June 27, 2005

Ms. Debbie Baldwin
Colorado Oil and Gas Conservation Commission
1120 Lincoln Street, Suite 801
Denver, Colorado 80203

RE: Geophysical Survey Summary
Bondad, Colorado

Dear Ms. Baldwin:

LT Environmental, Inc. (LTE) is pleased to provide the Colorado Oil and Gas Conservation Commission (COGCC) with this letter summarizing the results of the geophysical survey conducted by MicroGeophysics Corporation (MGC). The geophysical survey included magnetic and electromagnetic methods to identify potential subsurface wellheads in the seep area that may be acting as conduits for methane seep migration. In addition, MGC performed a seismic refraction survey to understand the structure of the surface gravel deposit and the underlying sandstone layer. The geophysical surveys were conducted at the Bondad Explosion Site (Site) located in Bondad, Colorado during the week of April 18, 2005.

BACKGROUND

Two methane seep surveys have been performed at the Site in response to an explosion of a residence located at 4034 US Highway 550 (Yoakum Residence). During the period from February 21 through February 24, 2005, and again from April 18 through April 20, 2005, LTE conducted soil gas survey activities in the project area extending radially outward approximately 3,000 feet in all directions from the Nick Spatter Bryce Farm #1 (NSBF #1) production well (Figure 1). The results of the soil gas surveys are presented in the *Methane Seep Survey Report* (March 2005) and a summary letter *Additional Methane Seep Survey and Natural Spring Survey* (May 2005). These reports, along with this report, are available on the COGCC website at www.oil-gas.state.co.us.

As a means to understand the migration of methane gas in the subsurface identified during the previous soil gas surveys, LTE recommended the use of geophysical methods to identify potential wellheads that may be acting as conduits but also to characterize the structure of the near surface geology to better understand gas flow.

SITE DESCRIPTION

The Site is located in Bondad, Colorado, approximately 20 miles to the south of Durango, Colorado (Figure 1). The Site is located approximately 0.25 miles north of the confluence of the Animas River to the west and the Florida River. The Site consists of several tracts of land covering more than 100 acres. The land use consists of residential properties, a fire station, US Highway 550, the Animas River, and the Florida River. The majority of land area is privately owned. Figure 1 shows the layout of the Site.

The geophysical survey area was approximately 500 feet long by 500 feet wide and positioned along the eastern edge of US Highway 50 and centered roughly North-South over the NSBF #1 well.

GEOPHYSICAL SURVEY RESULTS

MGC has prepared a comprehensive report outlining the methods and results of the various survey activities. These results are presented in MGC's May 11, 2005 summary letter and included as Attachment 1.

In general, the results of the magnetic surveys identified the presence of six anomalies in the vicinity of the NSBF#1 well. These areas are specifically noted in Figure 5 of MGC's report. Anomalies #1, #2, and #3 were located south and southeast of the NSBF#1 well and at greater depth. Anomalies #1 and #2 exhibit a weaker magnetic signal and are believed to be the steel anchors used to tie down a drilling mast. Anomaly #3 exhibits a much stronger signal and has the potential to be an additional wellhead or other vertical metal feature. Two of the areas are in close proximity to the NSBF#1 (anomalies #5 and #6) and were determined to be near-surface anomalies using the EM61 equipment. A horizontally-shaped near-surface anomaly (anomaly #4) was noted north of the former Yoakum residence. The anomalies are shown in green on Figure 1.

Anomaly #4, shown on Figure 4 of MGC's report, exhibits a magnetic signature consistent with a buried pipeline. Based on existing information, no known pipelines are noted in this area. The significance of this pipeline is that it runs directly below the former Yoakum Residence. If a pipeline or utility corridor is present, it is reasonable to assume that the conduit may act as a preferential migration pathway and may explain the elevated methane concentrations detected beneath the former residence. As previously stated, the full results of the geophysical survey are presented in MGC's report in Attachment 1.

MGC conducted a seismic refraction survey of the area using four transect lines illustrated on Figure 2 of MGC's report. The field measurements along with the calculation and modeling of field data have successfully characterized the thickness of the gravel deposit and the elevation of the sandstone surface underlying the gravel. Surface contours for both the ground surface and the top of the sandstone are presented in Figure 7 of MGCs report in Attachment 1. The data shows an accurate representation of the ground surface as observed by LTE's field personnel. The seismic data also show a reasonable depiction of the weathered sandstone surface. The top of the sandstone shows erosional channel features that are oriented roughly north-south. According to discussions with the geophysicist from MGC, Mr. David Butler, it appears that there is a slight dip noted on the sandstone layer from the north northwest to the south southeast but mainly the dip has a north-south component, assuming a uniform thickness of the sandstone.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the geophysical survey, there are at least six anomalies in the study area that have the potential to act as conduits for preferential migration of subsurface seeping methane gas. In particular, anomaly #3 and the horizontal anomaly north of the Yoakum Residence (anomaly #4) have the greatest potential to transmit the elevated gas levels that fueled the explosion.

The results of the seismic refraction survey have supported LTE's early hypotheses regarding subsurface migration of seeping methane gas. In general, it is reasonable to assume that the NSBF#1 is the primary conduit for methane seepage from the Fruitland Formation. Confirmation that the gas is from the Fruitland Formation could be ascertained by comparing the isotopic analysis of the samples collected by LTE in February 2005 to isotopic analysis of a sample of gas from a nearby production well producing from the Fruitland Formation (i.e. Cain 31-2).

LTE believes that the gas migrating vertically in and around the plugged and abandoned (PNAd) NSBF#1 is able to penetrate horizontally at different levels in the subsurface through layers of varying permeability. In particular, the shallow aquifer layers accessed by nearby water wells appear to be impacted as evidenced by methane gas detected within the water wells and immediately adjacent to and outside of the water well casing. Based on available data and historic experience, it is unlikely that the methane detected in the water wells is migrating vertically through nearly 2,500 feet of shale and sandstone from the Fruitland Formation. The deep migration pathway is more likely to be the PNAd NSBF#1 production well for the seeping gas observed at the surface and in the water wells nearby.

LTE also believes that the sandstone layer beneath the surface gravel deposit is allowing the horizontal migration of methane gas. The distribution of elevated methane concentrations at the ground surface show horizontal migration radially outward to the south, east, and west to a distance of approximately 300 feet from the NSBF#1. Based on the elevated concentrations (>75% methane) detected at the ground surface more than 300 feet from the NSBF#1 well, it is reasonable to assume that there is a source of methane gas located near the ground surface. It seems likely that the low permeable sandstone layer has trapped gas originating from the NSBF #1 well conduit.

The gas also appears to be migrating horizontally below the sandstone layer to the north more than twice as far as the observed horizontal migration to the south, east, and west. The seismic refraction survey demonstrated a slight dip in the sandstone layer to the south southeast. The horizontal migration of methane gas from the NSBF#1 more than 600 feet to the north-northwest may be explained by methane gas trapped beneath the sandstone migrating up-dip, then vertically through fractures into the gravel layer and to the ground surface. LTE has observed the vertical fractures along outcropping portions of the sandstone layer that support this transport scenario. The elliptically-shaped extent of methane seepage surrounding the NSBF#1 appears to be related to the dip direction observed in the sandstone during the seismic refraction survey. The limited flow conduits made possible by the PNAd borehole(s) and vertical fractures forces methane gas to migrate laterally to find the path of least resistance. Figure 2 illustrates the conceptual model of gas migration in the subsurface at the site.

LTE's most recent soil gas survey of the area included additional investigation along the Animas River valley wall, west of US Highway 550. During the field activities, LTE noted the presence of seeping gas below the sandstone layer in an up-dip position relative to the NSBF#1 well (Figure 1). Two natural springs noted below the sandstone layer and near the areas with seeping gas were also found to contain trace amounts of dissolved methane, further supporting the presence of a trapped gas source beneath the sandstone layer.

LTE recommends continued operation and maintenance (O&M) of the existing methane detection systems in the four houses and the fire station located within the project area. The monthly O&M will continue to be conducted by Standby Safety of Cortez, Colorado.

LTE recommends the excavation of the soil at these six areas to expose the potential subsurface metallic objects and determine their propensity to act as preferential migration pathways. Using the maps prepared by MGC and a GPS, we can successfully locate the surveyed anomalies and excavate the soil in the appropriate area to make field observations of the subsurface conditions.

LTE also recommends continued soil gas surveys to monitor changes in methane seep activity over time. The surveys should be performed in a manner similar to the April 2005 survey using a grid pattern and including the areas around the residences and the area along the Animas River Valley.

LTE appreciates the opportunity to provide environmental services to the COGCC. If you have any questions regarding this report or would like additional information, please contact us at (303) 433-9788.

Sincerely,

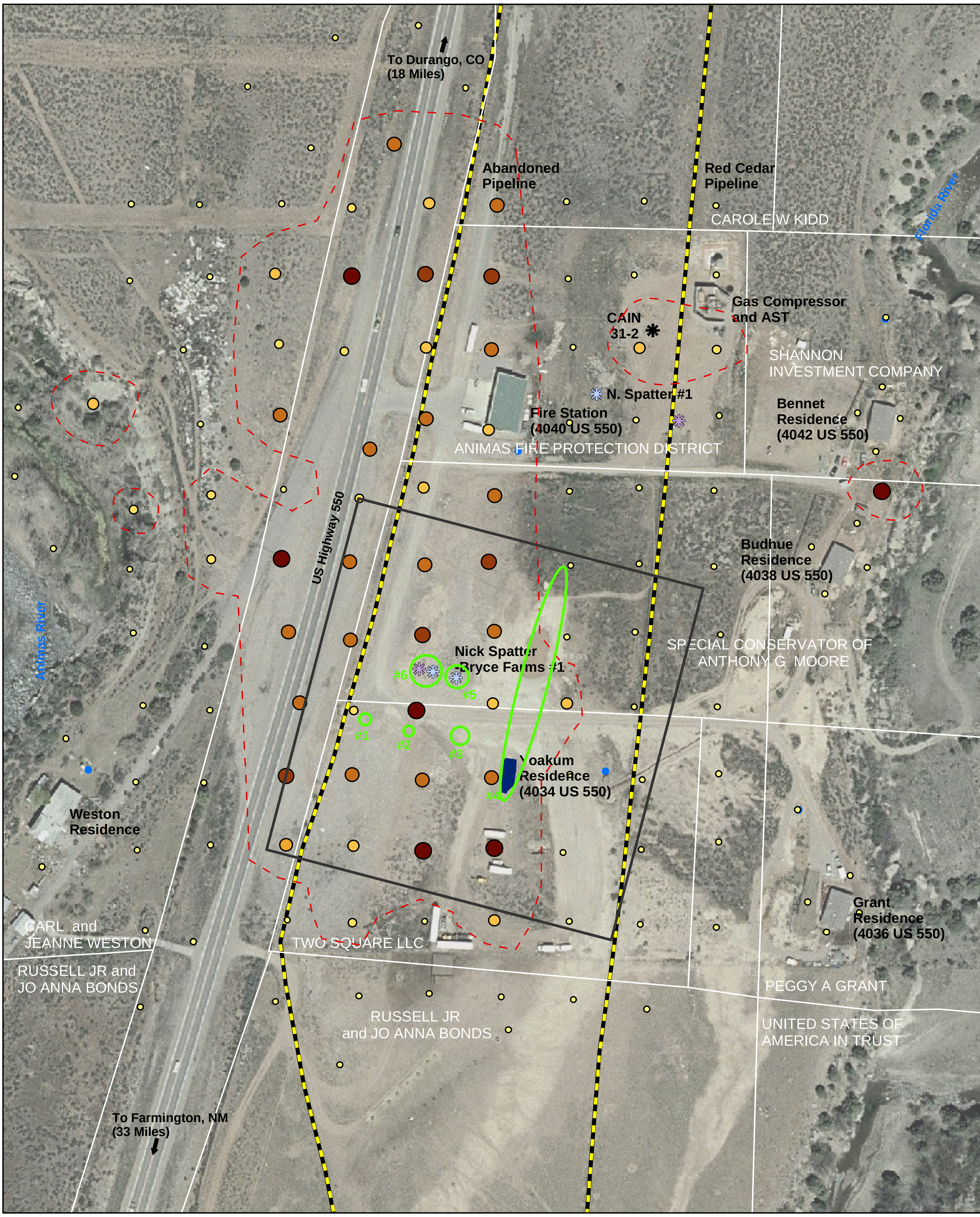
LT ENVIRONMENTAL, INC.

John D. Peterson, P.G.
Project Manager

Thomas M. Murphy, P.G.
Vice President

Attachments (2)

FIGURES



LEGEND

- Water Supply Well
- Gas Well
- Potential Former Oil and Gas Well
- Former Oil and Gas Well
- Natural Spring Location and Water Sample Location
- Yoakum Residence
- Geopysical Survey Area
- #1 Geophysical Anomaly
- Extent of Methane Seepage April 19, 2005

Utilities

- Buried Gas Pipeline

Landowner and Property Boundaries Labeled in White

Subsurface Methane Gas

- 0 - 25 ppm
- 25 ppm - 5%
- 5% - 15%
- 15% - 25%
- 25% - 50%
- 50% - 75%
- 75% - 100%

N

0 280

Feet

1 INCH = 140 FEET

FIGURE 1
SITE MAP
BONDAD GAS SEEP
BONDAD, CO

COLORADO OIL AND GAS CONSERVATION COMMISSION

OGCC050101 06/05

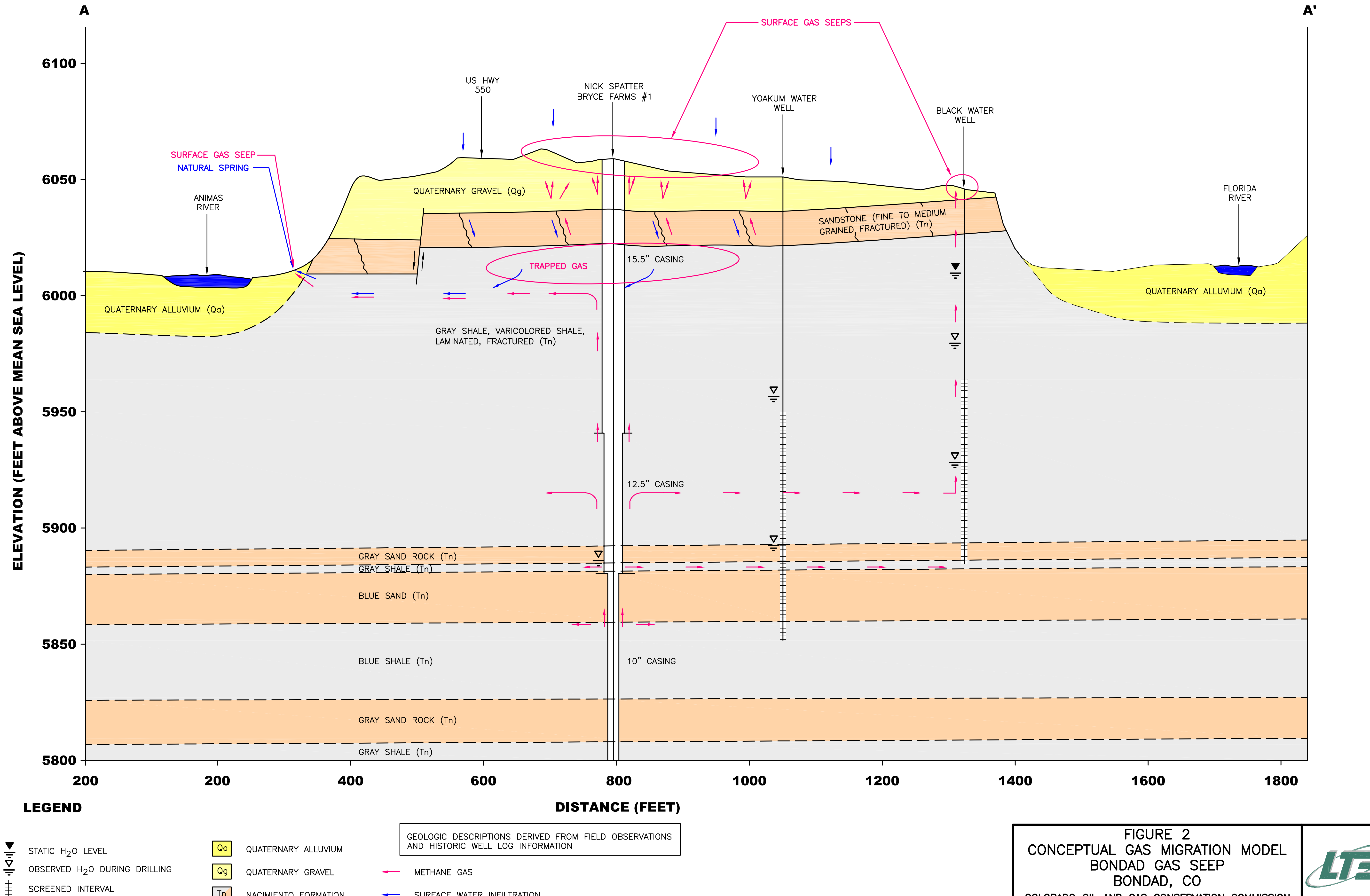


FIGURE 2
CONCEPTUAL GAS MIGRATION MODEL
BONDAD GAS SEEP
BONDAD, CO
COLORADO OIL AND GAS CONSERVATION COMMISSION

OGCC050103 5/05

ATTACHMENT 1

MGC GEOPHYSICAL SURVEY SUMMARY REPORT

MGC

May 11, 2005

John Peterson
L T Environmental, Inc.
4400 West 46th Avenue
Denver, Colorado 80212

Dear John,

This letter report summarizes the results of geophysical surveys performed by MicroGeophysics Corporation (MGC) for L T Environmental, Inc. (LTE) on April 18-21, 2005, at your study site located near Bondad, Colorado(Figure 1).

OBJECTIVES:

The geophysical survey objective is to detect underground metallic objects such as abandoned wells, storage tanks or piping, suspected to exist at this location. Additionally, the top of the sandstone (bedrock in this area) is to mapped.

ELECTROMAGNETIC METHODS:

The methods used for this survey to detect subsurface metallic objects were electromagnetics (EM), total-field magnetics (MAG).

The EM technique measures a metal response and will detect metallic bodies at the surface or beneath it. (see the EM Method Appendix). The total-field magnetometer is sensitive to the disturbance that ferrous metals make to the earth's magnetic field. The equipment used for the EM measurements was an EM31manufactured by Geonics, Ltd. The depth of investigation of the EM31 can be as much as 19 feet depending on the soil conductivities at the site and the size of the body. The equipment used for the MAG measurements was a Geometrics G858 cesium vapor magnetometer. The depth of investigation of the MAG is dependant upon the size and orientation of the ferrous objects (see the MAG Method Appendix).

A geophysical survey grid was established based on maps furnished by you. Geophysical survey lines at ten-foot intervals were established parallel to the highway (Figure 2). EM and MAG data were acquired on each line at a nominal station spacing of 2-2.5 feet.

The magnetometer was operated a nominal five feet above the surface to decrease the sensitivity to surface debris and clutter. No MAG base station was used. As abandoned wells were sought, only the large (>500 nanoTeslas {nT}) anomalies were expected. There was no indication of the occurrence of magnetic storms during the survey. The direction of the geophysical grid is referenced to the fence and the highway on the west side of the area. Grid origin is the southwest corner of the surveyed area. This grid is based on the destroyed residence and covers an area of 460'x510'. GPS locations of corners and internal fiducials were furnished by LTE. The GPS instrument used has submeter capability. Geographic coordinates were converted to Colorado State Plane coordinates(south zone). Note that the conclusions in this report are based on field observations in the survey area only. No groundwater, drilling nor trenching information was integrated with MGC's data.

EM AND MAG RESULTS:

The MAG data indicate areas of buried ferrous metallic debris. Magnetic anomalies are often complex, but a compact ferrous object will often have an increased magnetic field just south of its center and a corresponding, but smaller, lower value on the north side of the body. Multiple bodies often cause this dipolar effect to be difficult to discern, especially if the ferrous material is distributed rather than compact. A vertical ferrous pipe generates only a strong, positive, symmetrical anomaly directly above the pipe. A color contour map of the MAG data is shown in Figure 3 along with the surface culture mapped by the field crew.

The EM31 generates both a conductivity measurement and a metal response. The metal response is due to nearby metal objects though the orientation and shape of the objects and the objects location with respect to the coils strongly affects the measurement. As an example, the values recorded for the metal response when the EM31 traverses perpendicular to a buried pipe is a high-low-high pattern. Thus, EM31 anomalies are difficult to interpret as large shallow objects do not produce a 'bulls eye' effect. Figure 4 contains the inphase and conductivity color contour maps.

An EM61 was used in a reconnaissance mode to field check detected anomalies. As the EM61 has a theoretical depth of detection of only six feet for a 5 gallon metal bucket, the entire area was not surveyed with this instrument.

The entire data sets are presented on Figures 3 and 4 along with the cultural (surface) features on Figure 2. The southeast quadrant of the surveyed area contained trucks, cars, small trailers, large trailers, a D-4 cat, semitrailers and buildings. The response from these large metallic objects masks anomalies due to subsurface objects. Figure 5 contains a detail magnetic map derived from the MAG map on Figure 3 and the interpretation map. Possible buried metallic objects are indicated on the interpretative figure. The linear features are probably gas gathering lines. The MAG map is dominated by a large anomaly which is consistent with the presence Spatter #1, a known abandoned well.

EM DISCUSSION:

Both the EM and MAG techniques are subject to ambiguity. A proper distribution of small objects close to the measuring instrument may produce anomalies similar in amplitude and shape to anomalies produced by a larger, compact object at depth (see Figure M-1 in the MAG appendix). Thus close objects, such as manhole covers, may produce large amplitude anomalies, even anomalies as big as those produced by a shallow tank.

Several points bear further discussion with respect to the EM and MAG data. First is a possible sewer or gas line in the SE section of the surveyed area. If this line is present, it is poorly mapped as it crosses under the area of maximum surface clutter due to vehicles and buildings.

The second point concerns the MAG detail map. As mentioned above, the anomaly due to a single vertical pipe is theoretically quite symmetrical. The detail map on Figure 5 shows the vicinity of Spatter #1 and is not symmetrical. Lobes of high Mag are present to the east, consistent with an EM61 anomaly which extends 25-30 feet to the east and northeast and away from the marked surface location of this well.

The interpretation map also shows six anomalies, principally based on the MAG data three of which (#1,#2,#3) were not mapped with the EM61. Anomaly #3, the southeastern most of these three , has the highest MAG reading and some indication of EM31 anomalies, These three anomalies are consistent with buried car parts, old well tiedowns, buried piping, or other ferrous materials. Comparison of these anomalies to the anomaly of Spatter #1 indicates that they do not affect as large an area and are not as intense as the anomaly due to Spatter #1.

Anomaly # 4 is an EM only anomaly but lies close to a small road culvert. Anomaly # 4 is consistent with various metallic objects including a north-south pipe from the vicinity of the pipeline which would trend toward the destroyed residence. This anomaly also may be partly explained by the road culvert. Anomalies # 5 and #6 are close to Spatter #1 and may be the cause of the assymmetry of the large anomaly. Anomalies #3 and #4 may deserve investigation if such action is consistent with your ongoing investigation.

SEISMIC REFRACTION METHOD:

The objective of the investigation was to determine the depth to the bedrock interface along lines selected by you (see Figure 2) in order to map the bedrock-overburden interface. The seismic velocity contrast of the sedimentary bedrock with the overlying alluvial materials was the geophysical target.

A crossed pattern of four seismic lines was centered on the area of investigation to the east of the highway fence (Figure 2). A geophone spacing of ten feet and six or seven shotpoints for each 230' spread were used. Offset shotpoints outside the active spread were nominally 50' and 100' from each end of the spread. Each line consists of two spreads; minor adjustments in line locations were made to accommodate surface impediments, small lakes, and topography (see Line 2, Figure 2).

The seismic sources were a sledge hammer and plate and an accelerated weight drop (EWG). Additional detail about the seismic refraction method is given in a method appendix attached to this report.

The two-person crew used an R-24 24-channel, digital, instantaneous-floating point seismograph and 50-Hz fundamental frequency geophones (damped at 0.6 critical) to obtain the seismic data. Measurements were recorded in SEG2 format in the seismograph's internal hard disk. The refraction data were processed and interpreted using two state-of-the-art geophysical programs: FIRSTPIX and GREMIX. Both programs are commercially available from INTERPEX Ltd., Golden, Colorado.

FIRSTPIX was used to determine the first-break times of the refracted arrivals at each geophone along the seismic line. GREMIX utilizes the Generalized Reciprocal Method (GRM) for calculation of refractor depths based on Palmer's method (1980). GRM was chosen for this investigation to map the depth to an irregular or non-planar bedrock surface.

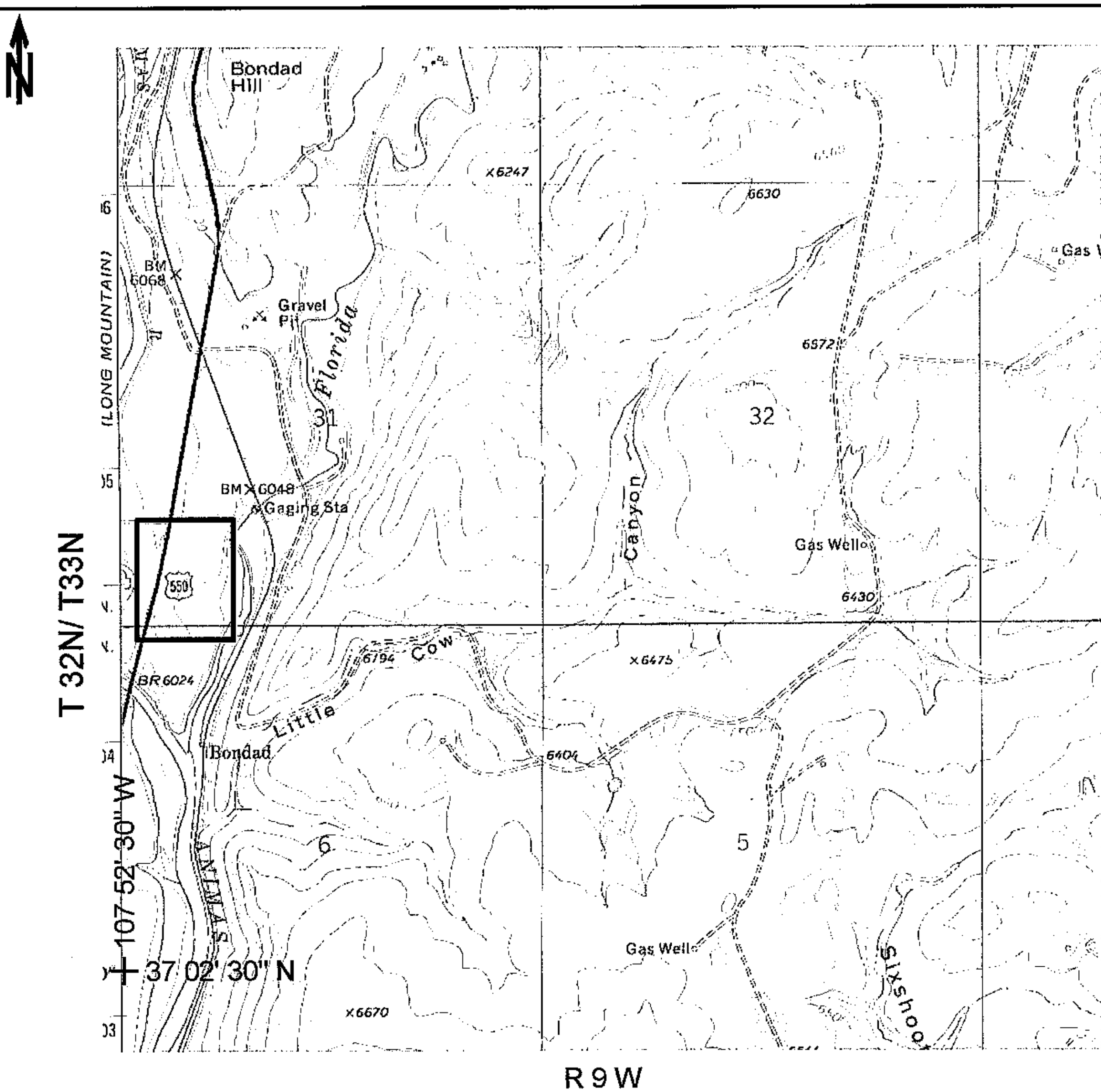
SEISMIC RESULTS:
The interpreted refraction data have been presented in cross-sectional format where the alluvial-bedrock refractor interface is plotted with respect to distance along each line and depth beneath each geophone position on Figure 6. This figure presents the interpreted refraction cross-sections generated for each line, measured travel times and refractor velocities. The seismic velocities presented on Figure 6 are representative of the computed velocities beneath each geophone. Figure 7 contains color contour maps of the surface and of the refractor. Elevations are relative to the beginning of Line 1. Note that the control for the color contour map is confined to the station locations (shown on the map) and in areas away from the control, the values are generated by the gridding and contouring program rather than being measured by hand leveling or seismic refraction methods.

CONCLUSIONS:
Geophysical anomalies consistent with the presence of subsurface metallic materials are mapped as items for investigation. A bedrock configuration is also mapped along the seismic refraction lines.

If we can answer any additional questions for you, please do not hesitate to contact us.

Sincerely,

David Butler
Chief Geophysicist



SCALE 1:24 000
Contour Interval = 20'

NOTES:

1) The map was derived from a USGS 7.5 minute topographic map titled Bondad Hill, Colorado, dated 1968.

2) Geophysical Survey Area. (approximate)

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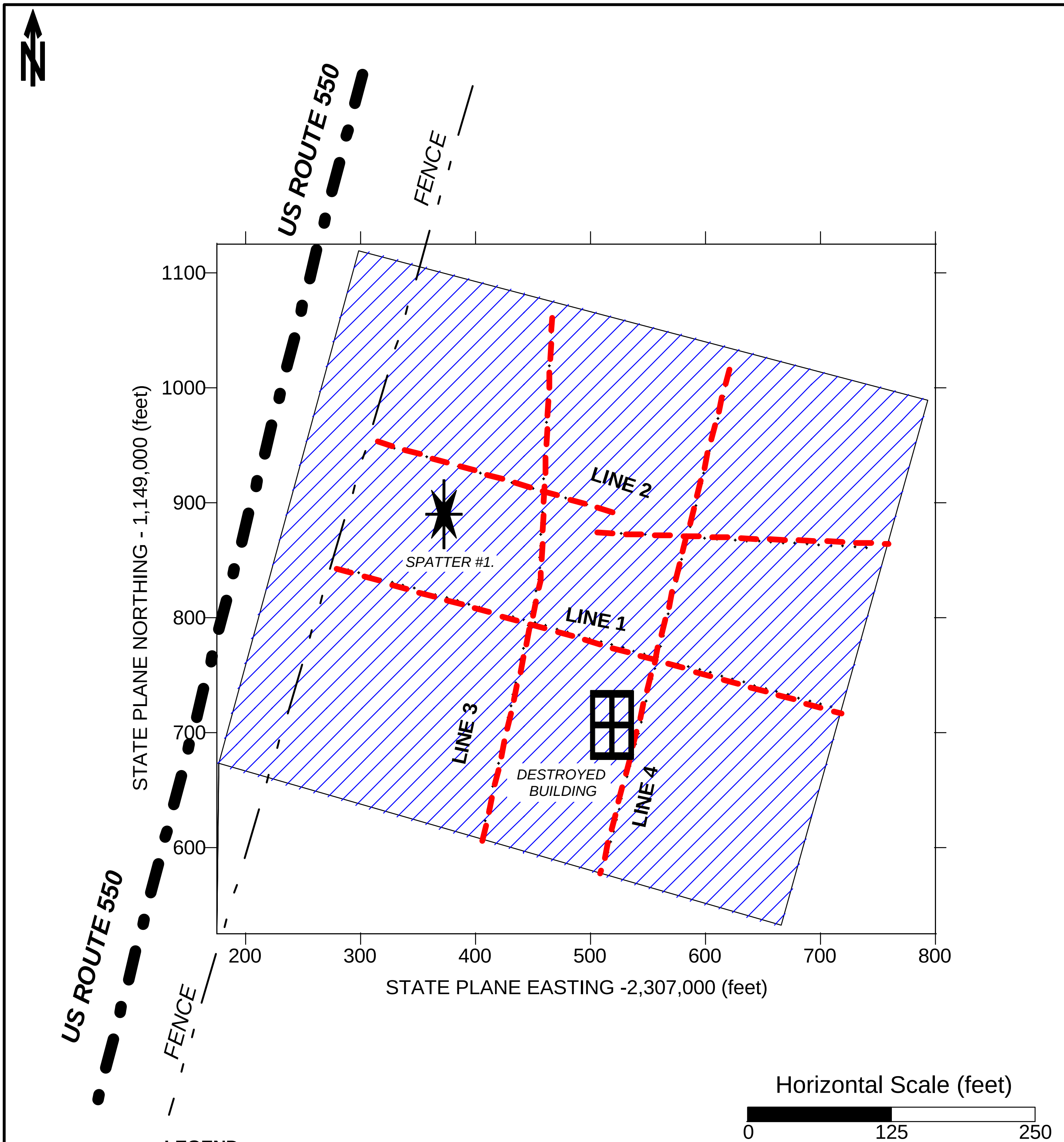
L T ENVIRONMENTAL, INC.
Denver, Colorado

BONDAD EXPLOSION SITE
Bondad, Colorado

SITE LOCATION MAP

GEOPHYSICS	MICROGEOPHYSICS CORPORATION WHEAT RIDGE, COLORADO	TECHNICAL APPROVAL	DAVID BUTLER
DRAWN	A.N. OMALEY	SUBMITTED	MARY ANN FORE
CHECKED	DAVID BUTLER	APPROVED	MARY ANN FORE

MAY, 2005	FIGURE 1



LEGEND:

EM31 AND MAGNETIC COVERAGE.

SEISMIC REFRACTION LINES.

NOTES:

1) Site locations derived from GPS measurements provided by L T Environmental.
2) Geographic coordinates converted to Colorado State Plane Coordinates (south zone) by Corpscon, an U.S. Corps of Engineers program.

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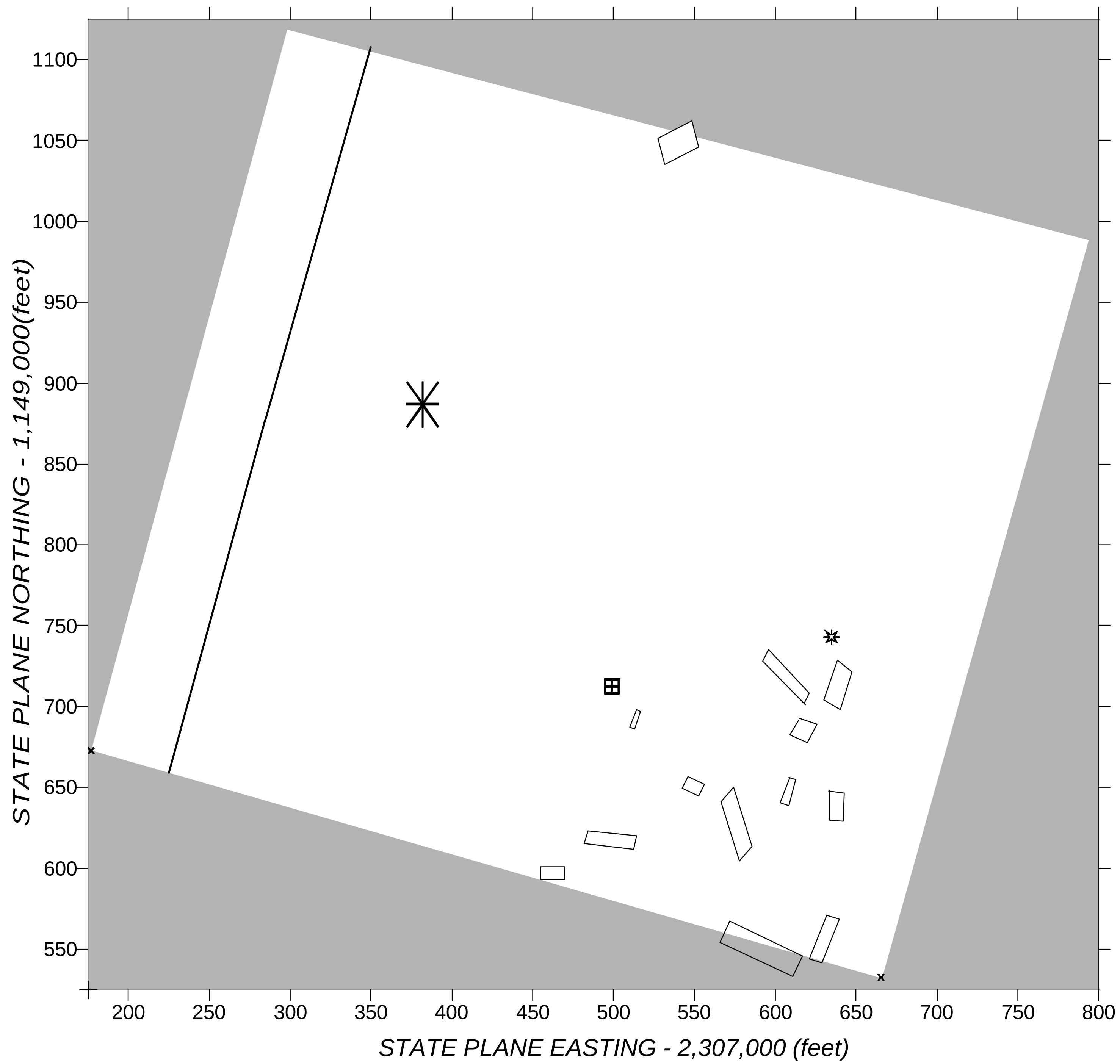
Denver, Colorado

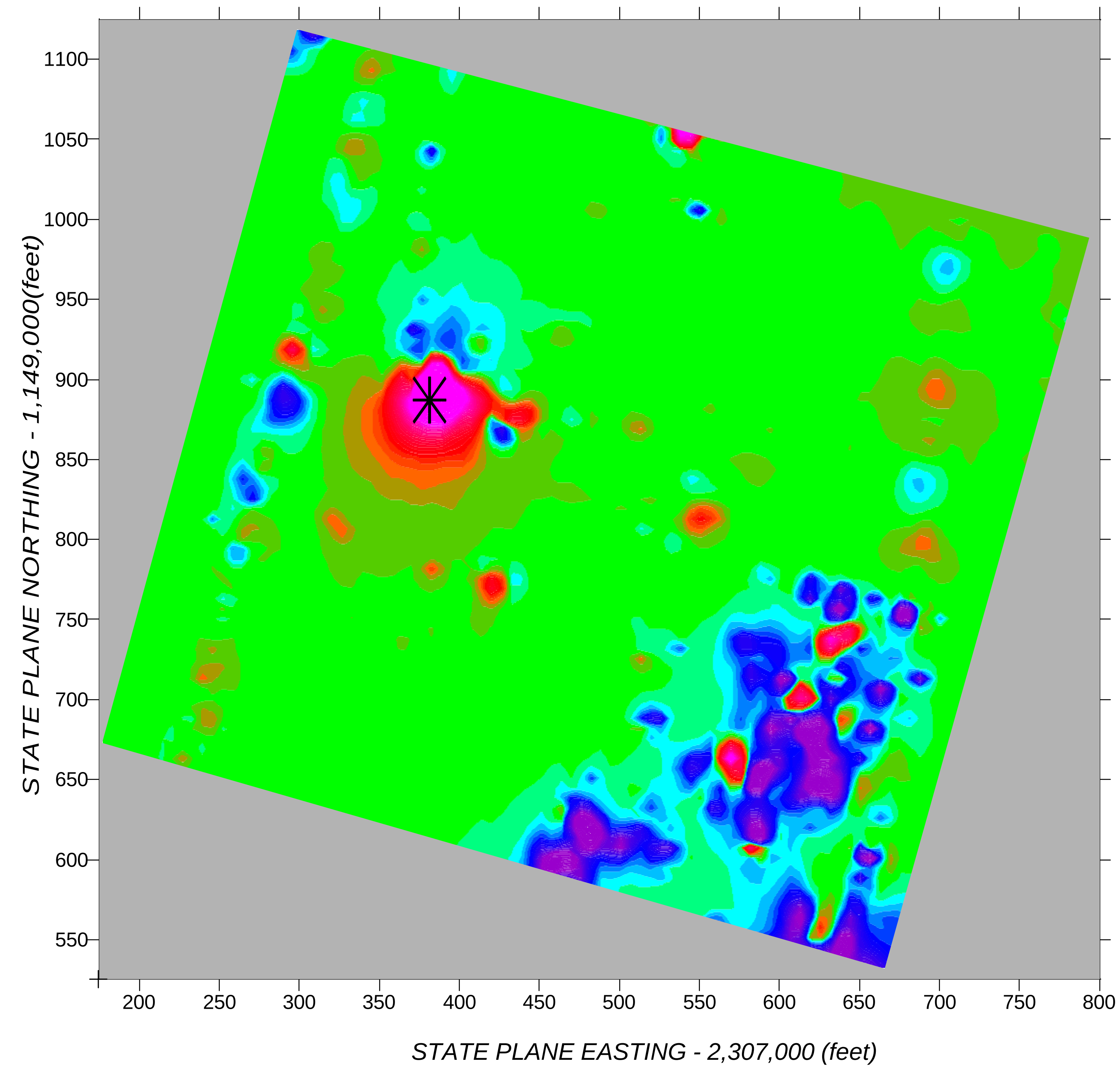
BONDAD EXPLOSION SITE
Bondad, Colorado

SITE MAP

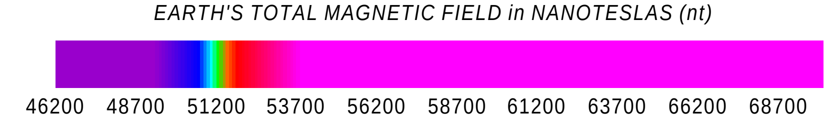
GEOPHYSICS	MICROGEOPHYSICS CORPORATION WHEAT RIDGE, COLORADO	TECHNICAL APPROVAL	DAVID BUTLER
DRAWN	AN. OMALEY	SUBMITTED	MARY ANN FORE
CHECKED	DAVID BUTLER	APPROVED	MARY ANN FORE

MAY, 2005 | FIGURE 2





EARTH'S TOTAL MAGNETIC FIELD in NANOTESLAS (nt)



LEGEND:

- DESTROYED RESIDENCE
- SPATTER # 1
- VEHICLE OR BUILDING
- VERTICAL PIPE
- LARGE CULVERT PIPE ON SURFACE
- FENCE AND MARKED GAS PIPELINE

NOTES:

1)Magnetic data acquired April 18-21, 2005, using a G858 magnetometer by Geometrics, Inc. Magnetometer operated five feet above surface. No base mag Nominal station spacing of two feet along lines spaced ten feet apart..
2) See Figure 1 for project location and Figure 2 for site map..
3) Surface culture located by MGC field crew using measuring tape. Grid locations by GPS locations furnished by L T Environmental, Inc.
5) Colors of contour map selected to emphasize anomalous areas.

HORIZONTAL SCALE (feet)

0 90 180

NORTH

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Denver, Colorado

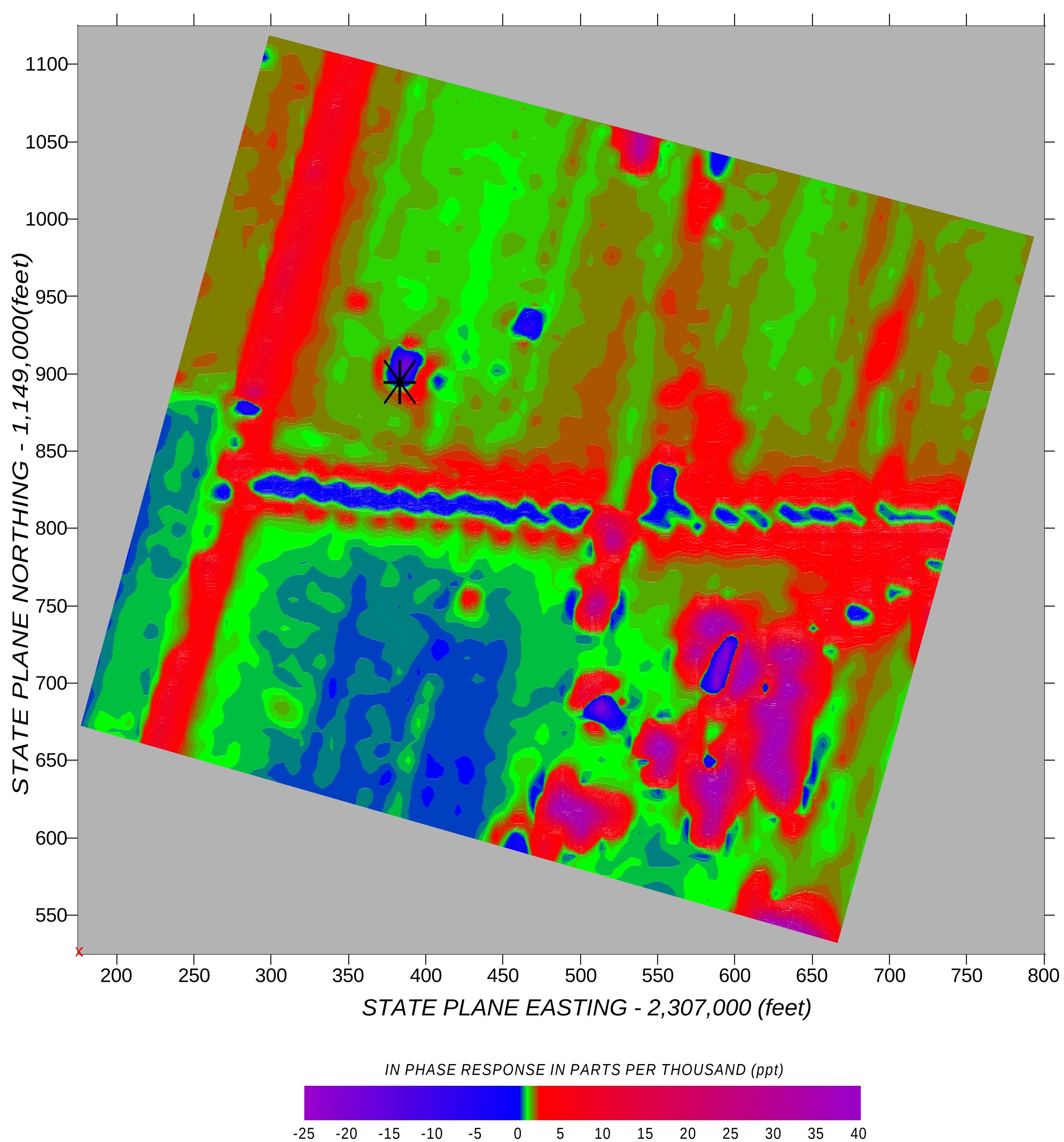
BONDAD EXPLOSION SITE
Bondad, Colorado

CULTURE AND MAGNETIC COLOR CONTOUR MAP

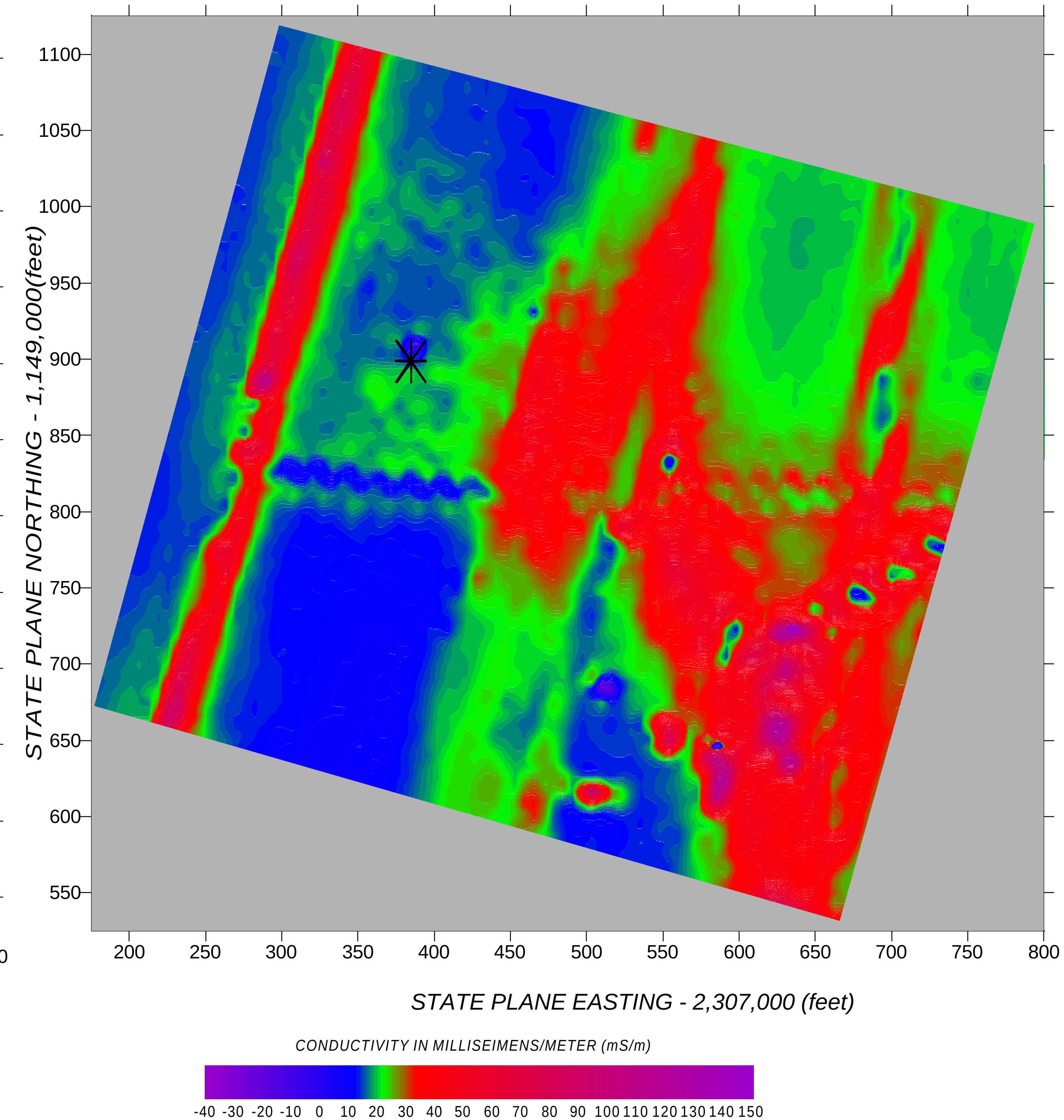
GEOPHYSICS: MICROGEOPHYSICS CORPORATION WHEAT RIDGE, COLORADO
TECHNICAL APPROVAL: DAVID BUTLER
DRAWN: AN. OMALEY
SUBMITTED:
CHECKED: DAVID BUTLER
APPROVED: MARY ANN FORE

MAY, 2005 | FIGURE 3

EM 31 INPHASE RESPONSE



EM 31 CONDUCTIVITY

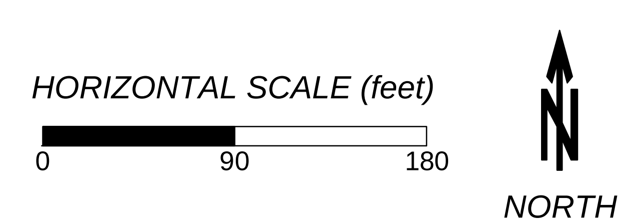


NOTES:

1)Electromagnetic data acquired April 18-21, 2005, using an EM31 by Geonics, Inc.
2) See Figure 1 for project location and Figure 2 for site map..
3) Grid locations by GPS locations furnished by L T Environmental, Inc.
5) Colors of contour maps selected to emphasize anomalous areas.

LEGEND:

✳ SPATTER # 1



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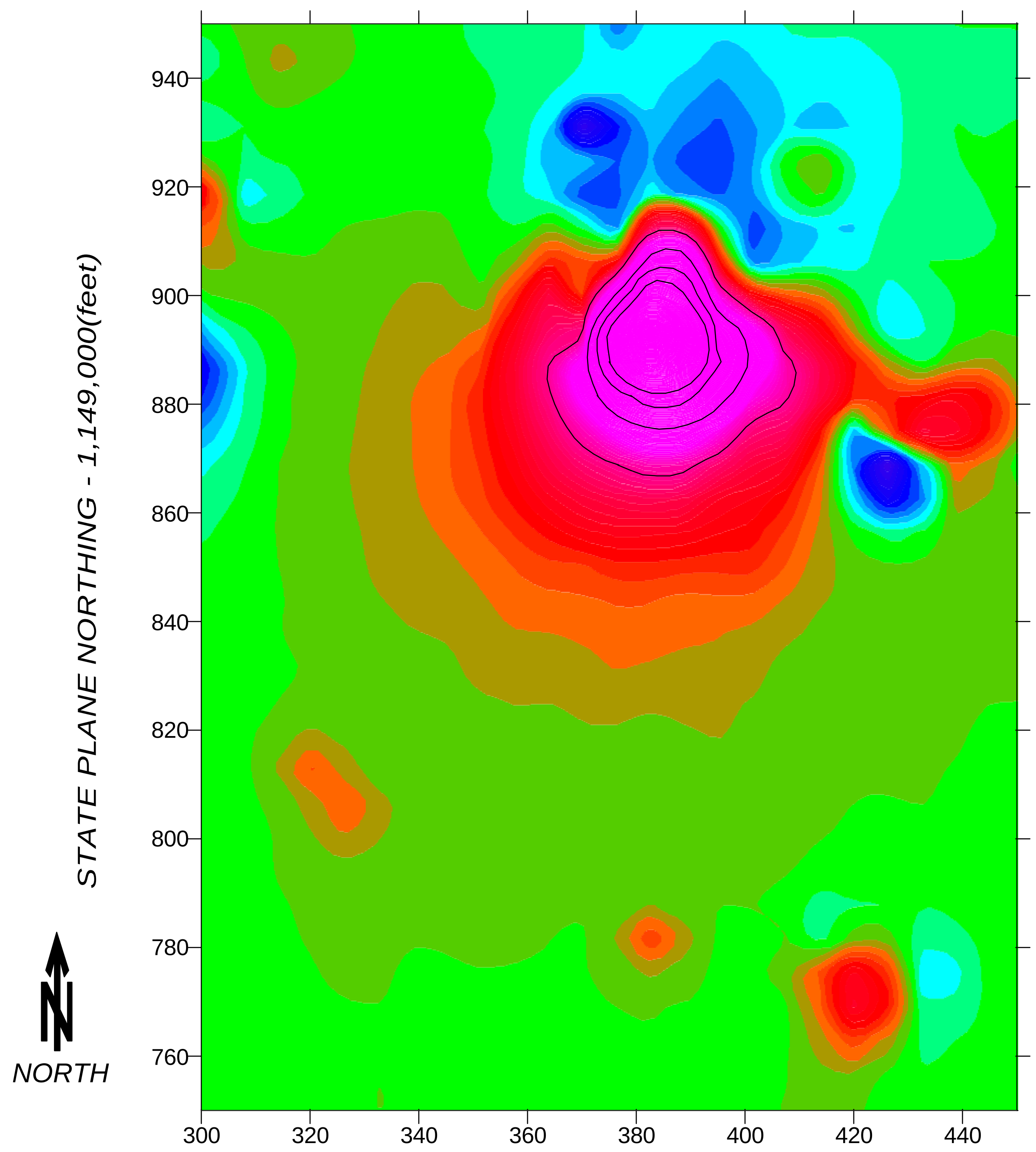
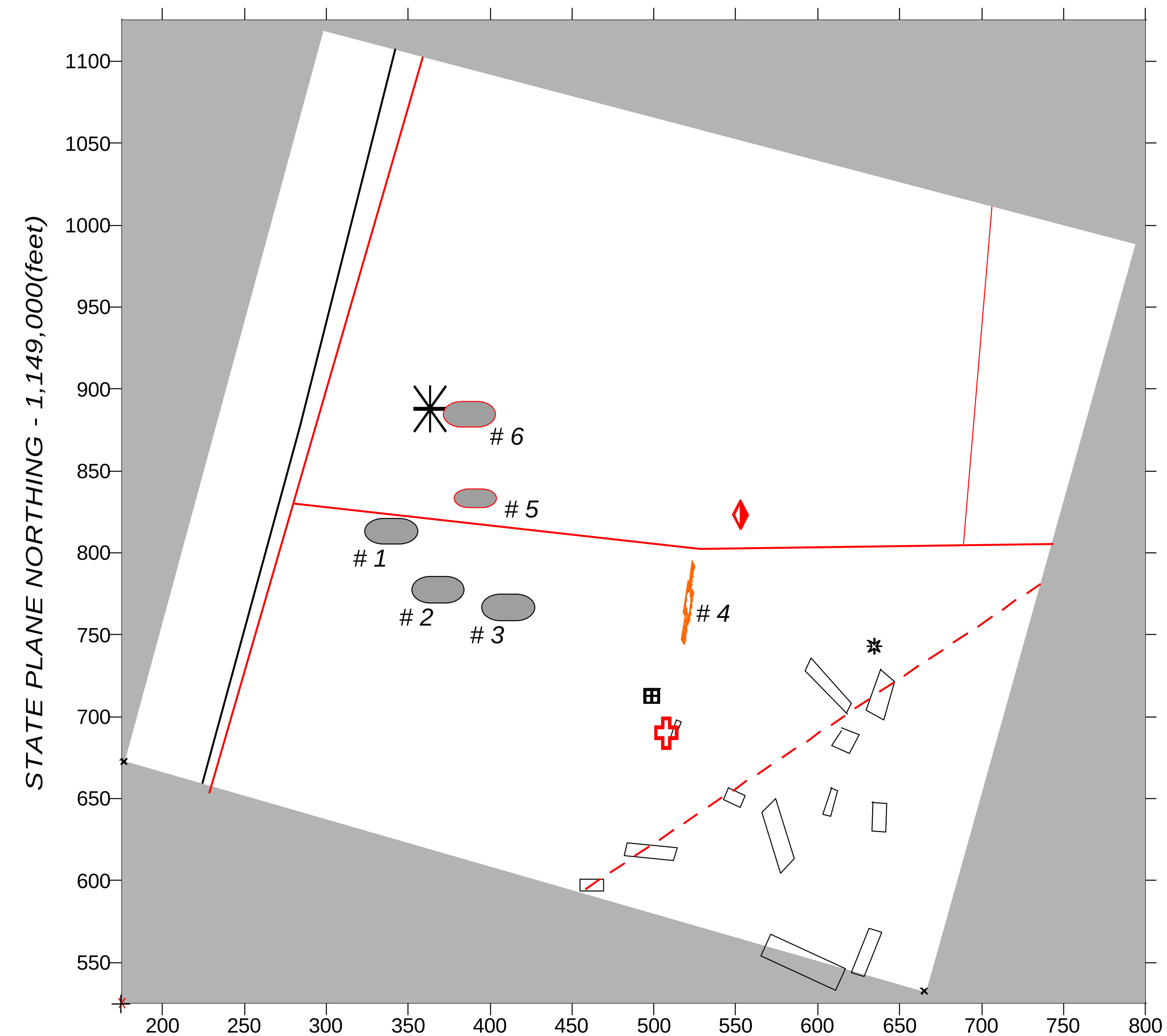
Denver, Colorado

BONDAD EXPLOSION SITE
Bondad, Colorado

ELECTROMAGNETIC COLOR CONTOUR MAPS

GEOPHYSICS	MICROGEOPHYSICS CORPORATION WHEAT RIDGE, COLORADO	TECHNICAL APPROVAL	DAVID BUTLER
DRAWN	AN. OMALEY	SUBMITTED	
CHECKED	DAVID BUTLER	APPROVED	MARY ANN FORE
MAY, 2005		FIGURE 4	





HORIZONTAL SCALE (feet)
0 30 60

TOTAL EARTH'S MAGNETIC FIELD in NANOTESLAS (nT)
46200 48700 51200 53700 56200 58700 61200 63700 66200 68700

HORIZONTAL SCALE (feet)
0 90 180

NOTES:

1)Magnetic data acquired April 18-21, 2005, using a G858 magnetometer by Geometrics, Inc. Detail map derived from magnetics map on Figure 3.
2) See Figure 1 for project location and Figure 2 for site map..
3) Grid locations by GPS locations furnished by L T Environmental, Inc.
4) Colors of contour map selected to emphasize anomalous areas. Magnetic contour lines for 53,000nT to 60,000nT at 2,000nT intervals shown on magnetic detail map. Normal earth's field about 51,200nT here.
5) EM61 anomalies located in reconnaissance mode.

LEGEND:

- SPATTER # 1
- MAGNETIC CONTOUR LINES
- ROAD CULVERT
- EM 61 ANOMALY (NEAR SURFACE)
- VEHICLE OR BUILDING
- POSSIBLE GAS OR SEWER LINE
- POSSIBLE SEPTIC TANK
- PROBABLE GAS LINE
- EM-ONLY ANOMALY
- DESTROYED RESIDENCE
- VERTICAL PIPE
- # 1 UNKNOWN ANOMALY WITH NUMBER

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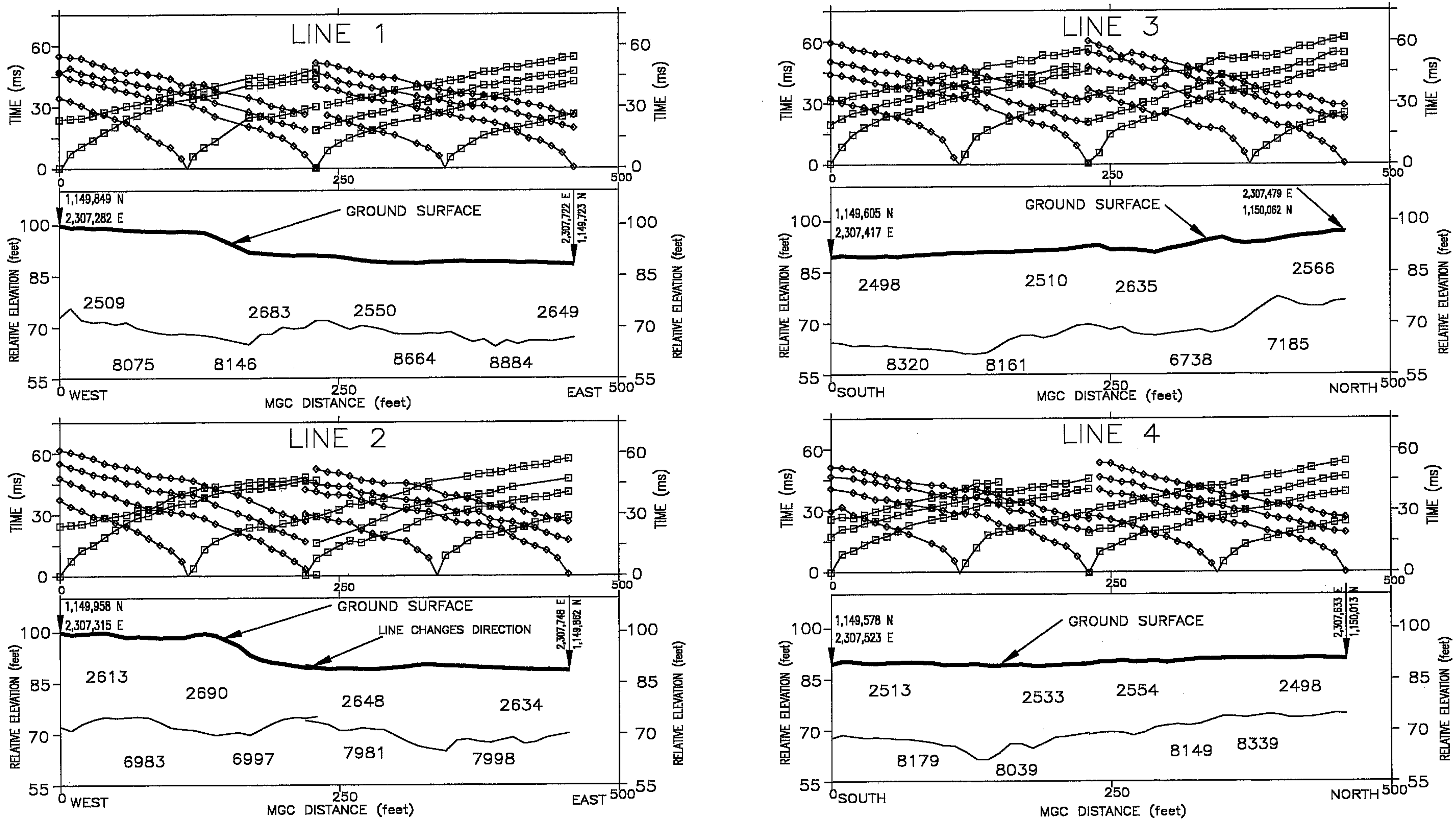
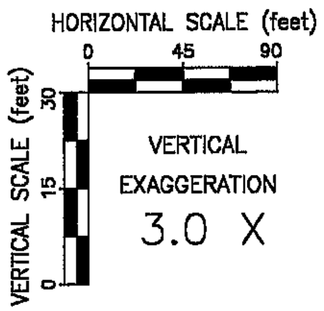
L T ENVIRONMENTAL, INC..
Denver, Colorado

BONDAD EXPLOSION SITE
Bondad, Colorado

MAGNETIC DETAIL AND INTERPRETATION MAP

GEOPHYSICS MICROGEOPHYSICS CORPORATION WHEAT RIDGE, COLORADO	TECHNICAL APPROVAL DAVID BUTLER
DRAWN AN. OMALEY	SUBMITTED
CHECKED DAVID BUTLER	APPROVED MARY ANN FORE
MAY, 2005	FIGURE 5

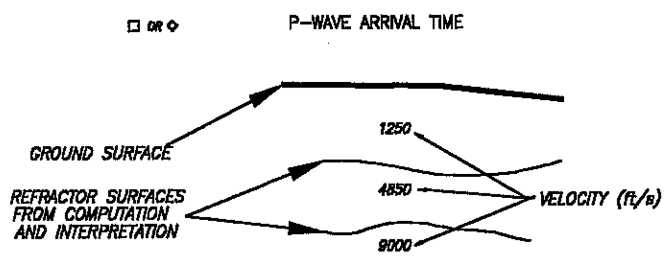




NOTES:

1) Seismic refraction data acquired by MGC on April 18–21, 2005.
2) See Figure 1 for project location and Figure 2 for line locations.
3) Elevations referenced to beginning of Lines 1 and 2.
4) Subsurface velocity variations may or may not correlate with geologic boundaries.

LEGEND:



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Denver, Colorado

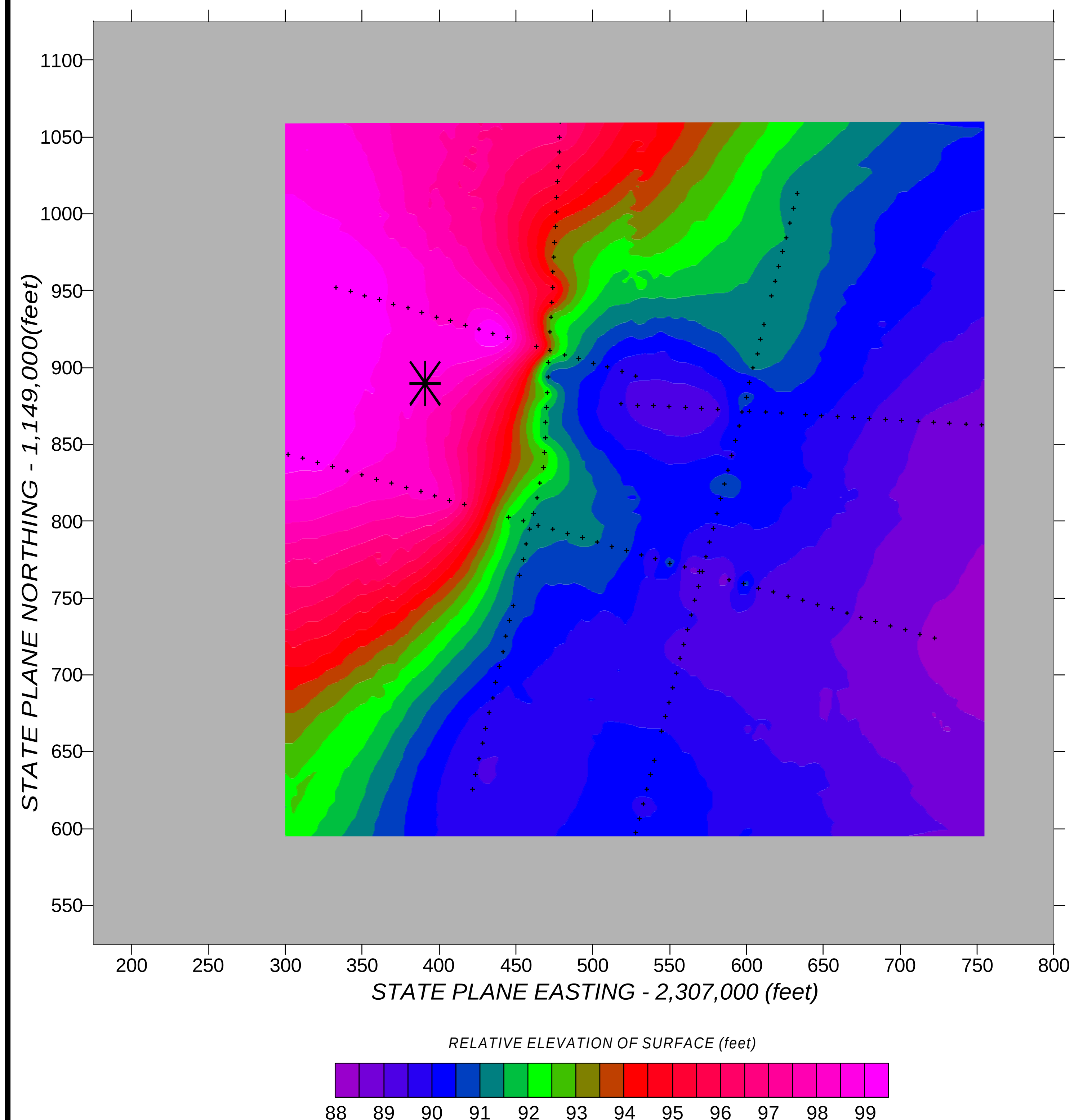
BONDAD EXPLOSION SITE
Bondad, Colorado

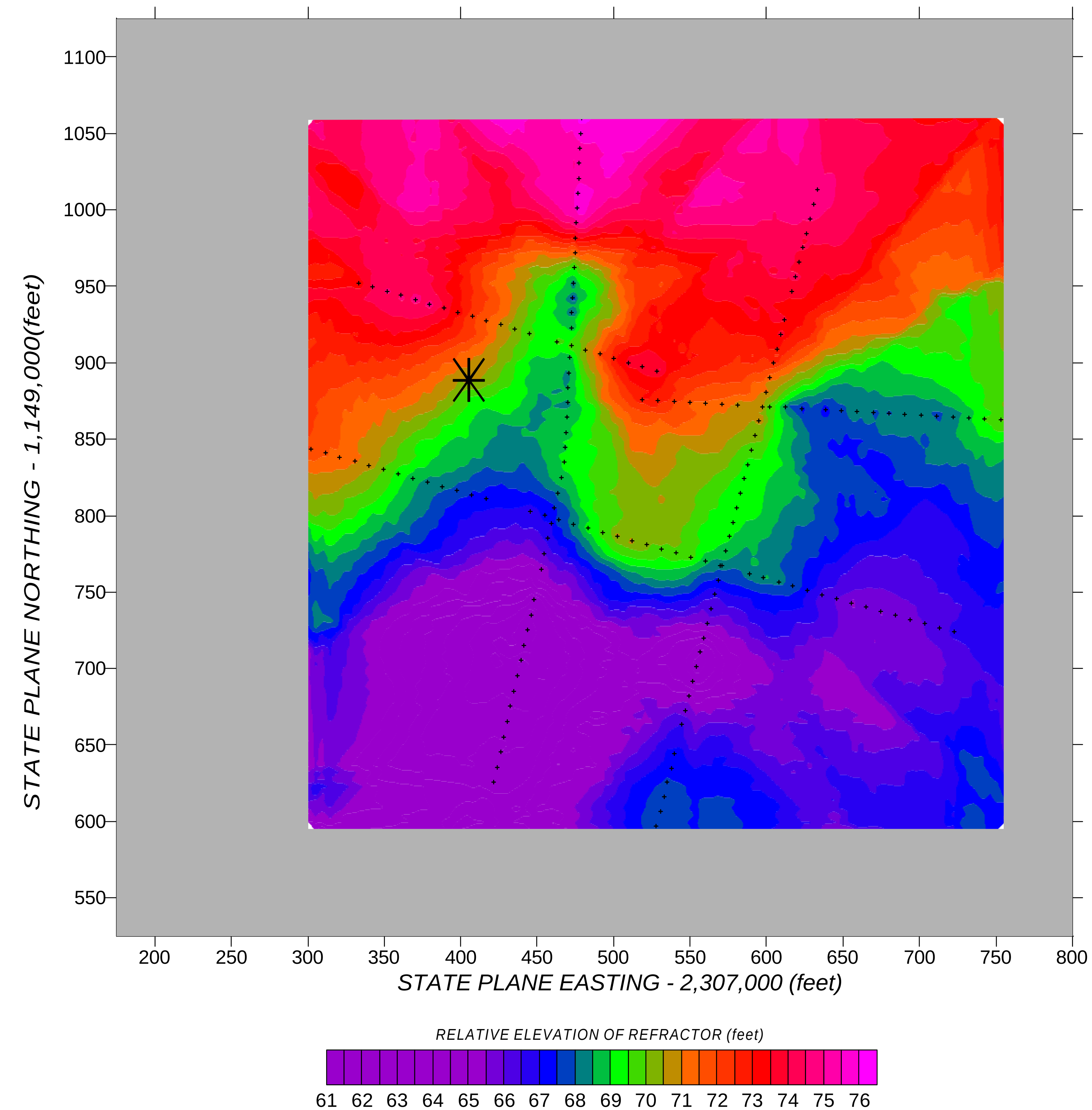
SEISMIC CROSS–SECTIONS

TRAVEL–TIME CURVES AND INTERPRETED REFRACTOR CROSS–SECTION

GEOPHYSICS MICROGEOPHYSICS CORPORATION WHEAT RIDGE, COLORADO APPROVED
DRAWN SUBMITTED
CHECKED FILE

DENVER, COLORADO MAY, 2005 FIGURE 6





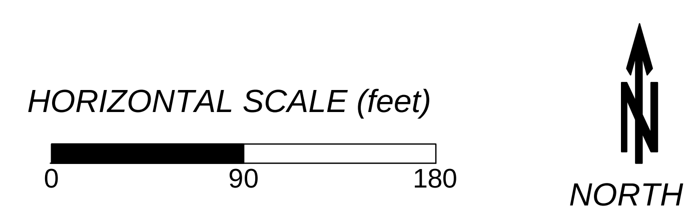
NOTES:

1)Seismic refraction data acquired April 18-21, 2005.
2) See Figure 1 for project location and Figure 2 for site map..
3) Grid locations by GPS locations furnished by L T Environmental, Inc. Elevations by hand level with respect to start of Line 1 and Line 2.
4) Colors of contour map selected to emphasize anomalous areas. Note that control of surface and refractor elevation is limited to geophone positions on seismic lines.

LEGEND:

✳ *SPATTER # 1*

\+ *GEOPHONE POSITION ON SEISMIC LINE*



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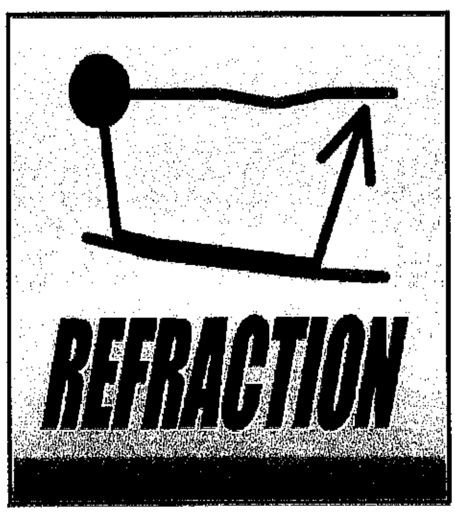
L T ENVIRONMENTAL, INC..
Denver, Colorado

BONDAD EXPLOSION SITE
Bondad, Colorado

SURFACE AND REFRACTOR RELATIVE ELEVATION COLOR CONTOUR MAPS

GEOPHYSICS	MICROGEOPHYSICS CORPORATION WHEAT RIDGE, COLORADO	TECHNICAL APPROVAL	DAVID BUTLER
DRAWN	AN. OMALEY	SUBMITTED	
CHECKED	DAVID BUTLER	APPROVED	MARY ANN FORE
MAY, 2005		FIGURE 7	

METHOD APPENDIX
SEISMIC REFRACTION TECHNIQUES



GENERAL SEISMIC REFRACTION TECHNIQUES

Refraction defines the subsurface in both velocity and structure. Because these two factors are intrinsically related their independent determination is ambiguous. Geologic knowledge reduces the affect of this ambiguity and the refraction method is generally useful in subsurface investigation. The method involves placing a line of sensors or geophones on the surface and measuring the relative arrival time of a seismic wave. Figure 1 is a schematic illustration of the method. The seismic source can be any well-timed sonic disturbance such as hammer blows or explosive charges. The relative arrivals are used to define a subsurface structure and/or velocity.

The critical ingredients of successful refraction profiling include accurate sensor location, timing of relative arrivals to precisions of less than a few milliseconds, and modeling or calculating the bedrock depths and velocities. The geophone locations are routinely level surveyed relative to the shot points to precisions of +/- 0.5 feet. Recording instrumentation utilized by MGC allows accurate timing of first arrivals to better than +/- 2 milliseconds.

The analysis procedure for seismic refraction data is illustrated in Figure 2. The first step in the analysis is to plot the arrival data in a travel-time curve. The seismograms are picked to obtain source-receiver travel times. These travel times along with

Source-receiver distances are utilized to construct a time-distance plot for each shotpoint. The velocities inferred from the travel time curves are apparent velocities, and not necessarily true velocities. True velocities are determined from arrival times from shotpoints at both ends of the sensor line during the modeling procedure. In addition, small variations of individual data points from a true "straight-line" velocity on the time distance curve can indicate either undulations of the subsurface structure or lateral velocity changes. All information obtained from the time-distance plots is used as a basis for further modeling. In some instances shot coupling is not optimum, or sufficient cultural noise is present to make picking of arrival times inaccurate. As a result, some of the stations or shot arrivals may not be used in this analysis.

The refraction method can be implemented with either compressional (P) or shear (S) waves. Obtaining velocity information from both wave types allows the estimation of material properties such as Poisson's ratio.

For S-wave refraction, the geophones sensitive to horizontal ground motion are used and a source which generates ground motion perpendicular to the line of sensors and parallel to the ground surface is used. The geophones are planted with their sensitive axis oriented parallel to the source-motion direction.

An S-wave source often used is a thick plank laid on the ground and weighted with a vehicle to couple it to the ground. The plank is oriented perpendicular to the line and struck with a hammer to produce S-waves with particle motion parallel to the axis of the geophones. One unique feature of S-wave refraction is that the source has a polarity - either end of the plank can be struck. By recording S-waves with both polarities a simple data processing technique (subtraction) can be used to enhance the S-wave signal and diminish the P-wave noise generated by the source.

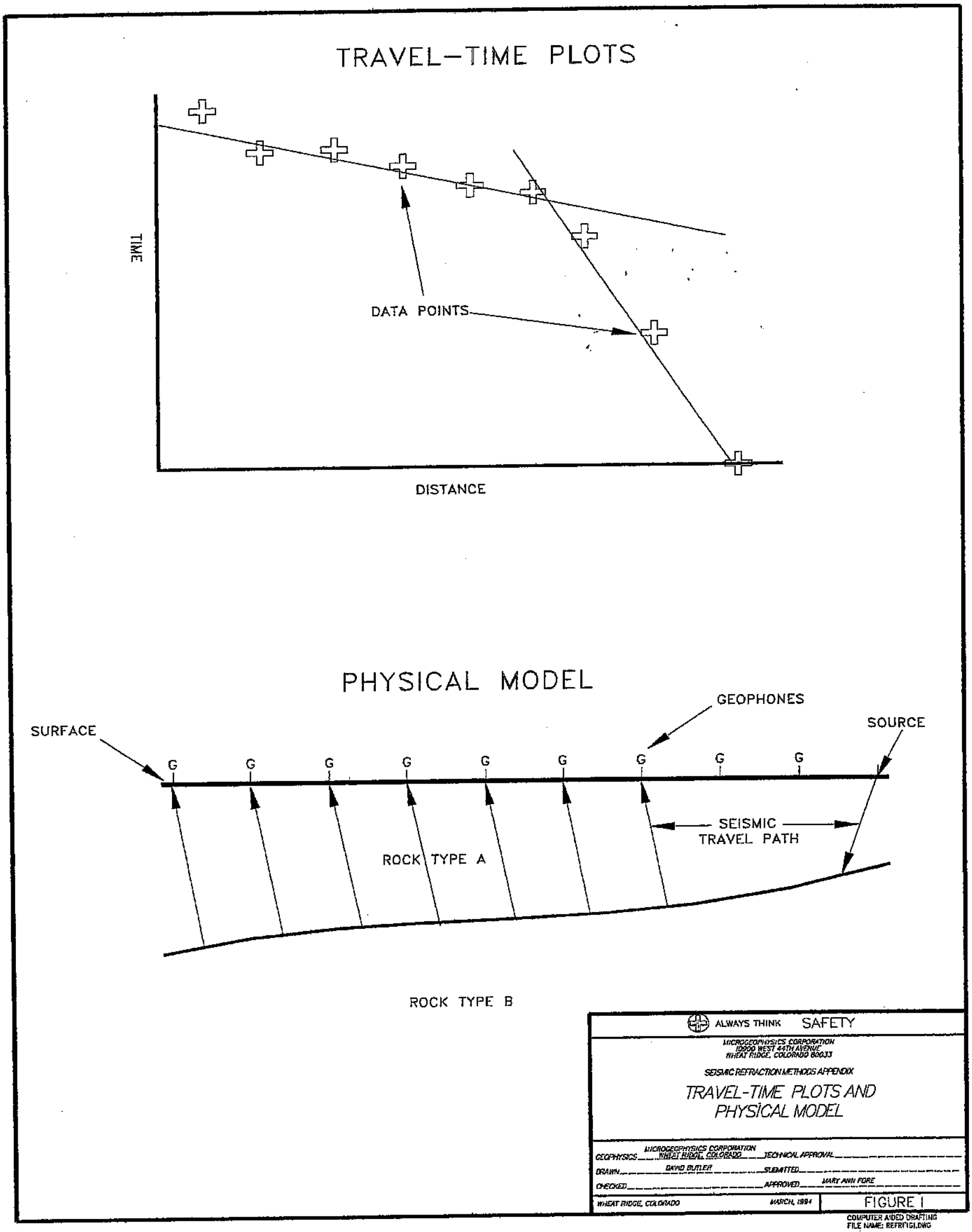
ADDITIONAL CONSIDERATIONS

Because the two factors of velocity and structure are intrinsically related in refraction theory, their independent determination from refraction surveying alone is impossible. The ambiguity is that structure can be traded for velocity differences over a broad range of velocity-structure pairs.

Additionally, modeling ambiguity can be introduced due to the existence of low-velocity layers. Because there is no refracted information from a buried layer with a velocity less than that of the overlying material, the low-velocity layer will be hidden in the arrival time data. When this situation occurs, calculated depths to deeper refractors can be offset and in error. Boreholes, downhole logs, and geologic information are critical to limiting the range of these uncertainties.

One additional physical principle applies when considering low-velocity zones - Fermat's principle. Fermat stated that the energy will take the least-time path from one point to the next. This principle is the basis for seismic refraction, but it also means that the first arrival energy will "go around" a low velocity zone. Unless the geometry is favorable (no high velocity path possible) the first arrival information will not reveal a low velocity area.

One should not be discouraged by these potential pitfalls. When accurate subsurface ties to borings and good estimates of the probable geology are available, these problems are minimized and an accurate subsurface map is produced.


TRAVEL-TIME PLOTS
TIME
DATA POINTS
DISTANCE
PHYSICAL MODEL
GEOPHONES
SURFACE
SOURCE
G
SEISMIC TRAVEL PATH
ROCK TYPE A
ROCK TYPE B
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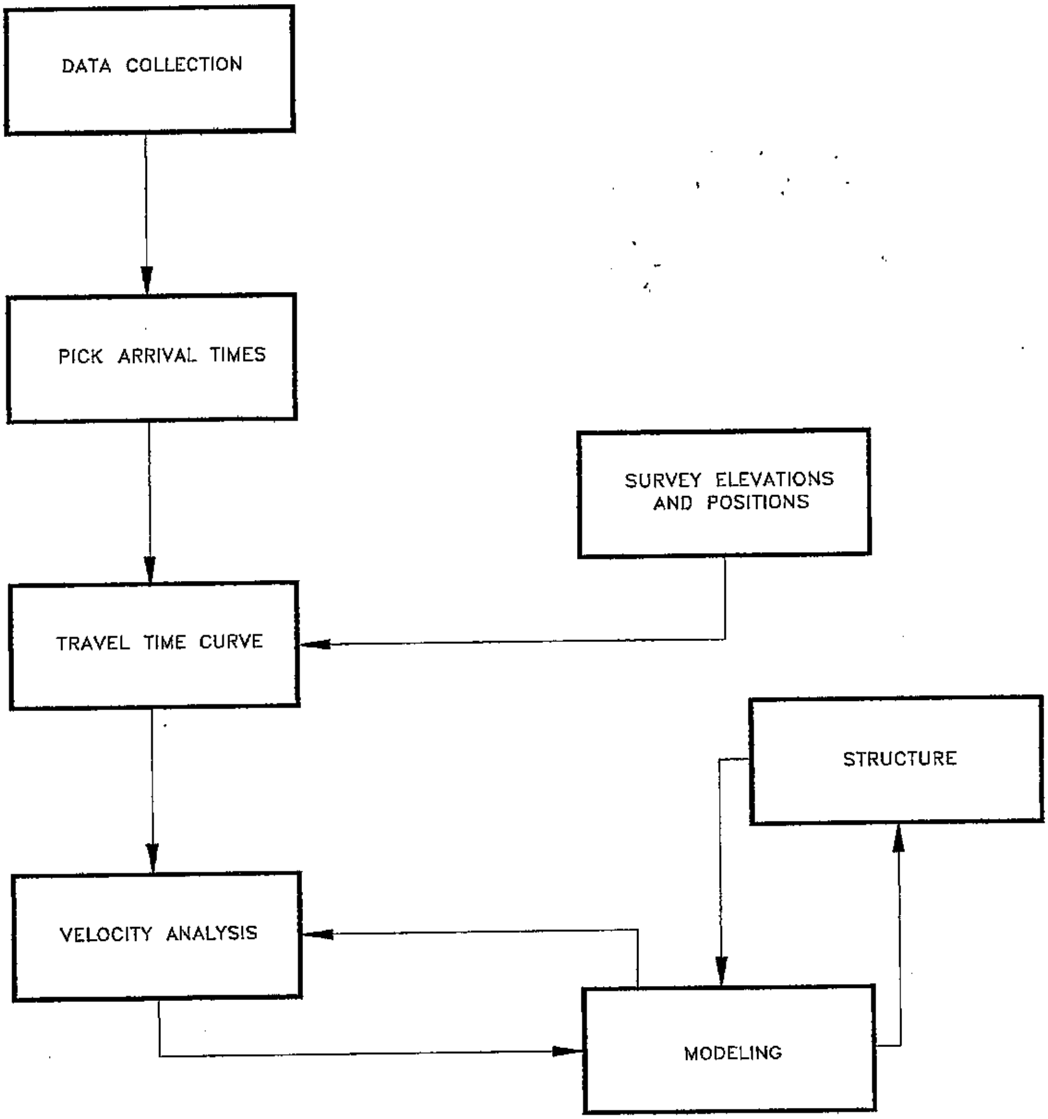
SEISMIC REFRACTION METHODS APPENDIX
TRAVEL-TIME PLOTS AND PHYSICAL MODEL
GEOPHYSICS MICROGEOPHYSICS CORPORATION WHEAT RIDGE, COLORADO
TECHNICAL APPROVAL
DRAWN DAVID BUTLER
SUBMITTED
CHECKED
APPROVED MARY ANN FORE
WHEAT RIDGE, COLORADO
MARCH, 1994
FIGURE 1
COMPUTER AIDED DRAFTING
FILE NAME: REFRFIG1.DWG



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SEISMIC REFRACTION METHODS APPENDIX

DATA COLLECTION AND PROCESSING FLOW CHART

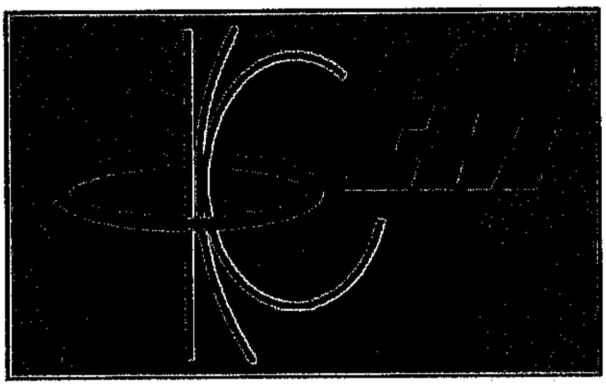
GEOPHYSICS: MICROGEOPHYSICS CORPORATION, WHEAT RIDGE, COLORADO — TECHNICAL APPROVAL:
DRAWN: DAVID BUTLER — SUBMITTED:
CHECKED: — APPROVED: MARY ANN FORE

WHEAT RIDGE, COLORADO — MARCH, 1994 — FIGURE 2

COMPUTER AIDED DRAFTING
FILE NAME: REFRFIG2.DWG

METHOD APPENDIX

ELECTROMAGNETIC METHODS



NOTE: This method appendix is furnished as background for those unfamiliar with electromagnetic methods. The EM-31 and EM-34 operate similarly. The EM-61 is specifically described in the latter part of this appendix.

ELECTROMAGNETICS

INTRODUCTION

With frequency-domain electromagnetic methods, the source most commonly consists of a closed loop of wire in which alternating current flows. Electric current in the transmitter loop generates a magnetic field. The magnetic field is the energizer in electromagnetic methods as compared with electric current in direct current methods. This magnetic field penetrates the earth and is coupled to the earth materials and any conductors present. Secondary fields are generated due to the mutual coupling between the primary fields and whatever is present in the subsurface. These secondary field are recorded along with the primary field by a receiver loop sensitive to magnetic fields. The nature of the secondary fields, in certain simple geometries, can be related to earth structure.

Tens of different electromagnetic techniques have been applied in geophysics. This discussion will focus on inductive frequency- domain electromagnetic techniques, specifically terrain conductivity. The terrain conductivity techniques differ from most other EM techniques in that:

1. The operating frequency is low enough at each of the intercoil spacings that the electrical skin depth in the ground is always significantly greater than the intercoil spacing. (low induction numbers).

2. Soundings are done by varying the coil spacing or orientation rather than the frequency. If the frequency is varied significantly, the conditions in 1) are not satisfied.

3. The quadrature phase component is directly proportional to the bulk conductivity of the material in the vicinity of the two coils.

Time domain instruments operate on the same physical principles as the frequency domain instruments. They form a powerful magnetic field within the earth which couples very well with any conductors present. When the field is turned off, the eddy currents persist within the conductors, leading to a detectable magnetic signal at time windows late with respect to the off time of the primary pulse. If the behavior of the signal near the off time is recorded in detail, the electrical properties of nearby earth materials can be discerned. If both early and late time information is recorded, both general earth properties (early times) and nearby conductors (late times) can be detected.

Time domain instruments are often focused on "anomaly detection" and are sometimes labeled as metal detectors such as the EM-61.

Electromagnetic measurements allow a rapid determination of the average conductivity of the ground because they do not require electrical contact with the ground like direct current methods such as dipole-dipole and Schlumberger soundings. The disadvantage is that unless all three intercoil spacings (as in the case of Geonics EM-34) at both coil geometries (a total of six measurements) are taken at a location, minimal vertical sounding information is obtained. If geology to the depth being explored is fairly homogeneous or slowly varying, then the lack of information about vertical variations is not a problem.

The EM-34 consists of two 1-meter area coils operated at a separation of 10, 20, or 40 meters in a horizontal axis co-planer orientation or a vertical axis co-planer orientation. An audio frequency excitation is output by the transmitter coil and recorded by the receiver coil. The time-varying magnetic field arising from the alternating current in the transmitter coil induces very small currents in the earth. These currents generate a secondary magnetic field H_s which is sensed, together with the primary field H_p, by the receiver coil. In general this secondary magnetic field is a complicated function of the intercoil spacing, s, the operating frequency, f, and the ground conductivity, c. Under certain constraints, technically defined as "operation at low values of induction number", the secondary magnetic field is a very simple function of these variables. These constraints are incorporated in the design of the instrument allowing the secondary magnetic field to be calculated as

$$H_s/H_p = icwu_0s^2/4$$

where H_s = secondary magnetic field at the receiver coil
H_p = primary magnetic field at the receiver coil
w = 6.28 f
f = frequency in Hz
u_0 = permeability of free space
c = ground conductivity in Siemens per meter or mho per meter
(milliSiemens are the common unit,1/1000 of a Siemen)
s = intercoil spacing in meters
$i = (-1)^{1/2}$

The ratio of the secondary to the primary magnetic field is now linearly proportional to the terrain conductivity, a fact which makes it possible to construct a direct reading, linear terrain conductivity meter by simply measuring this ratio. Given H_s/H_p the apparent conductivity indicated by the instrument is defined as

$$c_a = 4\ (H_s/H_p)\ /\ (wu_0s^2)$$

The results, including phase information sent from the transmitter to the receiver by a connecting wire are converted by the receiver box into a terrain conductivity in milliSiemens/meter. The inphase portion of the signal is nulled by varying the coil spacing, a convenient method of assuring consistent geometry. Thus the inphase value is not available as an independent parameter when using the EM-34. The conductivity value derived represents an average of the resistivity of the surrounding earth materials to a depth of approximately one-quarter to one-half of the coil spacing and laterally to an equal degree. The EM-31 has a fixed coil spacing and both the conductivity and the inphase readings can be recorded.

Figure EM1 shows the cumulative response curves for both vertical coplanar transmitter/receiver dipoles and horizontal coplanar dipoles. These curves show the relative contribution to the secondary magnetic field or apparent conductivity from all material below a given depth. As an example, this figure shows that for vertical coplanar dipoles all material below a depth of two intercoil spacings yields a relative contribution of approximately 0.25 (i.e. 25%) to the response, i.e. the conductivity measurement, at the receiver coil. A comparison of the two curves on Figure EM1 illustrates that the vertical dipole mode of operation has approximately twice the effective exploration depth of the horizontal dipole mode. The most significant result of analysis of the curves is the near-surface differences. Note that the vertical dipole mode is considerably less sensitive to near-surface material than the horizontal dipole mode.

If the geology is very heterogeneous, then the "average" value obtained may be very misleading. Other complicating items include but are not limited to: dipping beds, nearby metallic objects, and topographic effects. To illustrate the reasons for these complications, Figures EM-2 and EM-3 were prepared. The primary magnetic field, H_p, is generated by the transmitter loop. This primary field is received by the receiver loop and the amount of field detected generally depends on the nature of the material near and under both loops. The figures show the qualitative effect of a conductive body on these fields. Secondary fields, H_s, are generated within the conductor and link into the receiver but with opposite sign when the conductor is between the two loops as shown in Figure EM-3. Note that in figure EM-2 that when the conductor is beyond the end of the loops, the secondary fields add to the primary and the apparent response of the earth is enhanced. This simplified version of the effects does not account for the way that the presence of a conductor has varying effects on the inphase and quadrature components of the received fields. The presence of a conductor obviously can cause the assumptions inherent in the conversion of quadrature phase to conductivity to be in error and greatly complicate the quantitative interpretation of terrain conductivity data. Near conductive bodies which are of size and depth comparable to the coil spacings, the terrain conductivity and inphase measurements may be erratic. In this case, the technique becomes an "anomaly finder" and the recorded values have relative meaning only.

REFERENCE

McNeill, J.D., 1980, Electromagnetic Terrain Conductivity Measurement at Low Induction Numbers: Technical Note TN-6, Geonics Limited.

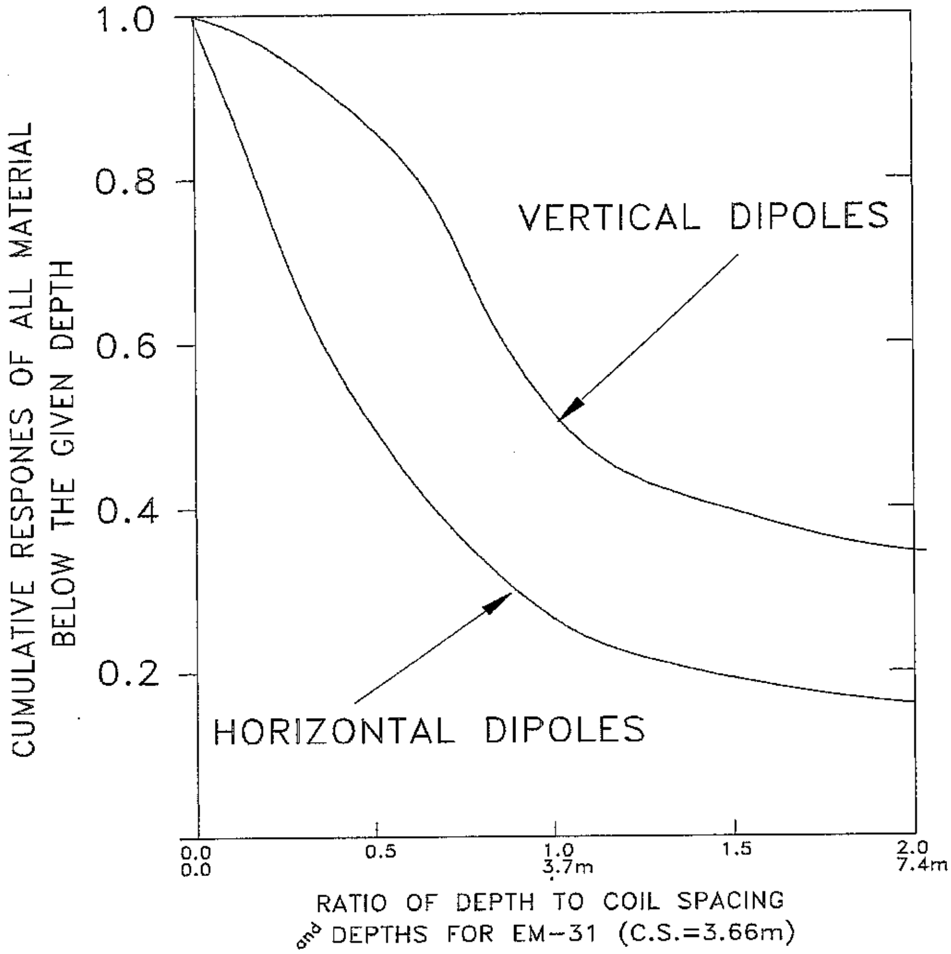
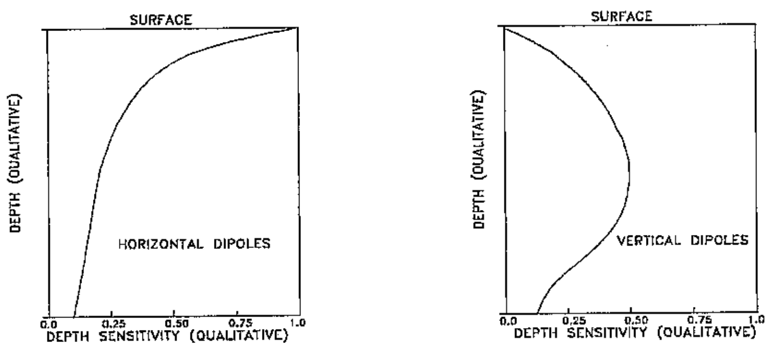


FIGURE EM-1



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ELECTROMAGNETICS METHODS APPENDIX

ELECTROMAGNETIC RESPONSE DIAGRAMS

CUMULATIVE RESPONSE CURVES, EM-I
QUALITATIVE DEPTH SENSITIVITY CURVES

GEOPHYSICS: MICROGEOPHYSICS CORPORATION, WHEAT RIDGE, COLORADO — TECHNICAL APPROVAL: ____
DRAWN: DAVID BUTLER — SUBMITTED: ____
CHECKED: ____ — APPROVED: MARY ANN FORE

WHEAT RIDGE, COLORADO — MARCH, 1994 — FIGURE EM-I

COMPUTER AIDED DRAFTING
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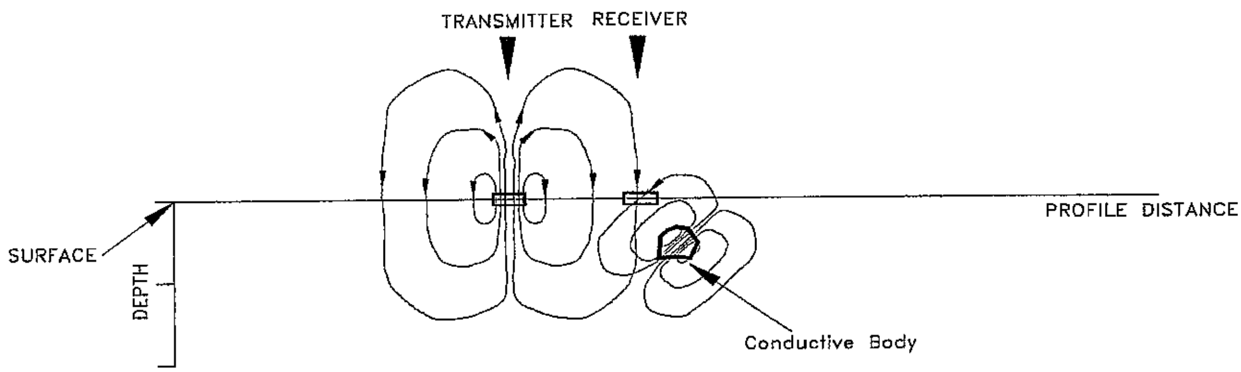

FIGURE EM-2

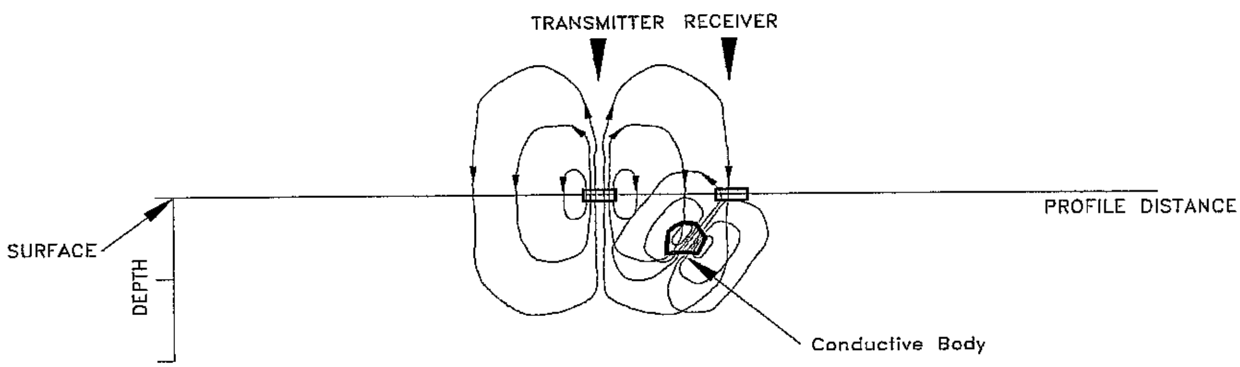

FIGURE EM-3

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ELECTROMAGNETICS METHODS APPENDIX

ELECTROMAGNETIC FIELD DIAGRAMS
CONDUCTIVITY BODY EXAMPLE, EM-2
CONDUCTIVITY BODY EXAMPLE, EM-3

GEOPHYSICS: MICROGEOPHYSICS CORPORATION WHEAT RIDGE, COLORADO	TECHNICAL APPROVAL
DRAWN: DAVID BUTLER	SUBMITTED
CHECKED	APPROVED: MARY ANN FORE
WHEAT RIDGE, COLORADO — MARCH, 1994	FIGURE EM-2,3

COMPUTER AIDED DRAFTING
FILE NAME: EM-2

EM-61 HIGH SENSITIVITY METAL DETECTOR

INTRODUCTION

The Geonics EM-61 is a high-sensitivity high-resolution time-domain metal detector which is used to detect both ferrous and non-ferrous metallic objects. It consists of a powerful transmitter that generates a pulsed primary magnetic field, which induces eddy currents in nearby metallic objects. The decay of these currents is measured by two receiver coils mounted on the coil assembly. The responses are recorded and displayed by an integrated data logger as two channels of information. For further processing and interpretation data can be transferred to PC computer.

The EM-61 detects a single 200 liter (55 gal) drum at a depth of over 3 meters beneath the instrument, yet it is relatively insensitive to interference from nearby surface metal such as fences, buildings, cars, etc. By making the measurement at a relatively long time after termination of the primary pulse, the response is practically independent of the electrical conductivity of the ground.

Due to its unique coil arrangement, the response curve is a single well defined positive peak, greatly facilitating quick and accurate location of the target. The depth of the target can be estimated from the width of the response and/or from relative response from each of the two receiver coils.

The EM-61 consists of three major parts: coil assembly, backpack with battery and processing electronics and digital data recorder.

EM-61 Interpretation

The EM-61 is designed in such a way that it is possible not only to separate anomalies spatially but it is also possible under some conditions, to distinguish deeper targets from shallow ones. In addition, the unique two receiver coil system allows suppression of near surface targets that may mask response from deeper more important ones. This feature is very useful when the purpose of the survey is to locate deeper targets, like underground storage tanks or drums, in presence of shallow near surface metallic objects (manhole covers or metal scrap).

Because the amplitude of response is highly depended on the distance between the coil assembly and target, small near surface anomalies will very often produce a response orders of magnitude larger than much bigger but deeper targets. This masking effect from near surface material is drastically reduced by using output of two coils and processing them in the differential mode. In this case output from channel 1 is subtracted from channel 2. Channel 1 represents data from top receiver coil, whereas channel 2 is data from coil closer to the ground. The calculation is automatically performed by EM-61 DAt61 computer program.

The most common way of interpretation of EM-61 data is by using channel 2 and difference channel data.

The difference channel is calculated in the following way:

$$D = k*CH1 - CH2$$

Where: D is differential output in mV

CH1 is output from top coil in mV
CH2 is output from bottom coil in mV
k is depth coefficient normally set to 1

It is possible to vary k, and adjust the depth at which the response will be suppressed the most. If k is selected to be 1, the response from targets right below the surface will be reduced the most. If the coefficient k is made smaller than 1, the deeper target will be suppressed more than shallow targets. In this case surface anomalies will have negative response in the difference channel.

It should be noted that the degree of cancellation will be affected by size, shape and depth of targets. The response from the targets shaped like balls, spheres or small plate-like targets parallel with the ground can be reduced more than response from larger 3- dimensional targets.

Note that the negative values on the differential channel map are often associated with the metallic objects located on the surface, assuming that the depth coefficient of 1 is used (normal practice).

Calculation of Apparent Depth of Target

The user can estimate an approximate depth (apparent depth) of a target. This parameter is calculated on the basis of ratio of amplitude from channel 1 and channel 2 response. The apparent depth estimation is most accurate when the instrument is positioned over the center of buried target. (an additional reason from choosing the spacing between the survey lines). In order to determine position of an anomaly, the peak response of the channel 2 profile should be examined along the survey line as well as on the neighboring survey lines. By comparing responses of nearby lines and selecting anomaly maximum, it is normally easy to locate the position of the target. The apparent depth is determined at the highest point of the anomaly.

It should be noted that the calculation of depth is an approximation. The accuracy of estimation will depend on the relation between the line (station) and center of the target, the size and shape of target, as well as the quality of data.

Depth estimation for the small ball-shaped targets will be more accurate that the estimate for larger targets (like underground storage tanks or pipes). Depth for the larger targets will be normally overestimated, meaning that the anomaly will appear deeper than it actually is.

In order to improve depth estimation accuracy, especially for deeper targets with low response, it may be necessary to remove a small offset from the readings. Although each instrument prior to leaving the factory, has outputs of both channels adjusted to read zero, it is possible that with time a small offset of several millivolts appears at the output(s). This effect could be recognized as a small non-zero shift in readings over the portion of the survey line that has no visible anomaly response.

Surface Metal Discrimination

The EM-61 has another very useful feature. For surveys carried out in areas where there is a large amount of near surface metal, a second coil is utilized. The design of this coil is such that this near surface metal response can be made virtually zero, greatly facilitating the detection of deeper targets such as buried drums. Conversely, it is also possible, using the coil, to make the response from near surface metal to have one polarity, while that from deeper metal (the actual depth can be adjusted) is of opposite polarity, so that distinguishing between the two is rendered very simple.

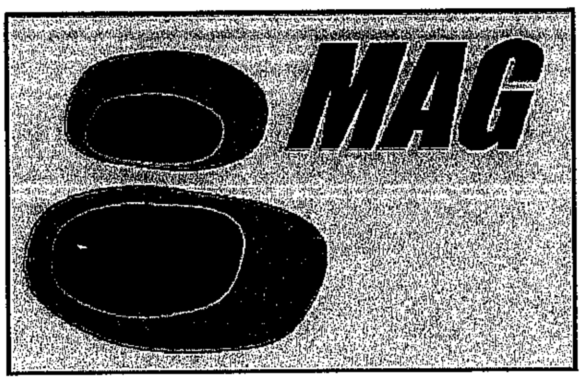
The interpretation of EM-61 data is often qualitative as the metal detector is an excellent "anomaly finder".

Technical Specifications - EM-61

Measured Quantity:	Two channels of secondary response in mV
EM Source:	Air cored coil, 1 x 1 m size
Current Waveform:	Bipolar rectangular current with 50% duty cycle
EM Sensors:	A) Main: Air-cored coil, 1 x 1 m in size, coincident with EM source B) Focusing Air-cored coil, 1 x 1 m in size 40 cm above main coil
Maximum Output:	40,000 mV for low gain 10,000 mV for high gain
Dynamic Range:	18 bits
Display:	4-line LCD with 16 characters per line
Data Storage:	Solid-state memory for up to 20,364 records
Power Supply:	12 V rechargeable battery for 4 h continuous operations
Operating Weight & Dimensions:	Backpack: 10 kg; Coil Assembly: 16.5 kg (24 kg trailer mode) Backpack: 60 x 30 x 10 cm Coil: a) Main: 100 x 100 x 5 cm b) Focusing: 100 x 100 x 2 cm
Shipping Weight & Dimensions	61 kg (86 kg with trailer) 104 x 104 x 22 cm (Box 1) 54 x 54 x 52 cm (Box 2) with trailer option only

METHOD APPENDIX

MAGNETICS METHODS



MAGNETICS

INTRODUCTION

The magnetometer is a sensitive instrument which can be used to map spatial variations in the Earth's magnetic field. Magnetometers are highly portable instruments which are operated manually. In the proton magnetometer a magnetic field which is not parallel to the Earth's field is applied to a fluid rich in protons causing them to partly align with this artificial field. When the controlled field is removed, the protons precess toward realignment with the Earth's field at a frequency which depends on the intensity of the Earth's field. By measuring this precession frequency, the total intensity of the field can be determined.

For some purposes a close approximation of the gradient of the field is determined by measuring the difference in the field between two closely spaced sensors. In principle, the gradient of any component of the total intensity of the field can be measured in the vertical direction or any horizontal direction. In practice the quantity measured most commonly is the vertical gradient of the total field.

Ground magnetic measurements are usually made with portable instruments at regular intervals along more or less straight and parallel lines which cover the survey area. Often the interval between measurement locations (stations) along the lines is less than the spacing between lines. Ordinary land surveying methods are used to establish stations at which measurements are made; accuracy of 1-10 feet in plan is usually required.

To make accurate anomaly maps, temporal changes in the Earth's field during the period of the survey must be considered. Normal changes during a day, sometimes called diurnal drift, are a few tens of gammas but changes of hundreds or thousands of gammas may occur over a few hours during magnetic storms. During severe magnetic storms, which occur infrequently, magnetic measurements should not be made. There are a number of methods used to correct surveys for temporal variations. For ground surveys, one method is to establish a base or reference station in the survey area and to repeat measurements at this base at frequent intervals. All of the measurements at field stations are then corrected by assuming a linear change of the field during the time interval between repeat base station readings. This method works well provided the earth's field is relatively stable. Sometimes continuously recording magnetometers are used at fixed base sites to monitor temporal changes. If time is accurately recorded at both base site and field location the field data can be corrected by subtraction of the variations at the base site. This method works very well for surveys of small areas, provided the base site is in or near the area. It does not work well for surveys of large areas because, over a large area (tens of kilometers), temporal variations vary spatially in an unpredictable manner.

Intense fields from man-made electromagnetic sources can be a problem in magnetic surveys. Most magnetometers are designed to operate in fairly intense 60 hertz and radio frequency fields. However extremely low frequency fields caused by equipment using direct current or the switching of large alternating currents can be a problem. Pipelines carrying direct current for cathodic protection can be particularly troublesome. With great care, airborne anomalies on the order of one nanoTesla (nT) or less can be mapped in areas of very gentle magnetic expression. Although some modern ground magnetometers have a sensitivity of 0.1 nT, sources of cultural and geologic noise usually prevent full use of this sensitivity in ground measurements.

After all corrections have been made magnetic survey data are usually displayed as individual profiles or as contour maps. Geologic interpretation of magnetic anomalies is carried out by comparison with theoretical anomalies calculated for idealized geologic models, comparison with anomalies over known geologic features, and from constraints provided by other geophysical and geological results in the area. Identification of anomalies caused by cultural features, such as railroads, pipelines, and bridges is commonly made using field observations and maps showing such features. There are no well established analytical procedures to follow for identification and location of such features.

BACKGROUND

The Earth possesses a magnetic field caused primarily by sources in the core. The form of the field is roughly the same as would be caused by a dipole or bar magnet located near the Earth's center and aligned parallel to the geographic axis. The intensity of the Earth's field is customarily expressed in S.I. units as nanoTeslas (nT) or in an older unit, the gamma. Except for local perturbations, the intensity of the Earth's field varies between about 45,000 and 60,000 nT over the coterminous United States.

Many rocks and minerals are weakly magnetic or magnetized by induction in the Earth's field, and cause spatial perturbations or "anomalies" in the Earth's main field. Man-made objects containing iron or steel are often highly magnetized and locally can cause large anomalies up to several thousands of nT.

Magnetic methods are generally used to map the location and size of ferrous objects. Determination of the applicability of the magnetics method is done by an experienced engineering geophysicist. Modeling and incorporation of auxiliary information may be necessary to produce an adequate work plan.

The Earth's magnetic field dominates most measurements on the surface of the earth. Permanently magnetized earth materials with fields like a common bar magnet are the exception. A secondary magnetic field is induced in most materials when the material is in the presence of a strong magnetic field such as the Earth's. Induced magnetization refers to the action of the field on the material wherein the ambient field is enhanced causing the material itself to act as a magnet. The field caused in such a material is directly proportional to the intensity of the ambient field and to the ability of the material to enhance the local field-a property called magnetic susceptibility. The induced magnetization is equal to the product of the volume magnetic susceptibility and the inducing field of the earth:

$$I = kF$$

Where I is the induced magnetization per unit volume in cgs electromagnetic units (A vector)
F is the external field intensity in Teslas (A vector)
k is the volume magnetic susceptibility.

For most materials k is much less than 1 and, in fact is usually on the order of 10^{-6} for most rock materials. From a geologic standpoint, magnetite and its distribution determine the magnetic properties of rocks. The susceptibility of magnetite is about 0.3. There are other important magnetic minerals in mining prospecting, but the amount and form of magnetite determines how most rocks respond to an inducing field. Iron, steel and other ferromagnetic alloys have susceptibilities one to several orders of magnitude larger than magnetite. The exception is stainless steel which is only weakly magnetic.

The influence of magnetite on a magnetics measurement cannot be exaggerated. Some tests on rock materials have shown that a rock containing one percent magnetite may have a susceptibility as large as 10^{-3}, or one thousand times larger than most rock materials. The following list gives some typical values for rock materials-note that the range of values given for each sample depends on the amount of magnetite present.

ROCK TYPE	SUSCEPTIBILITY
Altered ultra basics	10^{-4} to 10^{-2}
Basalt	10^{-4} to 10^{-3}
Gabbro	10^{-3}
Granite	10^{-5} to 10^{-3}
Andesite	10^{-4}
Rhyolite	10^{-5} to 10^{-4}
Shale	10^{-5} to 10^{-4}
Schist and other Metamorphic Rocks	10^{-4} to 10^{-6}
Most Sedimentary Rocks	10^{-6} to 10^{-5}
Limestone and Chert	10^{-6}

Thus it can be seen that in most engineering and environmental scale investigations, the sedimentary or alluvial sections will not show sufficient contrast such that magnetic measurements will be of use in mapping the geology. However, the presence of ferrous materials in ordinary municipal trash and in most industrial waste does allow the magnetometer to be used in direct detection of landfills and other disposal features. Underground steel tanks, where isolated from interfering anomalies, cause easily detected magnetic anomalies.

FIELD WORK

The magnetometer is operated by a single person. However, grid layout, surveying or the buddy system may require the use of another technician. The use of a base station is covered above. Additionally, some QC/QA procedures require that several field-type stations be occupied at the start and end of each day's work. The incorporation of computers and non-volatile memory in magnetometers has greatly increased the ease of use and data handling capability of magnetometers. The instruments typically will keep track of position, prompt for inputs, and internally store the data for an entire day of readings. Downloading the information to a personal computer is straight forward and plots of the results of the day's work can be prepared each night.

The base magnetometer is activated every day prior to collection of any ground magnetic data. It is placed at least 100 feet from any metal objects or traveled roads and at least 500 feet from any power lines. The sensor is mounted above the ground surface and rotated until the sensor is properly oriented (if there is a preferred orientation marked on the sensor). The base magnetometer is activated and measurements are taken and recorded, along with the measurement time, at a specified time interval. At the end of the field day, the unit is deactivated and the time is recorded.

Steel and other ferrous metals in the vicinity of a magnetometer can distort the data. Thus, large (steel) belt buckles, etc. must be removed when operating the unit. The magnetic effect of any potentially offensive article should be tested for its effect on magnetic data. If a compass is carried, the magnetometer reading must be made more than ten feet from it.

A final test is to immobilize the magnetometer and take readings while the operator's body is moved to different directions around the sensor. If the readings do not change by more than a nT or so, the operator is "magnetically clean". If the readings do change, the operator must find the ferrous object on the operator's person that is causing the problem. Zippers, watches, glasses frames, boot grommets, keys, pencils, and almost anything else can have steel or iron in them. On very precise surveys, the operator effect must be held under one nT.

To obtain a representative reading, the sensor should be held well above the ground. This procedure is done because of the probability of collections of soil magnetite disturbing the reading at the station. In rocky terrain where the rocks have some percentage of magnetite, sensor heights of up to 12 feet have been used to remove near-surface effects. One obvious exception to this is some types of ordnance detection where the objective is to detect near-surface objects. Often a rapid-reading magnetometer is used (cycle time less than 1/4 second) and the magnetometer is used to sweep across an area near the ground. Small ferrous objects can be detected, and spurious occurrence of soil magnetite can be recognized by their lower amplitude and dispersion. Ordnance detection requires not only training in the recognition of the dangerous objects, but experience in separating small intense and interesting anomalies from more dispersed geologic noise.

On some magnetics surveys the field magnetometer must be read several times at each station until three readings agree to within 1 nT . On other surveys you must read the unit several times and record each reading. The work plan will specify which technique is required for a given survey. In either case, the time of the reading is also recorded unless the magnetometer stores the readings and times internally.

Sheet-metal barns, power lines, and other potentially magnetic objects will occasionally be encountered during a magnetic survey. When a magnetic reading is taken in their vicinity, they must be described and the distance from them noted in the field book or on a separate cultural survey map of the site.

The experienced magnetics operator will be alert for the possible occurrence of the following conditions:

1. Excessive gradients beyond the magnetometers ability to make a stable measurement. Modern magnetometers give a quality factor for the reading or otherwise indicate a successful determination of the value of the field. Multiple measurements at a station, minor adjustments of the station location and other adjustments of technique may be necessary to produce repeatable, representative data.

2. Nearby metal objects which may cause interference. Some items, such as automobiles are obvious, but some subtle interference will be recognized only by the imaginative and observant magnetics operator. Curbs and foundation remnants, buried cans and bottles, power lines, fences, and other hidden factors can greatly affect magnetic readings.

INTERPRETATION

Total magnetic field disturbances or anomalies are highly variable in shape and amplitude; they are almost always asymmetrical, sometimes appear complex (even from simple sources), and usually portray the combined effects of several sources. Ambiguity is present in the method in that an infinite number of possible sources can produce a given anomaly. This ambiguity is illustrated in Figure M-l where identical magnetic anomalies are accounted for by quite different distributions of causative materials.

One additional difficult issue is the fact that most magnetometers used measure the magnitude of total field of the earth. The direction of the field is not recorded. The consequences of this fact is that only the component of an anomalous field in the direction of earth's main field is measured. Figure M-2 illustrates this consequence of the measurement technique.

The induced nature of the measured field makes even large bodies act as dipoles, that is like a large bar magnet. If the (usual) dipolar nature of the anomalous field is combined with the measurement system that measures only the component in the direction of the earth's field, the difficult nature of most magnetic interpretations can be appreciated. To achieve a qualitative understanding of how some anomalies may look, consider Figure M-3. From this figure, based on a distributed body of narrow width perpendicular to the profile, one can see how the dipolar nature of the anomaly is muted. The negative portion of the anomaly is less than 1/10 of the positive anomaly. Figure M-4 however, illustrates the anomaly due to a thin but more distributed body. The body in figure M-4 is long perpendicular to the profile. Its narrow width is another factor which adds to the negative anomaly off to the north of the body. In Figure M-4 the negative portion of the anomaly is nearly 1/3 of the size of the positive portion. Note that for the body in Figure M-4, the body is located closer to the inflection point in the total field measurement rather than to the peak of the anomaly.

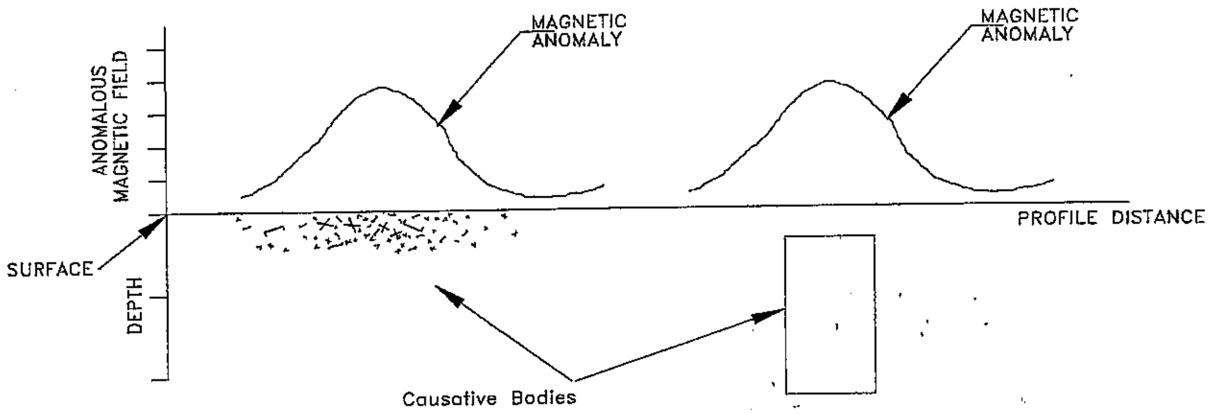


FIGURE M-1

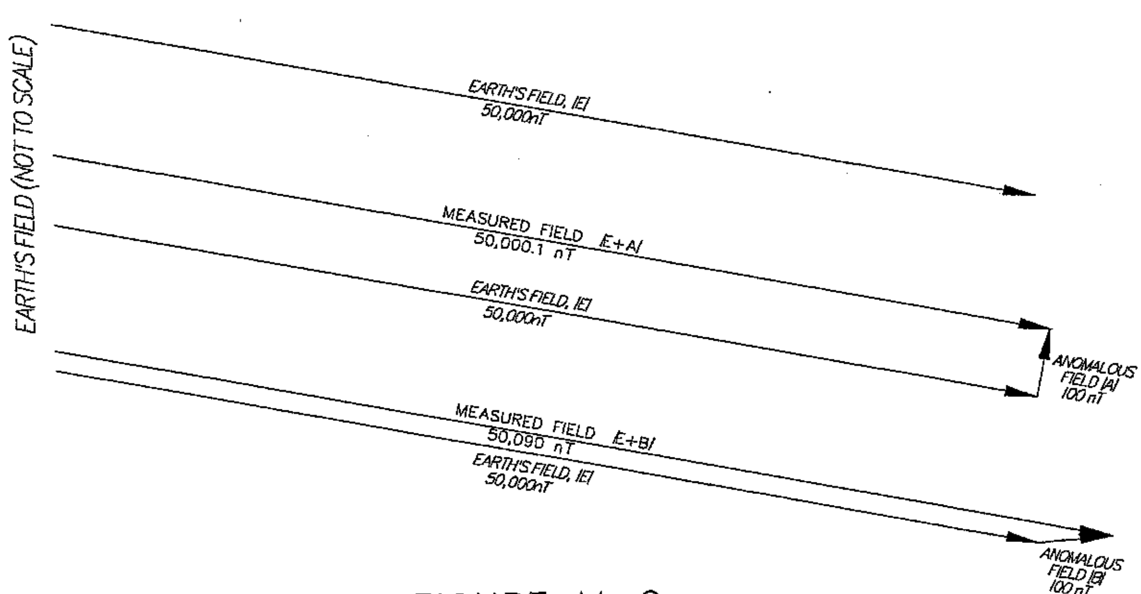


FIGURE M-2

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WHEAT RIDGE, COLORADO 80033

MAGNETICS METHODS APPENDIX

MAGNETIC FIELD DIAGRAMS
AMBIGUITY EXAMPLE, M-I
TOTAL FIELD MEASUREMENT EXAMPLE, M-2

GEOPHYSICS: MICROGEOPHYSICS CORPORATION WHEAT RIDGE, COLORADO	TECHNICAL APPROVAL
DRAWN: DAVID BUTLER	SUBMITTED
CHECKED	APPROVED: MARY ANN FORE
WHEAT RIDGE, COLORADO MARCH, 1994	FIGURE M-I,2

COMPUTER AIDED DRAFTING
FILE NAME: MAG-I.DWG

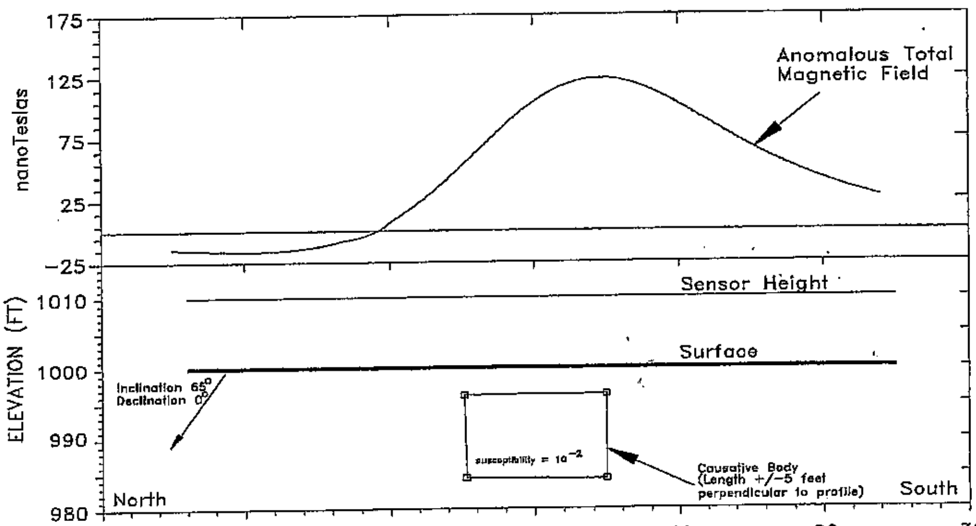

FIGURE M-3

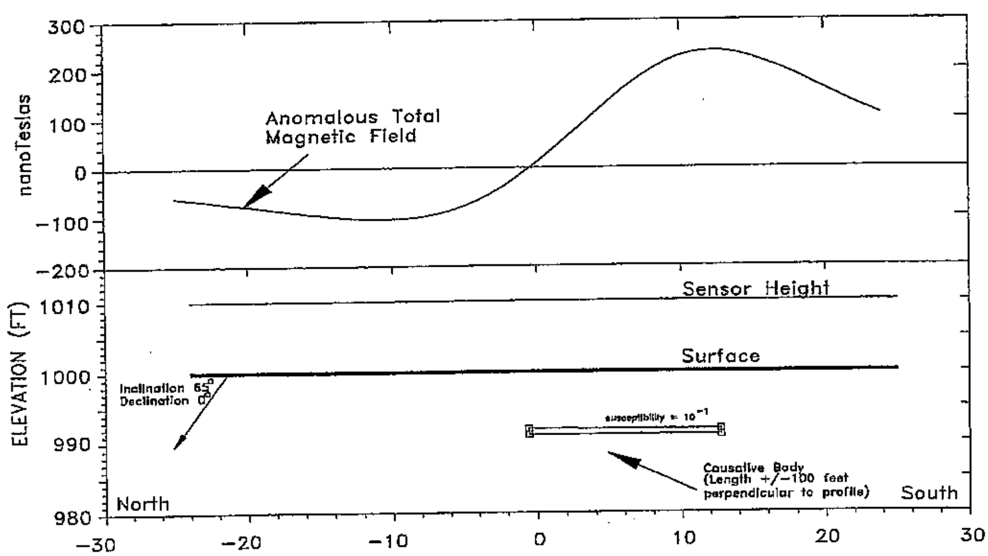

FIGURE M-4

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MAGNETICS METHODS APPENDIX

MAGNETIC FIELD DIAGRAMS

POLAR ANOMALY, M-3
BIPOLAR ANOMALY, M-4

GEOPHYSICS: MICROGEOPHYSICS CORPORATION, WHEAT RIDGE, COLORADO — TECHNICAL APPROVAL: ______
DRAWN: DAVID BUTLER — SUBMITTED: ______
CHECKED: ______ — APPROVED: MARY ANN FORE

WHEAT RIDGE, COLORADO — MARCH, 1994 — FIGURE M-3,4

COMPUTER AIDED DRAFTING
FILE NAME: MAG-2.DWG