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Engineers
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August 21, 2018

Mr. Matthew L. Gordon
Sunoco Logistics, L.P.
535 Fritztown Road
Sinking Spring, PA 19608

RE: Sunoco Pipeline, L.P. Pipeline Project
Geophysical Survey of Subsidence Feature
Horizontal Directional Drill – Joanna Road
RETTEW Project No. 096302010

Dear Mr. Gordon:

RETTEW Associates, Inc. completed a geophysical survey within a client-designated area of the Sunoco Pipeline, L.P. (SPLP) right-of-way (ROW) at the Joanna Road horizontal directional drill (HDD) site. The purpose of the survey was to detect and delineate possible subsurface voids beneath a subsidence feature along the HDD path. The following report, figures, and attachments describe the methods and results of the investigation.

EXECUTIVE SUMMARY

RETTEW completed a geophysical survey on August 6th, 2018. Microgravity readings were collected to check for subsurface voids which might have acted as receptors for soil piping which created a subsidence feature. This subsidence feature is a surficial depression that reportedly appeared at the surface along the HDD pathway during reaming activities. There is no evidence of subsurface voids – other than the HDD annulus itself, or possibly a sanitary sewer – which could act as the receptor for soil piping. Since the local bedrock is igneous diabase, natural solution cavities should not be present.

SITE DESCRIPTION

The Joanna Road HDD runs beneath a low marshy area along the East Branch of the Conestoga River in Caernarvon Township, Berks County, Pennsylvania. The HDD bore path passes beneath Joanna Road, and beneath the East Branch of the Conestoga River, and two unnamed tributaries of the East Branch of the Conestoga River, within primarily wooded areas. The HDD bore path is in a right-of-way containing two other completed SPLP pipelines.

The site bedrock geology consists of the Jurassic-aged diabase (see **Figure 1**). Diabase occurs in Pennsylvania primarily as dikes and sheets; the dikes are generally 5 to 100 feet thick and the sheets much thicker; in most places the rock is dark gray to black, dense and very fine-grained, and consists of 90 to 95% labradorite and augite. Diabase is not bedded. Bedrock jointing has a typical blocky pattern, is well developed and moderately abundant, with regular spacing, having a moderate distance between fractures, which are typically open and steeply dipping. Diabase is highly resistant to weathering and only slightly weathered to a shallow depth, producing large, rounded boulders mixed with a thin mantle.

Topography is characterized by undulating hills of medium relief, having moderately steep and stable natural slopes, and with dikes forming ridges. Subsurface drainage is fair, with very low secondary porosity in joint openings, and low permeability. From an engineering standpoint, excavation in diabase is difficult, with large boulders being a special problem. Foundation stability is good, provided the excavation is completed to sound material. Drilling rates are described as slow. Cut slope stability is good, and adversely influenced by local intense fracturing and depth of cut (Geyer and Wilshusen, 1982).

MICROGRAVITY SURVEY

The microgravity method can be employed in a specific fashion to determine the distribution of mass beneath a site (see **Appendix A**; Introduction to Microgravity), and thus locate underground voids which can act as receptors for soil piping/solution activity. For the Joanna Road HDD site, RETTEW completed the following specific tasks:

- Gravity readings were collected at 10-foot intervals along three profiles spanning accessible areas of the right-of-way near the subsidence feature (see cyan diamond symbols on **Figure 1**, and colored circles on **Figure 2**), using a Scintrex CG-5 microgravity meter. At each station, the metered gravity (representing a 60-second average), meter height, reading date, and time were recorded in the logger.
- A fixed base station was re-occupied with the gravimeter approximately once every hour to provide instrument drift control data.
- The location of each station was mapped, and several were surveyed using a Topcon GPS with sub-meter horizontal accuracy.
- The relative elevation of each station point was surveyed with a Topcon DGPS system and a Ziplevel Pro, both with sub-centimeter elevation accuracy.
- Initial data processing was automatically applied in the field by the instrument, which calculates the reference ellipsoid, earth tide, and coarse drift corrections. Free air, fine drift, and Bouguer corrections were calculated in a spreadsheet using standard formulae (see e.g. Telford et al., 1990), and applied during post-processing.
- The best-fitting (in the least squares sense) simple planar surface was removed from the Bouguer data, to delete the effects of any deep geologic source, or regional gravity trend.

Due to the limited site access and therefore few measurement stations, the resulting residual microgravity data are plotted as a color-coded "classed posting" (rather than a contour map) in **Figure 2**, using SURFER by Golden Software. The values depict the general plan-view shallow mass distribution beneath the survey area, with lower values (red) representing local mass deficiencies and higher values (green) representing local mass excesses. The color classes are divided by multiples of the standard deviation (σ) of the multiple re-occupations of the base station. That is, the variations in measured gravity at the fixed base station (theoretically displaying zero change in gravity) are used to characterize the resolution or sensitivity (or "noise level") of the survey. Readings that are different from zero (milligals) by less than σ are considered to be within experimental/instrument error, and statistically/scientifically the same as no variation at all (and are presented in shades of green to yellow on **Figure 2**). Readings that are more than 2σ different from the local average are considered to be "real" variations that might begin to warrant geologic interpretation. Measurably low values, more than 2σ from local zero, are shown as orange on **Figure 2**. Readings more than 3σ from the local average are considered real and "significant", warranting further investigation, interpretation, and possible engineering mitigation.

RESULTS

The microgravity data are depicted on **Figure 2** as color-coded classed posting dots representing the relative density of the subsurface, with dark green for high-density (mass-excess), light green to yellow for "site normal," and orange to red for locally low-density (mass-deficient) areas. Significant mass-deficient values less (i.e. more negative than 3σ below site average – red dots) are not apparent on **Figure 2**.

CONCLUSIONS

The microgravity data do not show any values greater than 2σ below local average (**Figure 2**), indicating that there are no significant local subsurface mass deficiencies. Obviously, surficial material was piped to the subsurface to create the subsidence feature. In the local geology, natural karst solution cavities are not possible, and thus, this subsidence feature cannot be a conventional sinkhole. This leaves several possibilities – all anthropogenic:

1) Unconsolidated material (soil) was lost to the HDD annulus itself; this is only possible if the subsidence feature occurred prior to installation of a grout plug in the annulus. This is the most-likely scenario since on-site personnel report that during reaming operations, pressurized drilling fluid and water were apparently forced up into the subsidence feature.
2) Soil was lost to an underlying sewer treatment plant outfall pipe. For this to occur, the outfall pipe would need to be breached in some fashion to accept incoming piped soil. This possibility could be evaluated by internal inspection of the sewer outfall pipe.
3) Given the diabase geology of the site, and the characteristic weathering pattern of diabase (i.e. forming clusters of rounded boulders or "noggins" nested together), it is possible that soil was lost to the macro-pore space between nested boulders.

For any of these possibilities/interpretations, the lack of observed significant low gravity readings indicates that whatever subsurface void space accepted the piped soil has now been filled, thereby reducing (if not eliminating) the possibility for further subsidence.

LIMITATIONS

The survey described above was completed using standard and/or routinely accepted practices of the geophysical industry, and the equipment employed represents, in RETTEW's professional opinion, the best available technology. RETTEW does not accept responsibility for survey limitations due to inherent technological limitations or unforeseen site-specific conditions. We will notify you of such limitations or conditions, when they are identifiable.

Also note that the survey is based on observation of current subsurface conditions. Therefore, while the results of this survey can be used to guide further investigations, RETTEW cannot make any warranties concerning future occurrence of subsidence features — particularly under the influence of altered surface and subsurface drainage patterns due to grading and construction activities.

We have enjoyed and appreciated the opportunity to have worked with you. If you have any questions, please do not hesitate to contact the undersigned.

Timothy D. Bechtel, PhD, PG
Sr. Project Manager

Felicia Kegel Bechtel, MSc, PG
Director of Geophysics

Enclosures
Figure 1: Topographic Basemap
Figure 2: Residual Gravity Readings
Appendix A: Introduction to Microgravity

References
Geyer, A.R. and Wilshusen, J.P., 1982, Engineering Characteristics of the Rocks of Pennsylvania, Pennsylvania Geologic Survey, Harrisburg, PA.

Telford, W.M., Geldart, L.P., and Sheriff, R.E. (1990), Applied Geophysics, Cambridge University Press.

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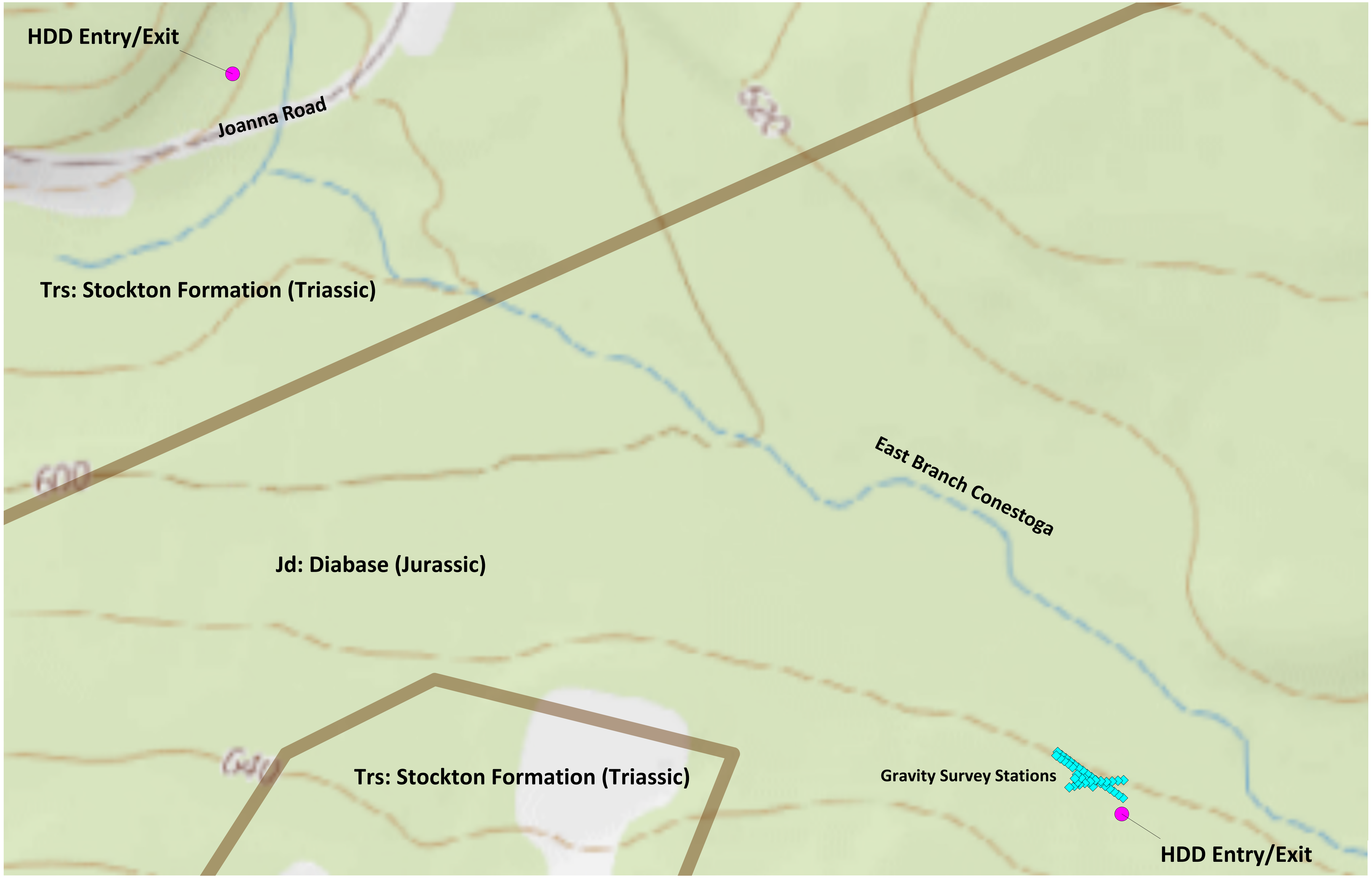
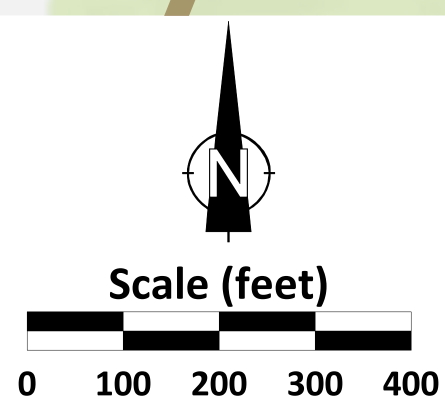
FIGURE 1
TOPOGRAPHIC BASEMAP





Notes:

Basemap from USGS TOPO WMS Server extracted 8/2018.

Geology from USGS MRdata kmz extracted 8/2018.

SURVEY DATE: 08/06/2018
RETTEW No.: 096302010
REVISION DATE:
DRAWN BY: TDB
DATE: 08/12/2018
SCALE: 1" = 200'
FIGURE NO. 1 of 2

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Figure 1 - Tographic Basemap

Sunoco Pipeline, L.P. Pipeline Project - PPP5 Geophysical Survey
Horizontal Directional Drill – Joanna Road

Caernarvon Township

BERKS COUNTY, PA

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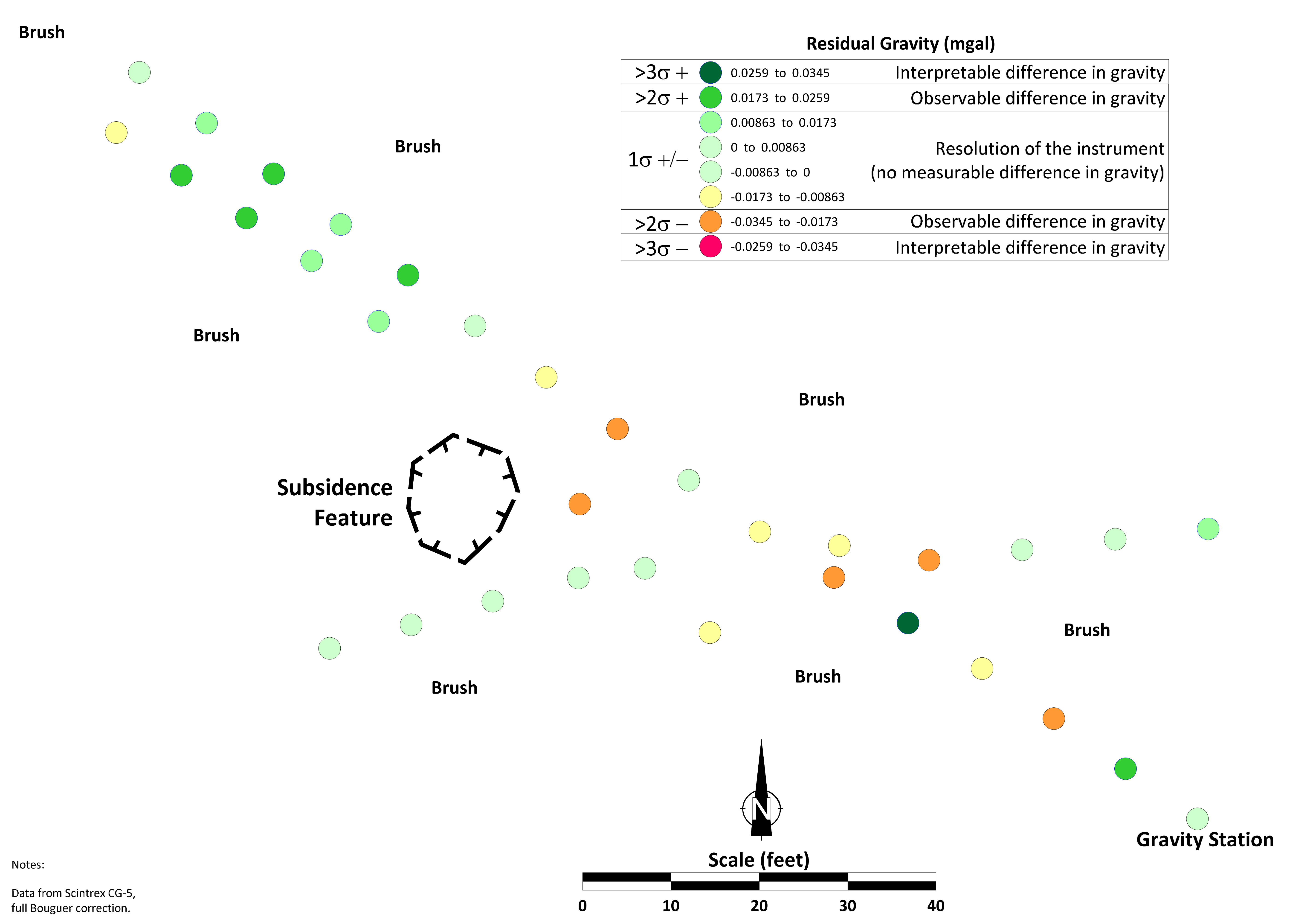
FIGURE 2
RESIDUAL GRAVITY READINGS



Notes:

Data from Scintrex CG-5, full Bouguer correction.

SURVEY DATE: 08/06/2018
RETTEW No.: 096302010
REVISION DATE:
DRAWN BY: TDB
DATE: 08/12/2018
SCALE: 1" = 10'
FIGURE NO. 2 of 2

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Figure 2 - Residual Gravity Readings

Sunoco Pipeline, L.P. Pipeline Project - PPP5 Geophysical Survey
Horizontal Directional Drill – Joanna Road

BERKS COUNTY, PA
Caernarvon Township

APPENDIX A
INTRODUCTION TO MICROGRAVITY

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INTRODUCTION TO MICROGRAVITY

BY TIMOTHY D. BECHTEL, PHD, PG

ENERGY

The natural mutual attraction between any two bits of matter or masses. According to Newton's Universal Law of Gravitation:

$$F_g = G\frac{M_1 M_2}{R^2}$$

where Fg is the force of gravity, M1 and M2 are the masses of two mutually-attracting bodies, and R is the distance between their centers.

SENSITIVITY

Sensitive to variations in the mass distribution in the vicinity of a gravity meter. That is, a test mass, suspended on a spring in the gravity meter represents M1, while the mass of the Earth beneath the meter is M2. Notice that objects or targets comprising M2 contribute less if they are deeper (increased R).

BASIC EQUIPMENT

A microgravity meter: This measures the vertical component of the three-dimensional gravity field at any given station. Where the mass beneath the meter is locally greater, the test mass in the meter is pulled-down, extending the spring. The spring deflection can be measured optically or electrostatically with great accuracy. Microgravity meters can measure gravitational accelerations to within several to roughly ten parts per billion of Earth's natural field. Also required is a high-precision device for measuring relative meter elevation at each station: laser, optical, or hydrostatic level, or real-time kinematic (RTK) GPS. This is because the meter height above the Earth (R in the equation above) has a strong influence on readings.

COMMON APPLICATIONS

Detection of subsurface mass deficiencies (tunnels, solution cavities, etc.) of excesses (ore bodies, shallow rock, etc.) Target depths and dimensions may also be estimated.

PRINCIPLES

Microgravity meters are capable of measuring the force of gravity with great precision. Worldwide, the acceleration of gravity has been adopted as 980 centimeters per second squared (cm/s2). However, this is an average value, since the actual measured value of gravity at a given station is dependent upon many things, including:

1) The elevation of the station reading (higher stations are farther from the center of mass of the earth)
2) The latitude and longitude of the station (the earth is not truly spherical)
3) The positions of the sun and the moon (which create not only the readily observed ocean tides, but small deformations of the entire earth called earth tides)

4) Minute changes in the calibration of the gravity meter (instrument drift)
5) The attraction of massive landforms near or obliquely above the station (i.e. the mass of a nearby mountain produces a gravitational attraction which can have a significant effect on a precise gravity reading)
6) The density of materials immediately beneath a station.

The variations in gravity due to the first four factors above typically have magnitudes measured in milligals (where 1,000 milligals equal one cm/s2). The fifth and sixth factors are typically measured in microgals (where 1,000 microgals equal one milligal). Since the purpose of a microgravity survey is generally to determine factor six above (i.e. the density or mass distribution in the subsurface of a survey site), the raw gridded or profile gravity measurements that comprise a gravity survey must be corrected for factors one through five. This yields a set of numbers (which are generally several parts per billion of the Earth's adopted average gravity) that can be interpreted to determine subsurface mass distribution (see e.g. Telford, W.M., Geldart, L.P., and Sheriff, R.E., 1990, Applied Geophysics, Cambridge University Press).

To arrive at a number representative of the subsurface mass distribution, raw gravity readings are subjected to the following corrections:

1) **Reference Ellipsoid Correction** — corrects for the non-spherical shape of the earth based on the latitude and longitude of a station
2) **Earth Tide Correction** — corrects for deformation of the earth under the gravitational influence of the sun and moon
3) **Drift Correction** — corrects for slow changes in the calibration of a gravity meter based on repeated measurements at a fixed base station
4) **Free Air Correction** — corrects for the elevation of a station above (or below) mean sea level based on a surveyed station elevation
5) **Bouguer Slab Correction** — corrects for the density of the hypothetical slab of material between the station elevation and mean sea level based on an assumed average terrain density.

Processed microgravity data are called Bouguer gravity and should retain only information on the mass or density distribution beneath a survey station. Bouguer gravity anomalies can be caused either by subsurface mass excesses (gravity highs) or deficiencies (gravity lows). Gravity highs commonly represent locally shallow bedrock pinnacles or float blocks in the soil profile, zones of particularly massive bedrock, etc. Gravity lows may represent locally deep bedrock cutters or clay seams where soil displaces bedrock; air-, water-, or mud-filled voids within bedrock; stoping voids in the soil above bedrock; or zones where soils have been made less dense by removal of fines, or anthropogenic features such as tunnels.

CAPABILITIES

Microgravity profiles or maps are often used to detect and map bedrock solution cavities or stoping soil voids in karst terranes. Microgravity has been famously used to detect secret rooms or bunkers beneath historic or strategic buildings and other structures. Tunnels and large-diameter pipes can also be mapped. Amongst all geophysical methods, gravity is the least susceptible to interference: there is no such thing as “gravity noise”.

LIMITATIONS

Detectability of targets always involves a trade-off between depth, dimensions, and density of a body with anomalous mass. Large bodies and large density contrast with the surrounding medium enhance gravity anomalies. Depth diminishes anomalies. So, in general, large or distinct (high-density-contrast) targets may be detectable at great depth, while small or subtle targets must be shallow.

The sensitivity of gravity meters (which contain mechanical components) means that they may be susceptible to vibration. Sometimes it is necessary to slow-down nearby traffic, pause drilling, compaction, or pile-driving on constructions sites, or shut-down heavy machinery (compressors, etc.) during a microgravity survey.