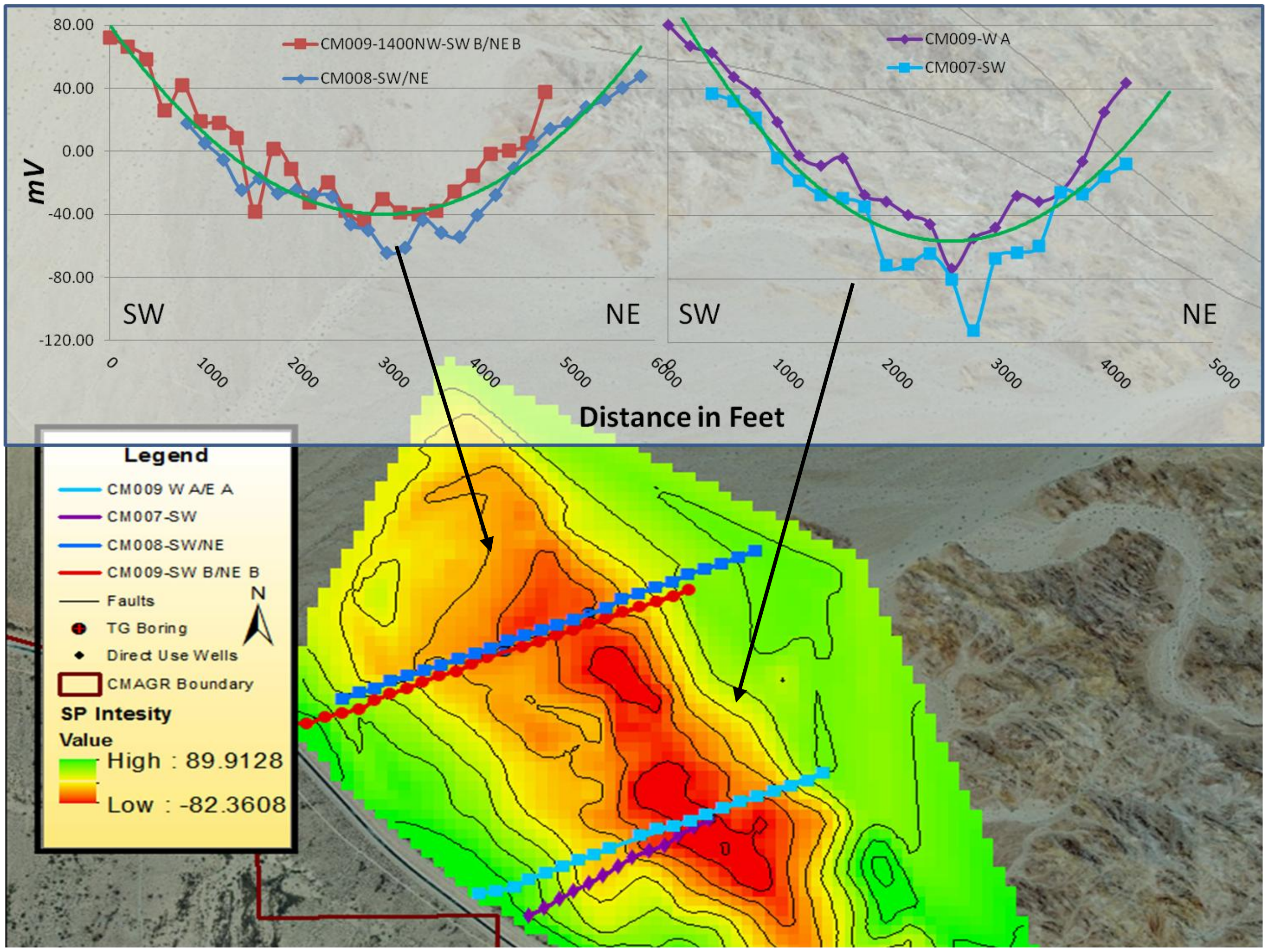

Figure 3. The charts in the upper half of the figure compares the results from initial phase 1 data (blue and light blue) with near parallel test lines collected in Phase 2 (red and purple). Both datasets demonstrate the dipolar nature of the anamoly with similar values from intermediate axis transects.

The Phase 2 survey also experienced a minor amount of rain the night before the first day of the survey. The precipitation could have concentrated groundwater flow across certain areas creating positive electrokinetic voltage, conceivably altering the self-potential field. Increased soil moisture content may have also lengthened the amount of time for infiltration potentials to fully decay before the readings were taken. The data variability encountered from the short distance between the two lines could be valid. If so it would emphasize the need for reoccupying actual station locations when attempting to create an accurate comparison.

The combined data strongly indicates that it arises from a natural source, such as upwelling geothermal fluids. Data closure on all sides and dual phase data agreement provides high confidence in the authenticity of the anomaly and suggests that our field methodology was thorough and well executed. This anomaly is also associated with elevated temperature gradients identified from the GPO drilling campaign and a trend of increasing temperatures toward the NW. Similar NW-SE trends found in the magnetic, gravity, and structural geology interpretations also suggest that this anomaly is fault-controlled.

HMS-B. This broad anomaly occurs in the SE portion of the survey area with lows in the range of -40 to -87 mV along a 7500 ft NNW trending profile. HMS-B is defined with over 20 survey lines from 5 different base stations recorded over both phases of the survey. There is also an antithetic spur that trends off the southern section of the profile to the NE with negative values of -53mV and -68mV. Although the anomaly has a recognizable trend the overall data is noisy and could be interpreted as a moderate low in a broad region of negative readings. This causes some irregularity in the contouring that is difficult to account for and may have benefitted from additional data acquisition to the SE.

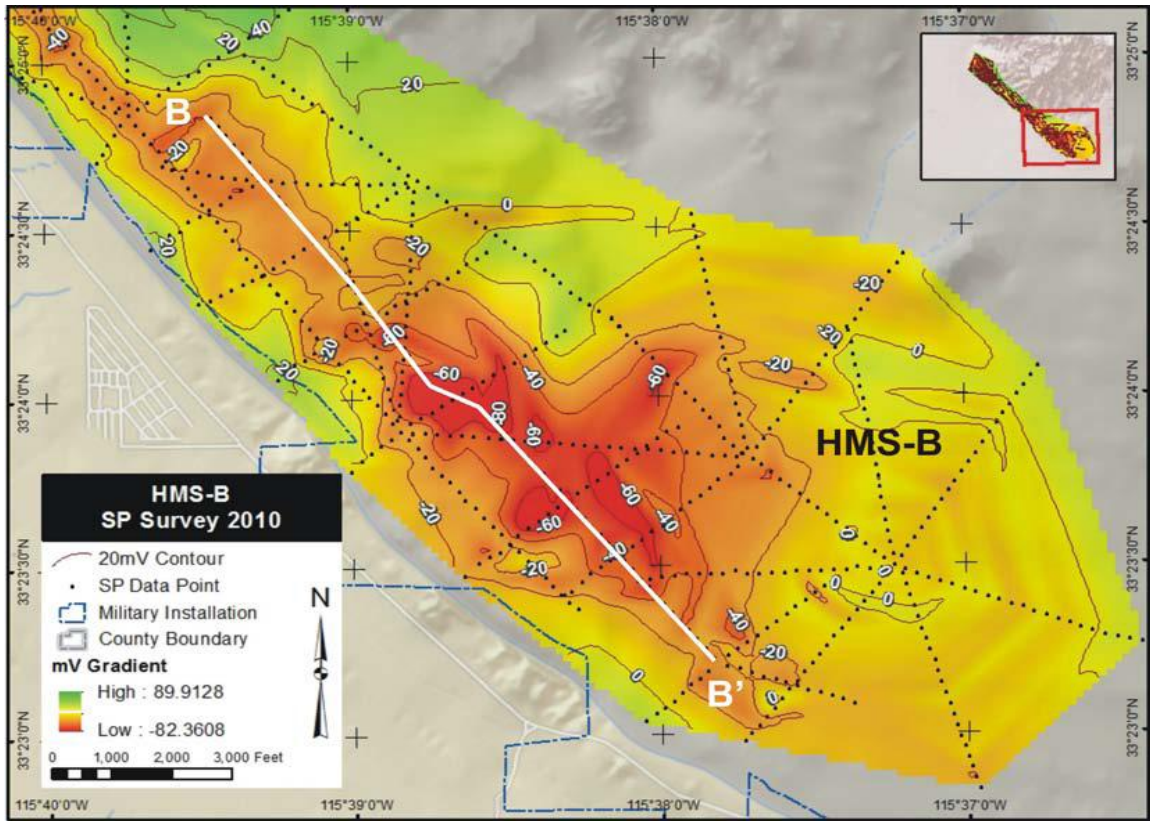

Figure 4. Location Map HMS-B with the long axis of the anomaly marked (B-B').

Potential noise issues could be similar to the ones mentioned in regards to HMS-A or due to the effects of uneven topography on current flows patterns described by Corwin (1979). Figure 5 displays the relationships between uneven topography and data noise. Figure 5 shows survey profiles that represent the long axis of the anomaly in a side by side comparison with an elevation profile from a LiDAR dataset. The presence of a relationship is difficult to discern since the resolution of the SP data sets is much lower than that of the LiDAR. However, it displays that the tightly grouped SP and elevation data in the NW portion of Figure 5 have a much lower standard deviation from the mean than the more variable data in the SE. This correlates well with a similar relationship in the elevation data, where there is a smoother elevation profile in the NW and an uneven or variable profile to the SE. In this example, the uneven topographic area directly correlates with increasing variability in the SP profile data.

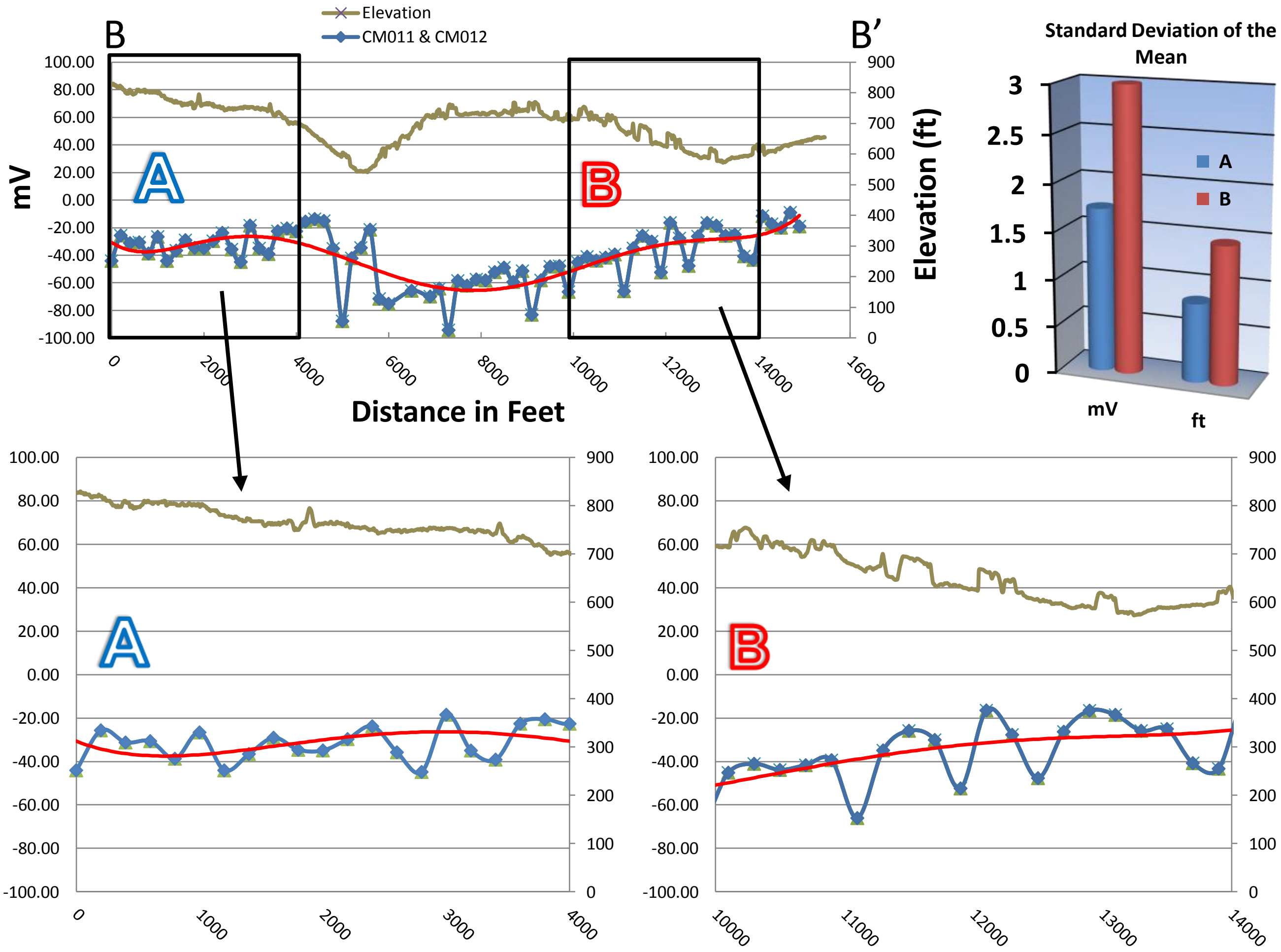

Figure 5. Long axis profile of SP anomaly HMS-B (Figure 4, B-B’) plotted with the associated elevation profile, derived from LiDAR. Expanded charts demonstrate the relationship between increased data noise with frequently uneven topography. Bar graph in the upper right supports this relationship by illustrating the standard deviation from the mean for mV and ft almost doubles with uneven topography.

HMS-B should be considered to have potential for being associated with a natural source such as upwelling geothermal fluids. Even though there appears to be noise associated with the data in the south, the dominant trend of the anomaly appears to align with the trend of HMS-A and regional structural patterns. Matched with encouraging thermal anomalies from nearby temperature gradient holes and similar structural trends as HMS-A, this anomaly is a priority for future exploration.

HMS-C. This is a small smoothly contoured anomaly located 1000 ft from the southern tip of HMS-A. It has a circular contour pattern 500 ft across with minimum values of -48, -76, and -88 mV. The anomaly appears along trend with other anomalies identified in the survey. Several lines from various base stations in both phases of the survey were measured across this anomaly to fully delineate a potential source.

SP values rapidly increase radially from the anomaly into positive background values. This is likely a continuation of HMS-A. A steep, well incised drainage in the range front may be funneling ground water across and masking what would otherwise be a larger more continuous anomaly. This would be a good target for further exploration with other low-cost surveys before attempting a borehole over this anomaly. Two-meter temperature probes, for example, would provide information on elevated near surface temperatures that could be compared with nearby well data for targeting of additional temperature gradient holes.

HMS-D. This anomaly is also on trend with other anomalies previously discussed as well as the regional structural pattern. It appears that this anomaly could be a continuation of HMS-B to the north and is separated by a broad zone of moderately low values in the range of -10 to -40 mV. The values across HMS-D range from -20 to -60 mV over 8500 ft. One of the major issues with this minor anomaly is the data coverage. Not enough data was collected perpendicular to what appears to be the general trend of the anomaly. This was a section of the survey area where there was little room between the range front and the Coachella Canal. The canal is another possible noise source for the entire dataset. It is well known that SP data is effective in identifying potential leaks in the cement liner used to prevent water-loss in the canal, and can be causing noise in nearby data points. The base stations were therefore kept 500 ft or more from the canal, and it was observed that data continually became more positive as survey lines approached the canal. For this reason, data acquisition in this area was kept to a minimum. However, a few short lines perpendicular to the regional trend would have been very useful to better define the extent and character of the anomaly.

This anomaly is still questionable and requires more information before moving ahead with drilling in this area. This anomaly could benefit from further exploration into the near surface temperature regime considering its proximity to the highest temperature recorded, 158°F, during the GPO shallow drilling campaign (Bjornstad, 2011). Reoccupying the nearest base station, reacquiring the survey line data, and collecting additional points perpendicular to the anomaly would help improve the interpretation of this anomaly. An improved investigation into the nature of this marginally interesting anomaly should be conducted before ruling out the potential upflow of geothermal fluids.

SUMMARY OF RESULTS

Survey results have identified several broad, high-amplitude SP anomalies in the Hot Mineral Spa exploration area of the CMAGR that appear to be real and worthy of further exploration. All anomalies have similar characteristics in that they are on trend with the regional structural patterns of the adjacent San Andreas Fault System termination and the Brawley Seismic Zone. HMS-A and HMS–B were both extensively verified with cross-cutting survey lines in the phase 2 survey effort that proved the data was reproducible. Reproducing data is critical to any SP survey because it shows that the survey was conducted with high integrity. The amplitudes of the anomalies generally range from -40 to -100mV, which is well beyond potential noise sources combined with local background potentials. The anomalies are defined with high data density on all sides with the exception of HMS-D, which is recognized to require further work to verify its authenticity.

These anomalies could greatly benefit from even further definition, possibly in the form of a 2m temperature probe survey to define their association with shallow thermal anomalies and help target future temperature gradient drilling. Once an SP anomaly has been associated with thermal activity at depth, it can be used to help focus other electrical studies such as DC resistivity or MT for imaging of potentially deeper circulating geothermal fluids.

This work is an example of how the GPO applies low-cost, large-aperture exploration methods, such as SP and 2m temperature probes, to large areas so that more expansive survey areas can be effectively reduced economically. Application of SP in the early stages of exploration is a cost effective method for moderate-temperature blind geothermal resource areas like the Hot Mineral Spa Exploration Area.

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