TECHNICAL MEMO

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ISSUED FOR USE

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DATE: September 4, 2012

FROM: Neil Parry, MBA, P.Geoph.
D.W. Hayley, P.Eng., FEIC

FILE: Y14103005-01

SUBJECT: Inuvik to Tuktoyaktuk Highway
Terrain Assessment and Geophysical Investigation

1.0 INTRODUCTION

Between the dates of July 25 to 28, 2012, geophysical data was collected at select sites along the proposed alignment of the Inuvik to Tuktoyaktuk Highway by Mr. Neil Parry, P.Geoph. and Mr. Jordan Augruso, B.Sc., Geoph. I.T. of Kiggiak-EBA's Edmonton office. Two geophysical methods, Ground Penetrating Radar (GPR) and Capacitively Coupled Resistivity (OhmMapper) were assessed at a total of seven sites representing specific issues of concern in the construction of the Highway.

The objective of the geophysical assessment was twofold:

- to quantify and evaluate (through site specific examples and discussion) the effectiveness of these methods in providing information of value to the engineering design team.
- to provide recommendations and comment on how more extensive future work should be conducted, if there is a tangible benefit.

This evaluation has been summarized in the form of this technical memo. A discussion of the specific site characteristics and construction issues are covered in a separate terrain report authored by Don Hayley (Kiggiak-EBA) and Olivier Piraux (Kavik-Stantec). A discussion of the technical characteristics and operation of each geophysical method is well documented in numerous papers and is not included.

2.0 GP1 KP12.5

2.1 Purpose: Assess the geophysical response to the ground conditions at an active thaw slump

A total of three GPR profiles, two with GPS coordinates, were collected at this site using a Ramac CUII system with 100 MHz antennas.

Figure 1 shows the line locations in relation to the thaw slump feature. Key questions of interest at this site were determining whether the GPR could identify massive ice at depth associated with the thaw slope.

Figure 2 shows the GPR profile collected along the crest of the thaw slump. No confirmation boreholes were collected at this site but photographs and logging were done at the thaw slump ice face. A reflector is identified approximately between 7 and 10 metres in depth from the ground surface depending on the propagation velocity used to calculate the depth to the reflection.

At this depth it is unlikely that the top of the massive ice was identified, as this would place the reflector at the base of the thaw slump. GPR reflections are generated when there is a significant change in the charge capacity (dielectric constant) of the soil. At the change some of the GPR wave energy is reflected back to the surface and detected while the remainder continues on through the material. If the change in charge capacity is insufficient to reflect much of the wave energy, or occurs in a graded manner over a distance greater than the Fresnel zone of the GPR antenna frequency, no reflection can be detected.

This seems to suggest that there was little contrast at this site between the soil immediately below the active layer and the massive ice that is thawing out. This suggests ice-rich soils from surface all the way to the reflector at 7 to 10 metres are present, with the only factor varying is the volumetric percentage of ice in the soil. It also indicates that these changes are graded rather than abrupt.

This situation is actually a good example of information that can be derived from what isn't seen in the geophysical data. It also indicates the importance of being able to interpret the geophysical data in context with surficial terrain interpretation of borehole logs, as, without knowing that the soils are likely ice-rich as a result of the thaw slump being present, there would be nothing to suspect that the deep reflector seen in the GPR data was not a simple stratigraphic feature such as a change in soil type. Resistivity data collected with GPR data would be instructive in the scenario at this site as it would show high resistivities and that, coupled with the lack of specular reflections, typically seen in granular material with GPR data, would strengthen the interpretation that ice-rich soil, rather than a coarse-grained soil, was present.

In conclusion, although the GPR does appear to have been successful in identifying features associated with the thaw slump, it required secondary sources of information for an unambiguous interpretation. If GPR was to be used as a corridor overview characterization tool, it would need to run with a secondary tool such as capacitively-coupled resistivity to increase the certainty of the geophysical interpretation. Secondly, even if similar features associated with potential massive ice were identified in a geophysical corridor survey, in isolation they do not determine that a thaw slump will occur as this information needs to be considered in conjunction with a detailed surficial analysis. Likewise, surficial features by themselves can only indicate what has happened in the past, not what will happen in the future. One can in effect consider the geophysical information as one more dimension of information that can be correlated with the surficial terrain data to better quantify risks.

3.0 GP2 KP17

3.1 Purpose: Assess the GPR response to determining the active layer and boundary conditions at a significant stream crossing

One GPR profile was collected at this site using a stepped GPR system called a Pulse Ekko IV. This system was selected because of the difficult site conditions.

The site consisted of relatively open vegetated plateaus on either site of an open creek with thick willow growth. Evidence of thaw settlement and cracks in the ground could be seen as one dropped down from the plateau either side of the creek. No boreholes were drilled at this site, but an active layer profile was collected approximately along the path of the GPR profile and is shown in Figure 3.

These conditions and the open water made it impractical to use the towed GPR system so data was collected in step mode using the Pulse Echo by taking stationary readings every 0.5 m. Figure 4 shows the line location.

The data collected (Figure 5) primarily shows two features of interest. Firstly, relatively good signal penetration is seen on the ground either side of the creek indicating well frozen, likely ice rich, soils. Within the creek itself the GPR signal is significantly attenuated to the extent that little penetration into the soil is achieved using the GPR. This illustrates the influence temperature and ice content has on the attenuation rate in fine grained soils and this is one of the signatures used in interpreting GPR data for thawed taliks.

The second feature of interest is the obvious increase in active layer thickness as the creek is approached. Variations in the active layer are commonly seen in GPR data and are controlled by a number of factors including vegetation, local drainage, slope exposure and direction, as well as soil type. Rapid changes in the active layer that can usually be seen quite clearly in GPR data are of particular interest because they can be indicators of active thaw back and be used to monitor both the stability of the natural ground under constructed fills and also to pinpoint locations for remedial methods such as the precise placement of thermosyphons.

4.0 GP3 KP18

4.1 Purpose: Assess the geophysical response in an area of potential progressive thaw degradation along a lake shore

One GPR profile and one OhmMapper (resistivity) profile were collected at this site, perpendicular to the shore line from the slope break along the lake bordering the north side of the road corridor to the centre of the proposed road alignment (Figure 4).

Both the GPR (Figure 6) and the OhmMapper (Figure 7) data show data with relatively low attenuation rates for surficial tills at the sites investigated suggesting a till with a coarser grained size distribution.

The resistivity data in particular was interesting at this location in that it shows very resistive materials in the top 1.5 to 2.75 metres, suggesting high ice content surficial soils immediately below the active layer. This resistive material is not uniformly distributed, with the highest resistivities and, therefore, potential ice contents, being seen in the 50 metres immediately upslope of the crest of the slope break. The interesting point to take away from this location is that the resistivity data clearly shows that there are variations in ice contents in the surficial soils immediately below the active layer that can be mapped using a towed system. These variations combined with surface topography and the surficial terrain analysis can be used to identify very localized areas along the road alignment that will be more sensitive to modifications in the thermal regime.

5.0 GP4 KP23.5

5.1 Purpose: Assess the effectiveness of geophysics in mapping drainage paths and identifying the ice wedge features

One GPR profile and one OhmMapper (resistivity) profile were collected at this location (Figure 8). The interest in geophysics at this site was to assess its utility in mapping the main drainage path in areas with low topographic relief to help aid in determining culvert placement.

As can be seen from Figures 9 (GPR) and Figures 10 (OhmMapper), both methods clearly identify where the low-lying, high ice, high moisture locations are. The GPR data in addition clearly shows a sensitivity to water, in that areas with open water show a noticeable velocity shift in the near surface reflections due to the radical change in dielectrics. This makes GPR a very reliable method to identify where the main flow channels are. In addition to identifying concentrations of water, very narrow reflections can be seen in the records at several locations. These in the field were noted to correlate with surface cracks that seem to be possible ice wedge features, possibly with some surface water collecting in the cracks due to active layer thawing and drainage. One borehole was collected at this site.

6.0 GP5 KP50

6.1 Purpose: Assess the effectiveness in characterizing the horizontal terrain boundaries using geophysical methods

One GPR profile and one OhmMapper (resistivity) profile were collected at this site (Figure 11). The main interest at this site was to see how the geophysics would characterize changes in the surficial soil types as the system passed from one to another. The GPR and OhmMapper data (Figures 12 and 13 respectively) did not seem to necessarily correlate with the surficial soil type transitions at this location. Rather higher concentrations in surficial ice contents were noted with a high ice area being noted at the base of the north facing slope where some surface cracking was noted.

In the case of the resistivity data, a very resistive layer was identified below two metres under the mound at the north end of the profile line and under the main slope. The borehole results hit gravel at this depth under the mound suggesting that the feature is a kame deposit.

In conclusion, of interest at this site is that it demonstrates that geophysics does have a potential role in helping to map granular deposits. Granular material is difficult to identify along the route due to poor surface expression and only limited surficial sampling historically. The site at km 50 is a good example of this, in that gravel was not expected. Given the non-intrusive nature of geophysics it is potentially simpler to permit than a drilling program. Therefore, there is a role in using geophysical methods such as GPR and OhmMapper to pre-screen areas to identify the most likely prospects for granular material. By doing this, permitting for drilling can focus on locations with the highest probability of good material. If areas are surveyed on a systematic grid basis, even discontinuous deposits can be mapped and their areal extend determined with more certainty.

7.0 GP6 KP81

7.1 Purpose: Assess the effectiveness of GPR in identifying stratigraphic features of concern at a till ridge between two lakes

Three GPR profiles were collected at this location (Figure 14). One profile was along the ridge line, one was along the toe of the ridge in the lacustrine soils and one profile was collected from the top of the ridge to the toe in the lacustrine soils.

The GPR profile along the ridge line (Figure 15) shows typical variations in active layer thickness and confirms that active drainage and a depressed active layer is present at the north end of the ridge at the lowest topographic elevation.

The GPR data in the lacustrine soils at the tow of the ridge show significantly more signal penetration and likely higher ice contents (Figure 16).

Figure 17 is the GPR profile perpendicular to the ridgeline and clearly shows that the transition point between these two soil types is at the toe of the ridge.

8.0 GP7 KP112

8.1 Purpose: Assess the effectiveness of geophysics in mapping the transition from till to lacustrine ice wedge polygon terrain

Two GPR profiles and one OhmMapper profile were collected at this site (Figure 18). The main interest at this site was determining how ice wedge polygons are detected in GPR records. Although detected at other sites in the GPR records, the ice wedge polygon is particularly well formed as one proceeds north and as seen in Figure 19, shows up very clearly. Evidence of ice wedge formation can be seen along the polygon boundaries, and the centre of the ice wedge polygon is also apparent.

The OhmMapper (resistivity) data does not show the same level of detail and simply shows the ice wedge polygon area as an area of higher resistivities reflecting the higher ice contents and standing fresh water.

9.0 CONCLUSION AND RECOMENDATIONS

In summarizing the discussion presented above the following points can be noted:

- GPR is very effective in mapping the horizontal location and width of ice wedge features. It was also effective in mapping the shallow structural features of associated ice wedge polygons of various sizes and degrees of regularity.
- GPR is very effective in mapping primary watercourse paths in poor drainage areas with low relief due to its sensitivity to the presence of water. This characteristic would likely be absent or muted during the winter, but it is suspected that other indicators such as variations in the active layer stratigraphy would still be detectable.
- GPR was very effective in mapping variations in the active layer thickness. These variations can be used as indicators of thawback and taliks. There is therefore a potential role in using this indicator as a monitoring tool to determine whether the road is modifying the thermal regime and causing thawing under the fill embankments.
- The OhmMapper resistivity data was useful in providing information on the presence of massive ice or very ice rich soils in localized areas. This data could be used to identify localized variations in ice content in the surficial soils, that combined with a terrain assessment of the risk of failure, could further refine the identification of localized problem areas that could be avoided or mitigated in routing and construction.
- The GPR and the OhmMapper combined are effective tools in mapping areas where granular materials are most likely to be found. This is of particular interest in identifying suitable granular deposits for construction as granular materials are scarce along the Highway route and are difficult to identify with certainty due to poor surface expression.

To conclude, both GPR and OhmMapper measurements should be considered useful geophysical methods moving forward. There are three potential application areas:

- Using geophysics as a pre-screening tool in areas that are of interest as granular sources. By conducting systematic grid coverage of these areas using both GPR and OhmMapper systems, the geophysics will be able to provide a qualitative assessment of which areas have both the highest likelihood of granular material and the greatest volumes. They will not be able to provide a quantitative assessment of the quality of the granular resource, but have the potential to save significant sums of money by directing the drilling to the most promising granular deposits in an area, as well as being able to extrapolate the drilling results to other similar locations in the same deposit area. This has added value when one also considers the local permitting requirements and restrictions and the limitations and logistics that these impose on any drilling program. This should be conducted as a winter program for cost reasons.

- Using geophysics to screen the entire route or critical sections of the route. This should be conducted as a winter program to keep costs realistic and there will be a cost/productivity trade-off that dictates a minimum number of kilometres worth collecting. The program can be structured in such a way that not all the data is evaluated at the same level of detail to control processing costs, with more attention being paid to critical areas as identified in the terrain analysis. Data will all be georeferenced and can be used as a reference point for re-evalution in the future.
- Geophysics can be used as a monitoring tool to assess sensitive locations for evidence of thaw settlement on an annual or other basis. This has value at specific locations where there is a high likelihood of maintenance issues that cannot be avoided. Monitoring should occur during the summer/fall when the active layer is at its maximum point.

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September 4, 2012

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Signature

Date September 4, 2012

PERMIT NUMBER: P449

The Association of Professional Engineers, Geologists and Geophysicists of the NWT / NU

GENERAL CONDITIONS

GEOPHYSICAL REPORT

This report incorporates and is subject to these "General Conditions".

1.0 USE OF REPORT

This geophysical report pertains to a specific site, a specific development, and a specific scope of work. It is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site or proposed development would necessitate a supplementary investigation and assessment.

This report and the assessments and recommendations contained in it are intended for the sole use of EBA's client. EBA does not accept any responsibility for the accuracy of any of the data, the analysis or the recommendations contained or referenced in the report when the report is used or relied upon by any party other than EBA's client unless otherwise authorized in writing by EBA. Any unauthorized use of the report is at the sole risk of the user.

This report contains figures, maps, drawings and sketches that represent processed geophysical data collected at a specific site. This processed data will have inherent interpretation assumptions and accuracies that are discussed in the report. Consequently, the report can only be considered in its entirety and individual figures, maps, drawings and sketches shall not be distributed without the text of the report unless authorized in writing by EBA.

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3.0 ENVIRONMENTAL AND REGULATORY ISSUES

Unless stipulated in the report, EBA has not been retained to investigate, address, or consider and has not investigated, addressed, or considered any environmental or regulatory issues associated with the development of the site.

4.0 NATURE AND EXACTNESS OF SOIL AND ROCK DESCRIPTIONS

Classification and identification of soils and rocks are based upon commonly accepted systems and methods employed in professional geotechnical practice. This report contains descriptions of the systems and methods used. Where deviations from the system or method prevail, they are specifically mentioned.

Classification and identification of geological units are judgemental in nature as to both type and condition. EBA does not warrant conditions represented herein as exact, but infers accuracy only to the extent that is common in practice.

Where subsurface conditions encountered during development are different from those described in this report, qualified geotechnical personnel should revisit the site and review recommendations in light of the actual conditions encountered.

5.0 LOGS OF TESTHOLES

The testhole logs are a compilation of conditions and classification of soils and rocks as obtained from field observations and laboratory testing of selected samples. Soil and rock zones have been interpreted. Change from one geological zone to the other, indicated on the logs as a distinct line, can be, in fact, transitional. The extent of transition is interpretive. Any circumstance which requires precise definition of soil or rock zone transition elevations may require further investigation and review.

6.0 STRATIGRAPHIC AND GEOLOGICAL INFORMATION

The stratigraphic and geological information indicated on drawings contained in this report are inferred from logs of test holes and/or soil/rock exposures. Stratigraphy is known only at the locations of the test hole or exposure. Actual geology and stratigraphy between test holes and/or exposures may vary from that shown on these drawings. Natural variations in geological conditions are inherent and are a function of the historic environment. EBA does not represent the conditions illustrated as exact but recognizes that variations will exist. Where knowledge of more precise locations of geological units is necessary, additional investigation and review may be necessary.

7.0 SURFACE WATER AND GROUNDWATER CONDITIONS

Surface and groundwater conditions mentioned in this report are those observed at the times recorded in the report. These conditions vary with geological detail between observation sites; annual, seasonal and special meteorological conditions; and with development activity. Interpretation of water conditions from observations and records is judgmental and constitutes an evaluation of circumstances as influenced by geology, meteorology and development activity. Deviations from these observations may occur during the course of development activities.

8.0 INFORMATION PROVIDED TO EBA BY OTHERS

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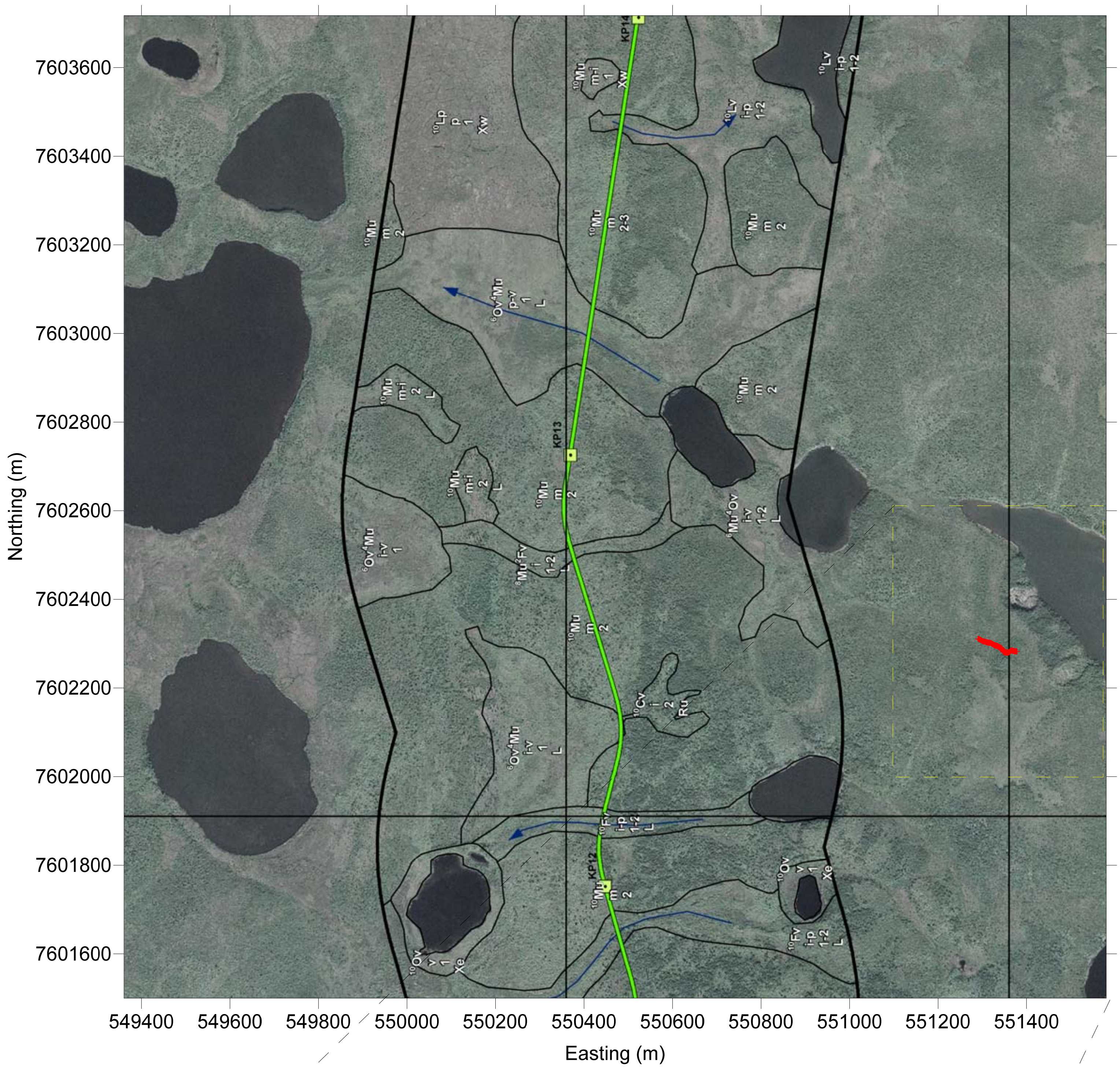

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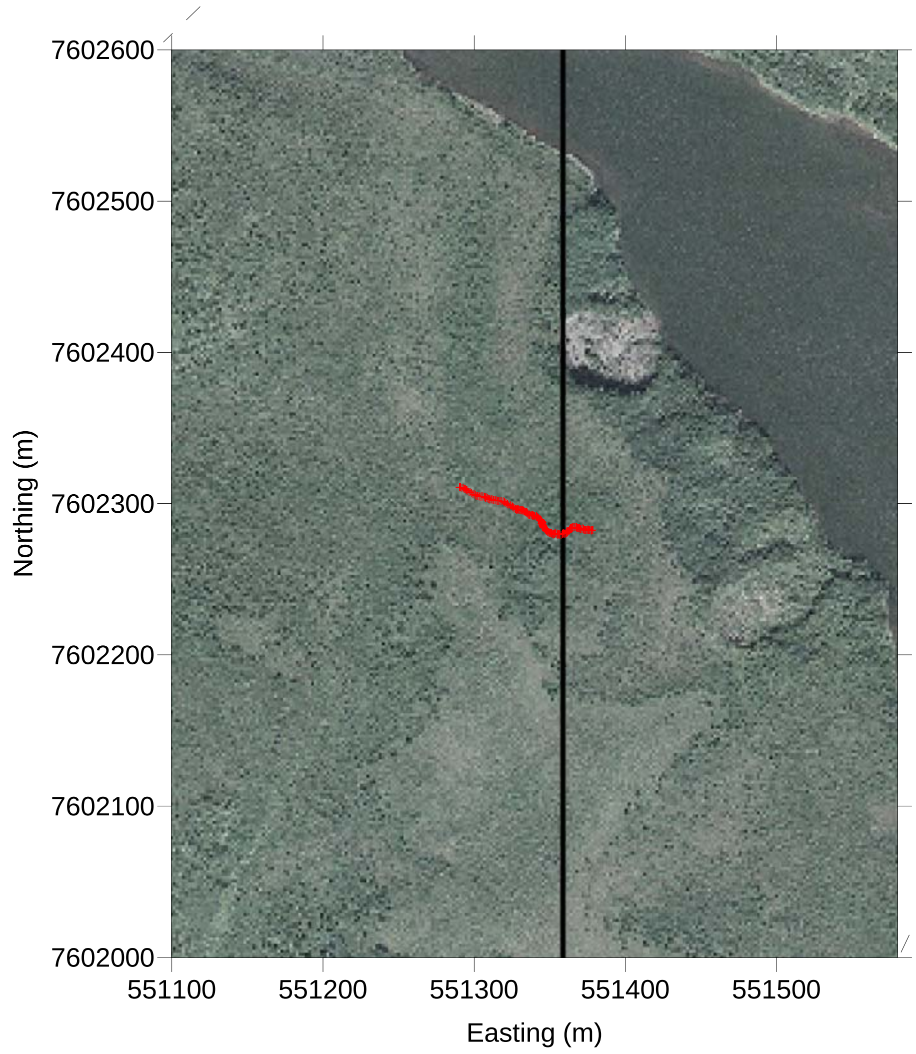

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NAD 83 DATUM

LEGEND

- Ground Penetrating Radar GPS Path
- Proposed Road Alignment
- Expanded Map View Area

CLIENT

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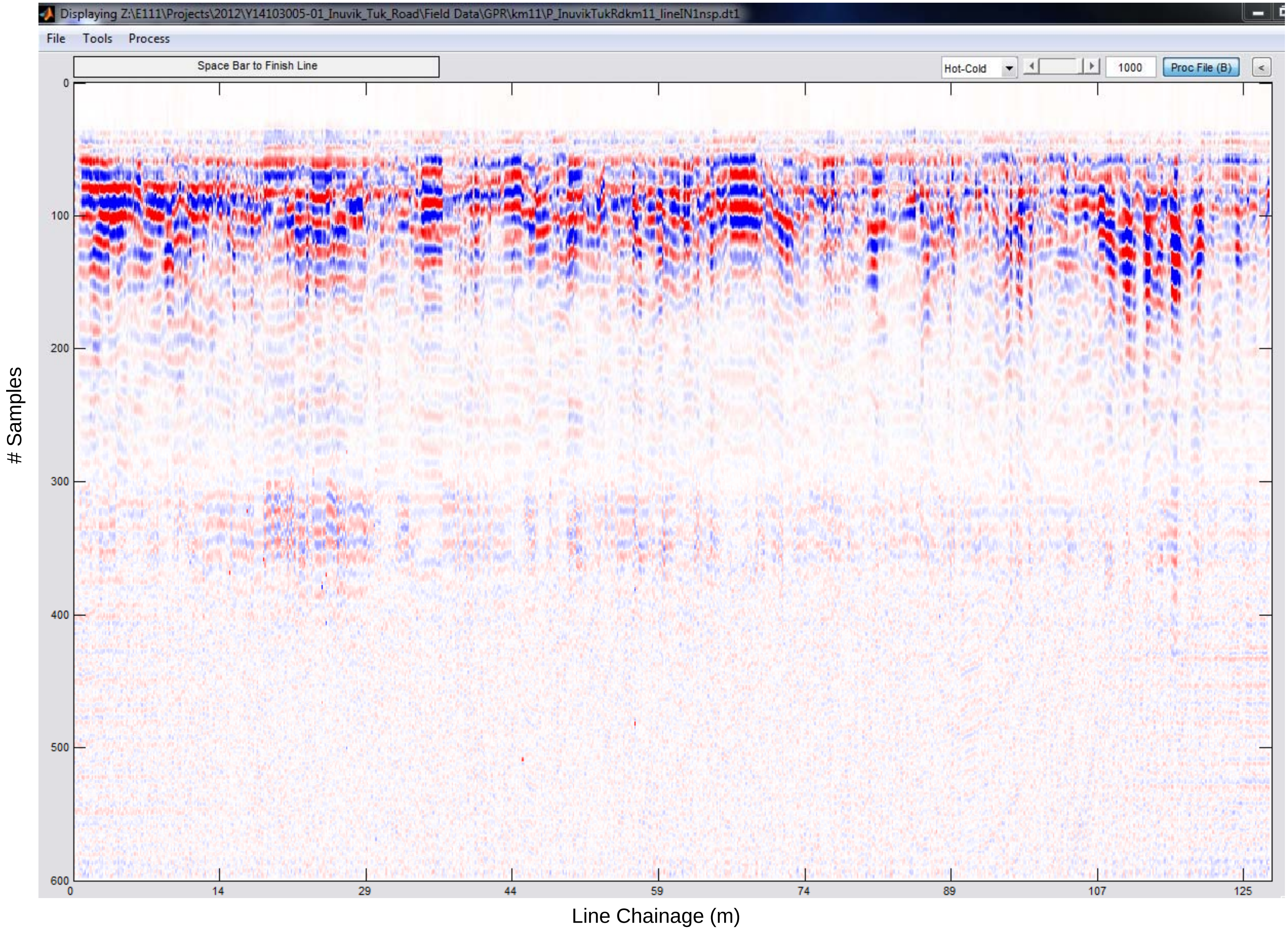
KIGGIAK - EBA

Inuvik to Tuktoyaktuk Highway
Terrain Assessment and Geophysical Investigation

GP1 KP12.5
Geophysical Data Overview Map

PROJECT NO.	DWN	CKD	APVD	REV
Y14103005-01	JA			000
OFFICE	DATE			
EBA-EDM	August 28, 2012			

Figure 1



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Inuvik to Tuktoyaktuk Highway
Terrain Assessment and Geophysical Investigation

GP1 KP12.5
GPR Profile
Crest of Thaw Slump

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Y14103005-01	JA			000	**Figure 2**
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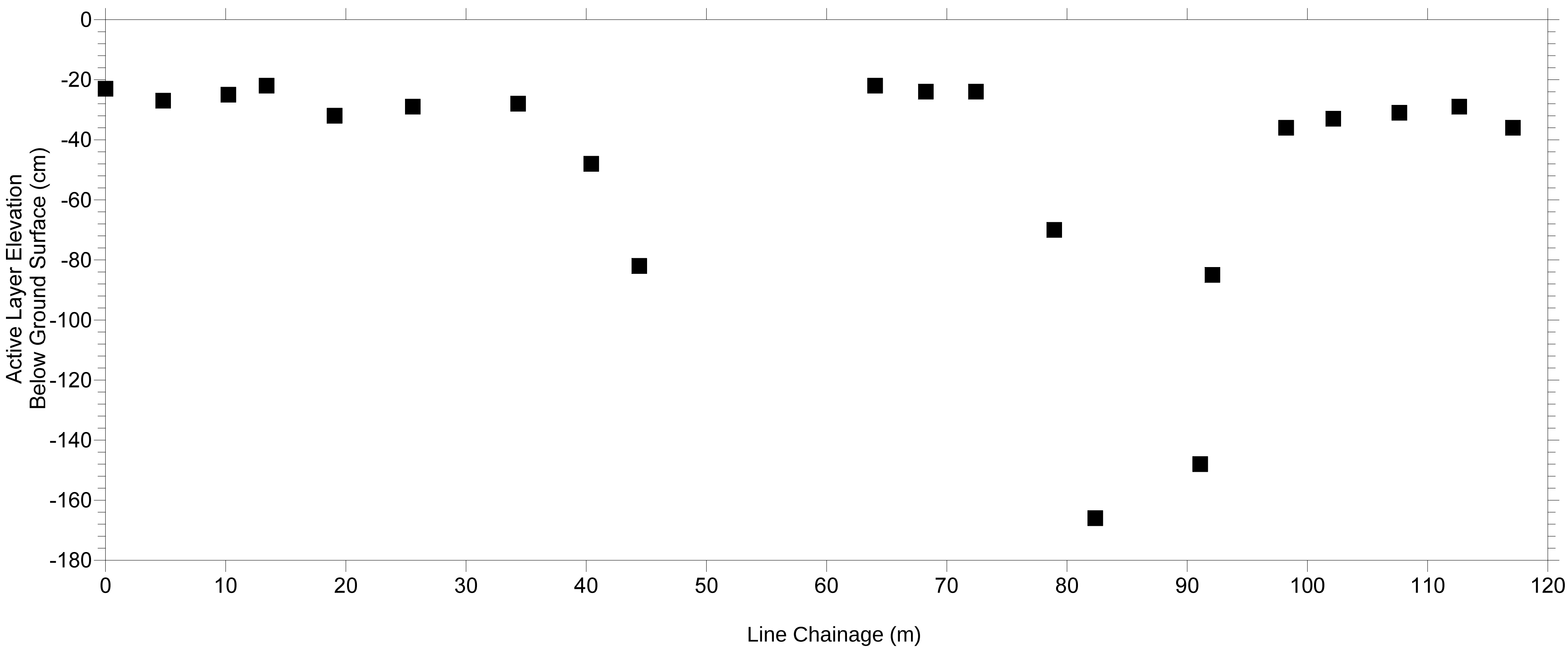

LEGEND

■ Active Layer Measurement

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Inuvik to Tuktoyaktuk Highway
Terrain Assessment and Geophysical Investigation

GP2 KP17
Active Layer Profile
Creek Crossing

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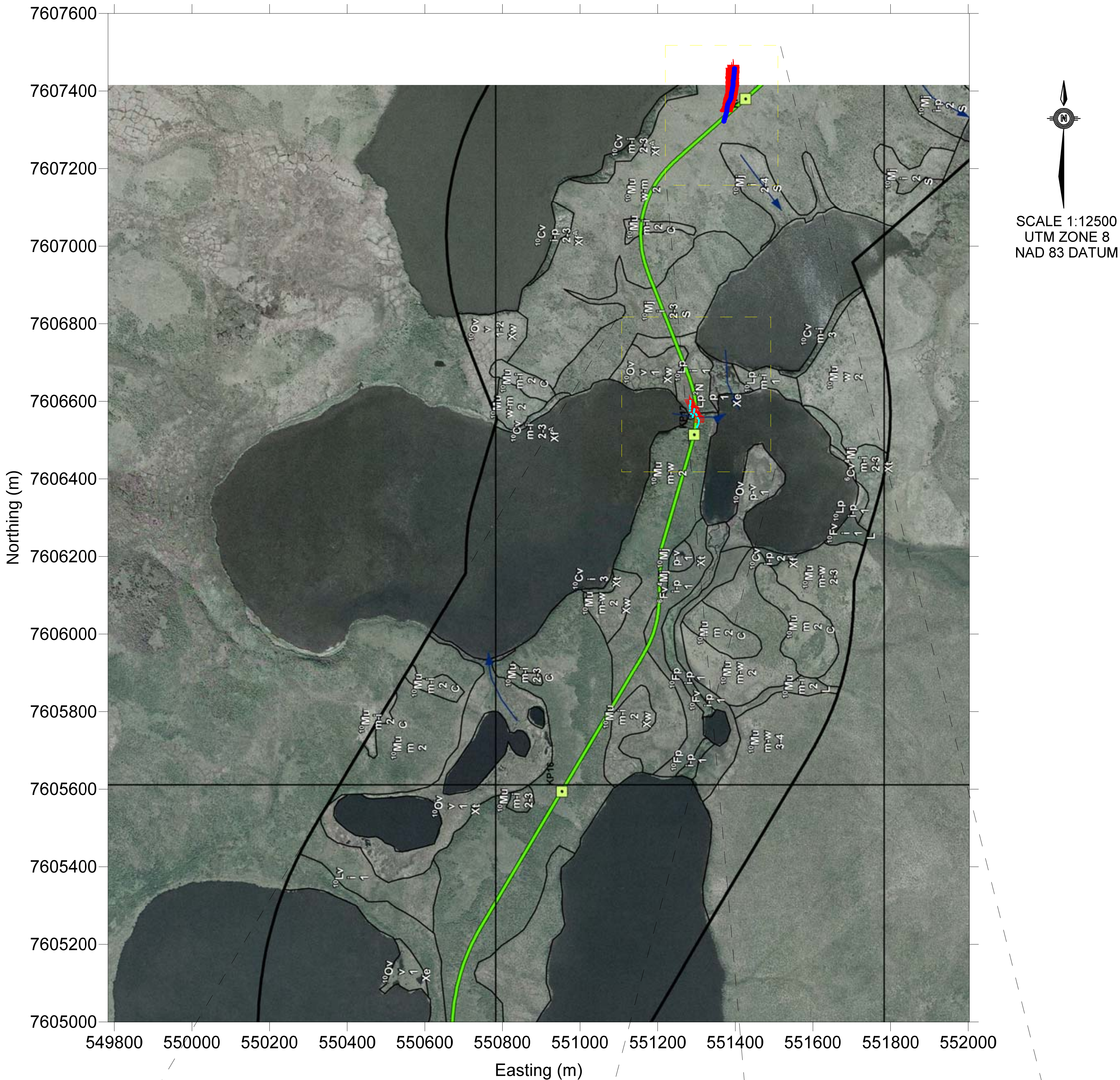
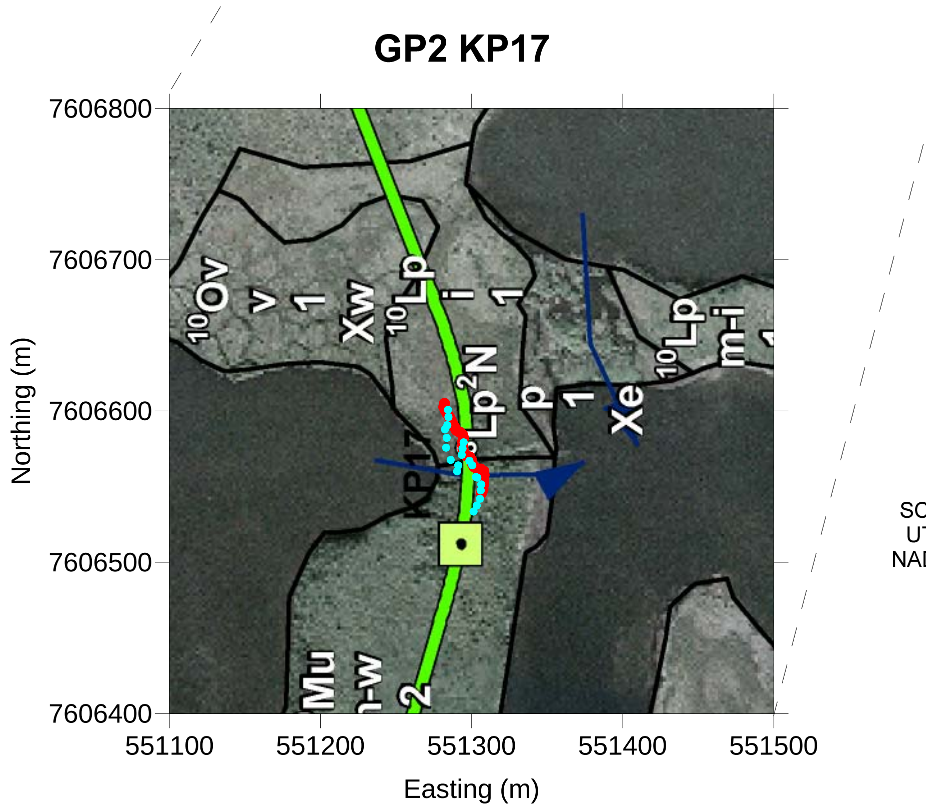
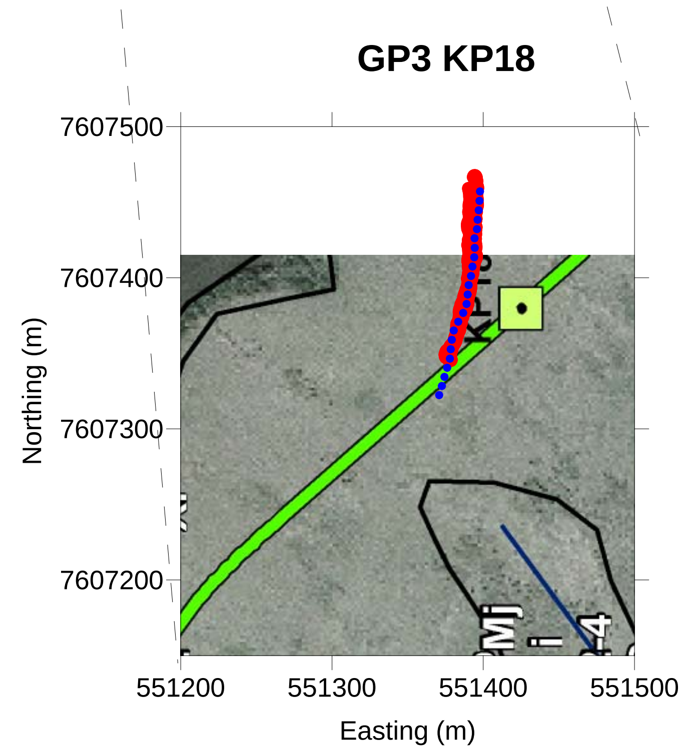
Figure 3







LEGEND

- Ground Penetrating Radar GPS Path
- Active Layer Measurement
- Proposed Road Alignment
- OhmMapper GPS Path
- Expanded Map View Area

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KIGGIAK - EBA

Inuvik to Tuktoyaktuk Highway
Terrain Assessment and Geophysical Investigation

GP2 KP17 & GP3 KP18
Geophysical Data Overview Map

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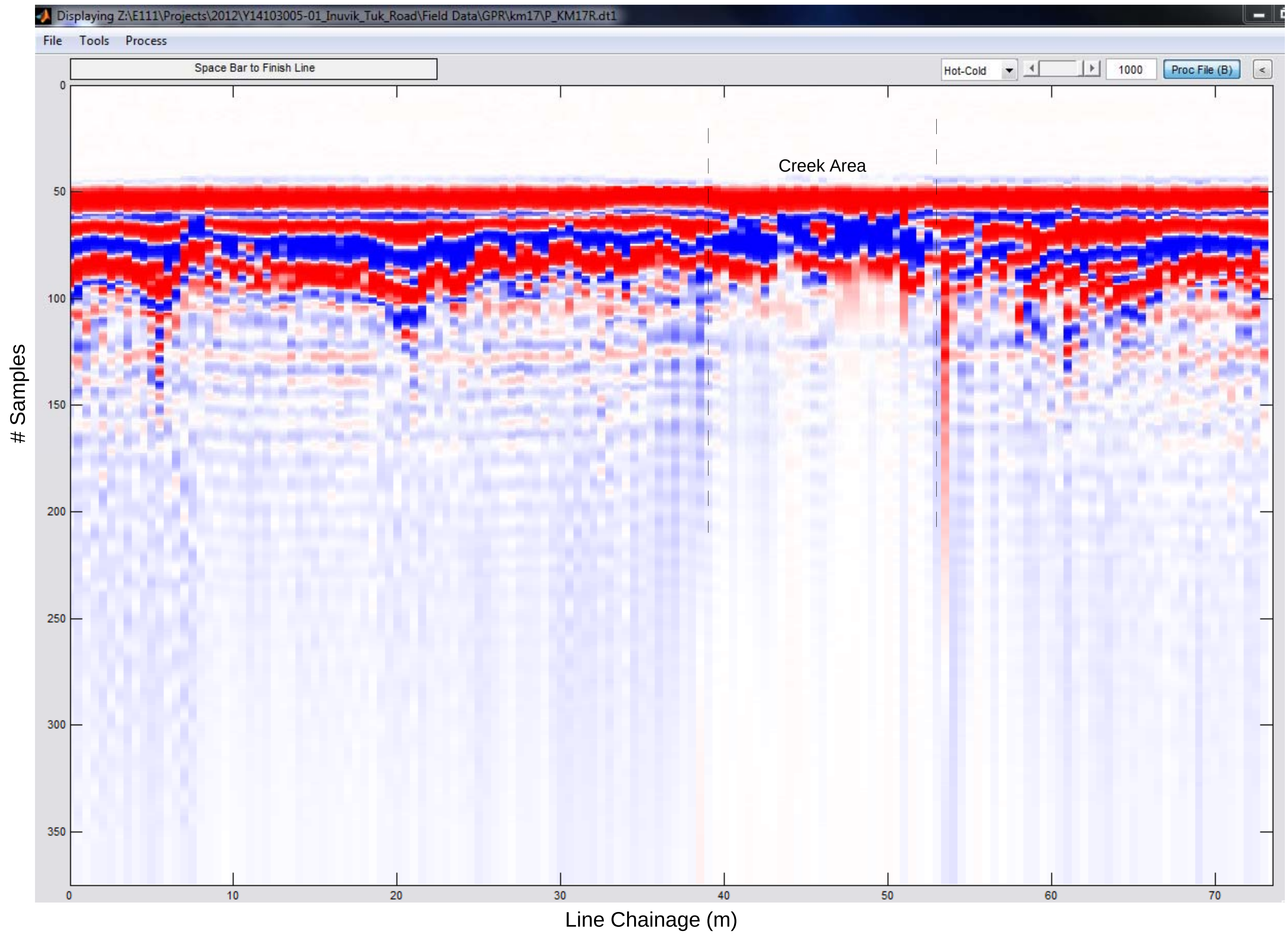
Figure 4



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Inuvik to Tuktoyaktuk Highway
Terrain Assessment and Geophysical Investigation

GP2 KP17
GPR Profile
Creek Crossing

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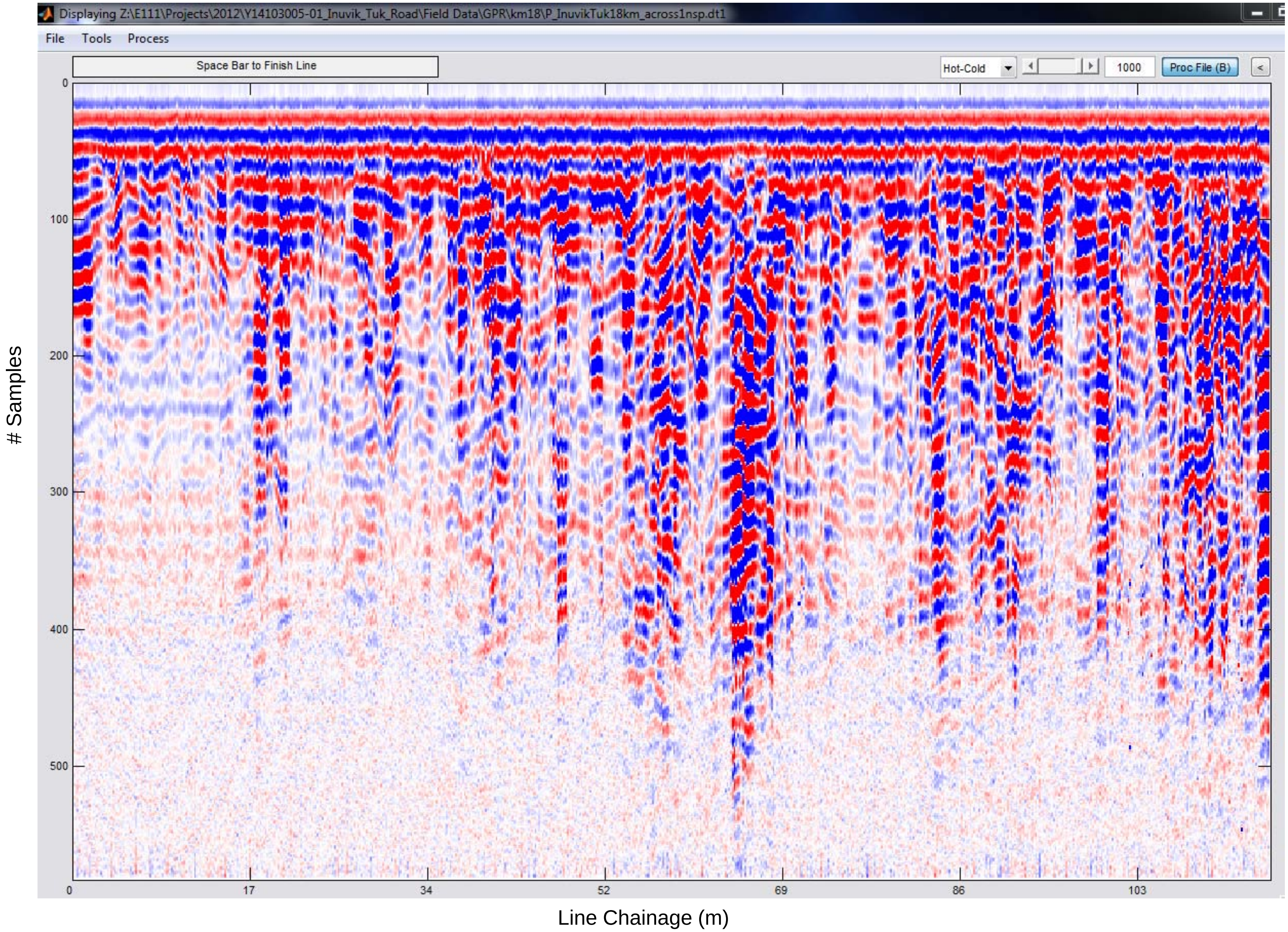
Figure 5



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Inuvik to Tuktoyaktuk Highway
Terrain Assessment and Geophysical Investigation

GP3 KP18
GPR Profile
Slope Break to Road Alignment (N to S)

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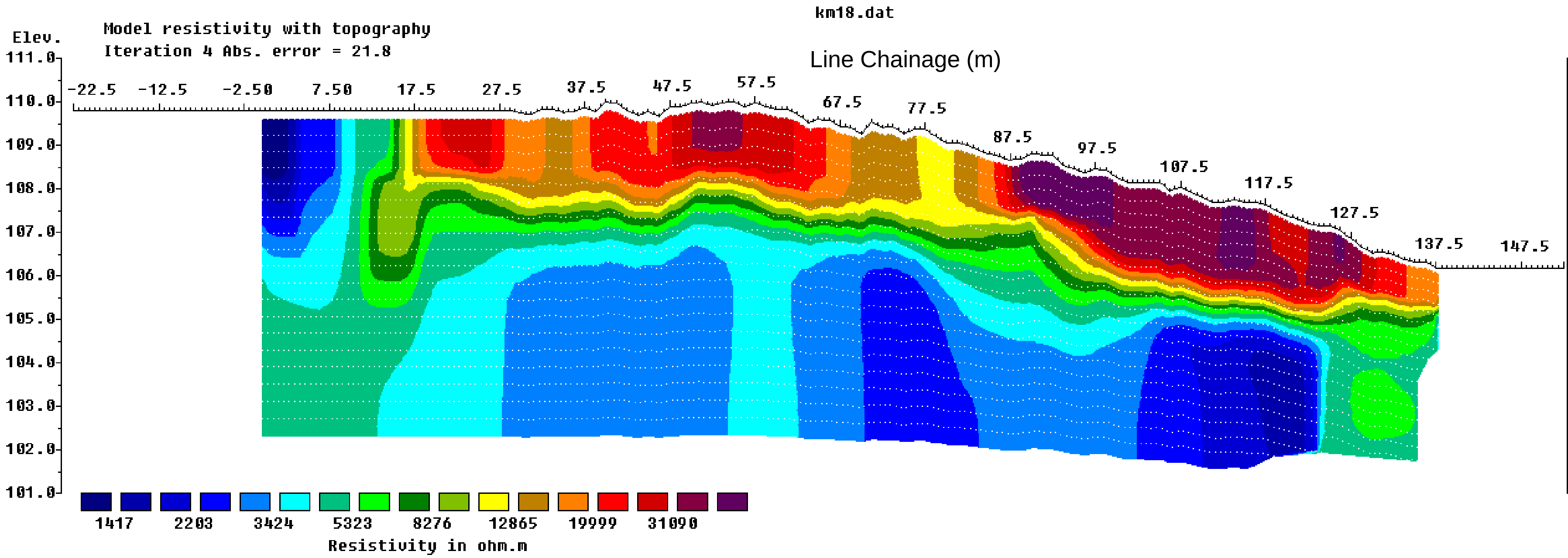
Figure 6



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Vertical exaggeration in model section display = 5.12
First electrode is located at -22.5 m.
Last electrode is located at 152.5 m. Unit Electrode Spacing = 0.625 m.

CLIENT	Inuvik to Tuktoyaktuk Highway Terrain Assessment and Geophysical Investigation				
Stantec	**GP3 KP18** **Modelled Resistivity Profile** **Road Alignment to Slope Break (S to N)**				
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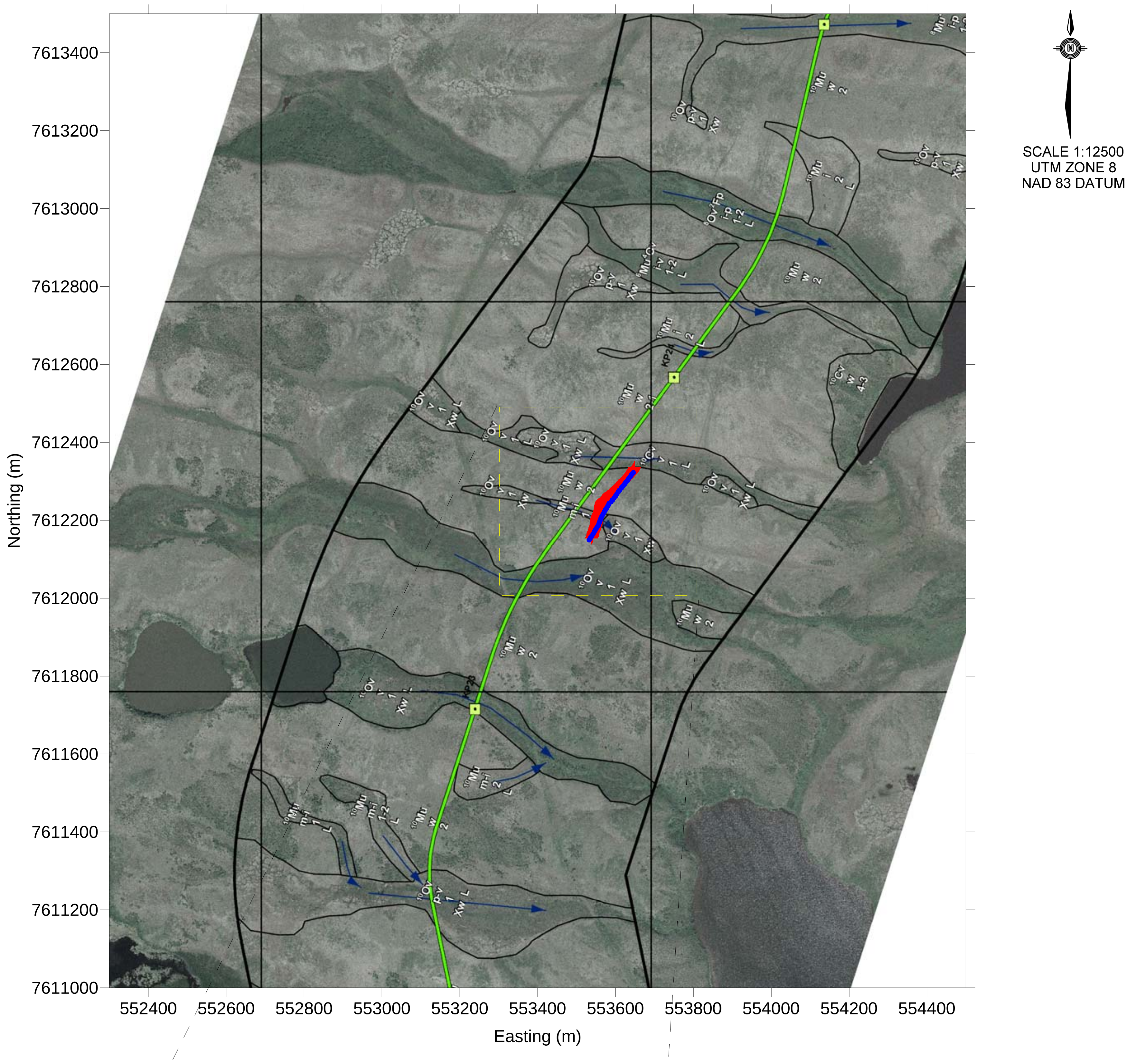
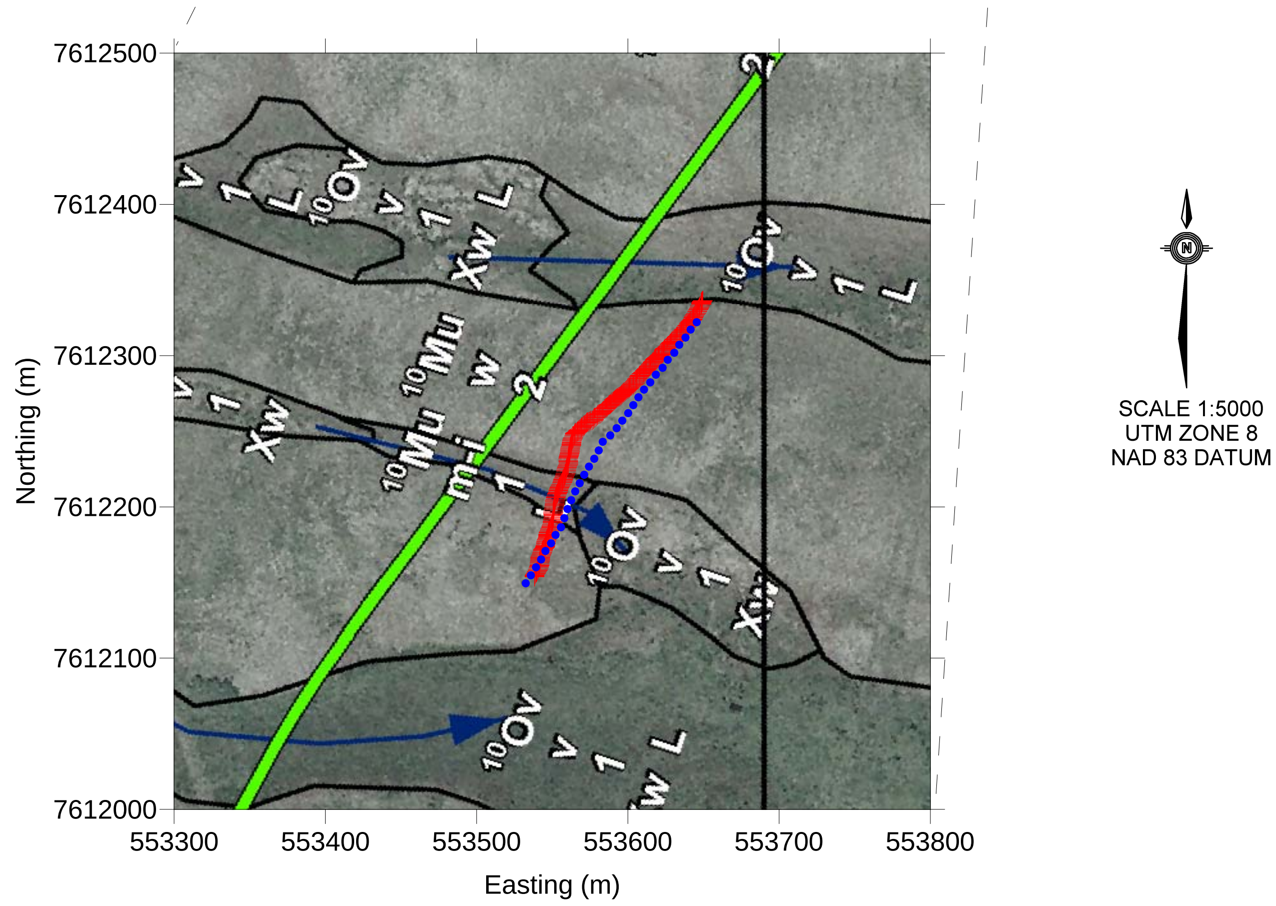
	OFFICE EBA-EDM	DATE August 28, 2012			**Figure 7**





LEGEND

- Ground Penetrating Radar GPS Path
- Proposed Road Alignment
- OhmMapper GPS Path
- Expanded Map View Area

CLIENT

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KIGGIAK - EBA

Inuvik to Tuktoyaktuk Highway
Terrain Assessment and Geophysical Investigation

GP 4 KP23.5
Geophysical Data Overview Map

PROJECT NO.	DWN	CKD	APVD	REV
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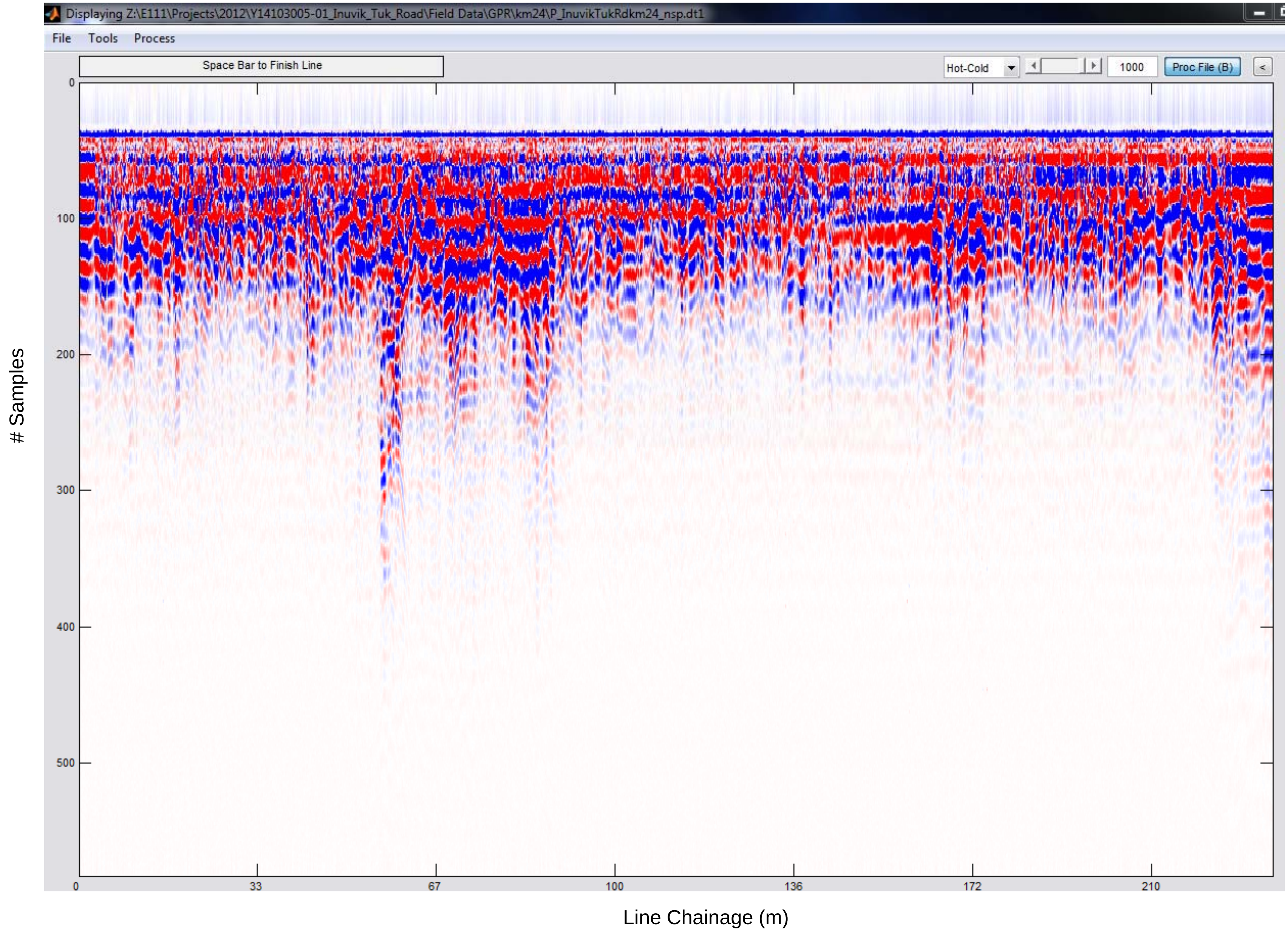
EBA-EDM	August 28, 2012

Figure 8



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Inuvik to Tuktoyaktuk Highway
Terrain Assessment and Geophysical Investigation

GP4 KP23.5
GPR Profile
Drainage Zone

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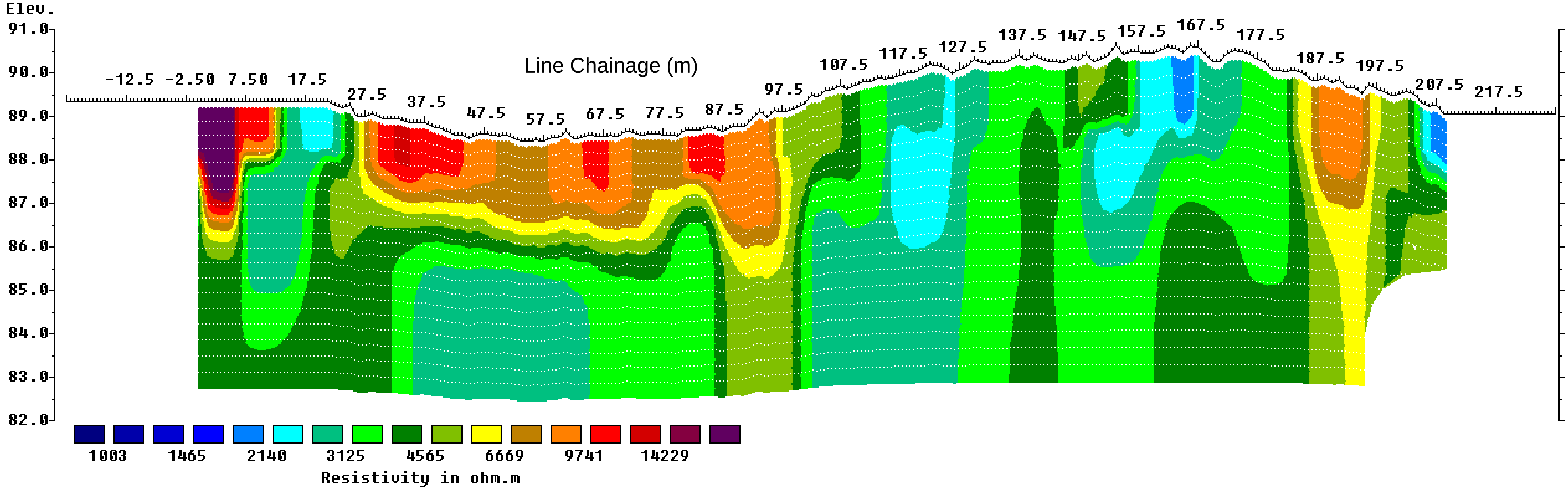
Figure 9

km24.dat

Model resistivity with topography
Iteration 4 Abs. error = 36.5



Horizontal scale is 3.00 pixels per unit spacing
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First electrode is located at -22.5 m.
Last electrode is located at 227.5 m. Unit Electrode Spacing = 0.625 m.

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Inuvik to Tuktoyaktuk Highway
Terrain Assessment and Geophysical Investigation

GP4 KP23.5
Modelled Resistivity Profile
Drainage Zone

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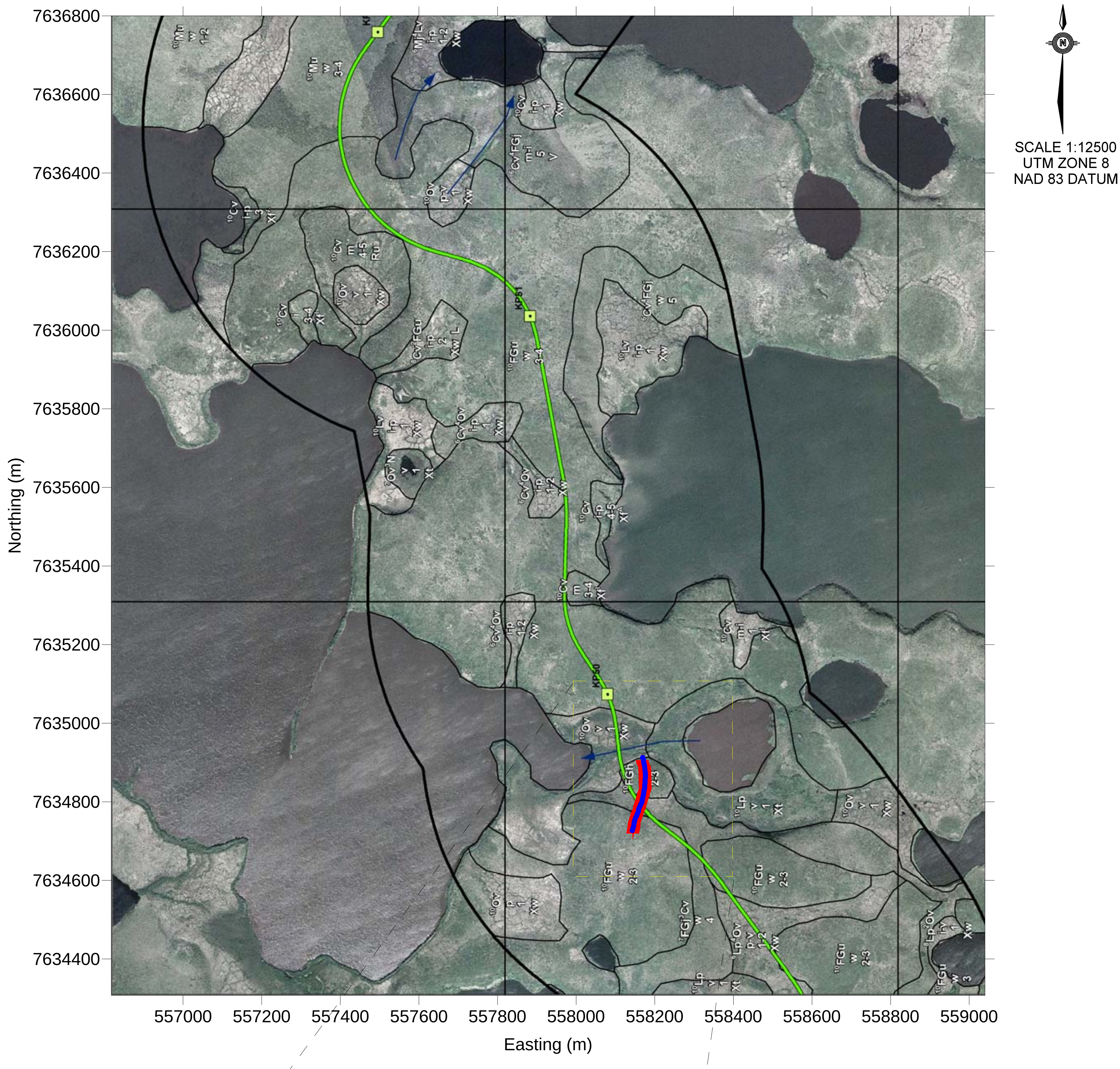
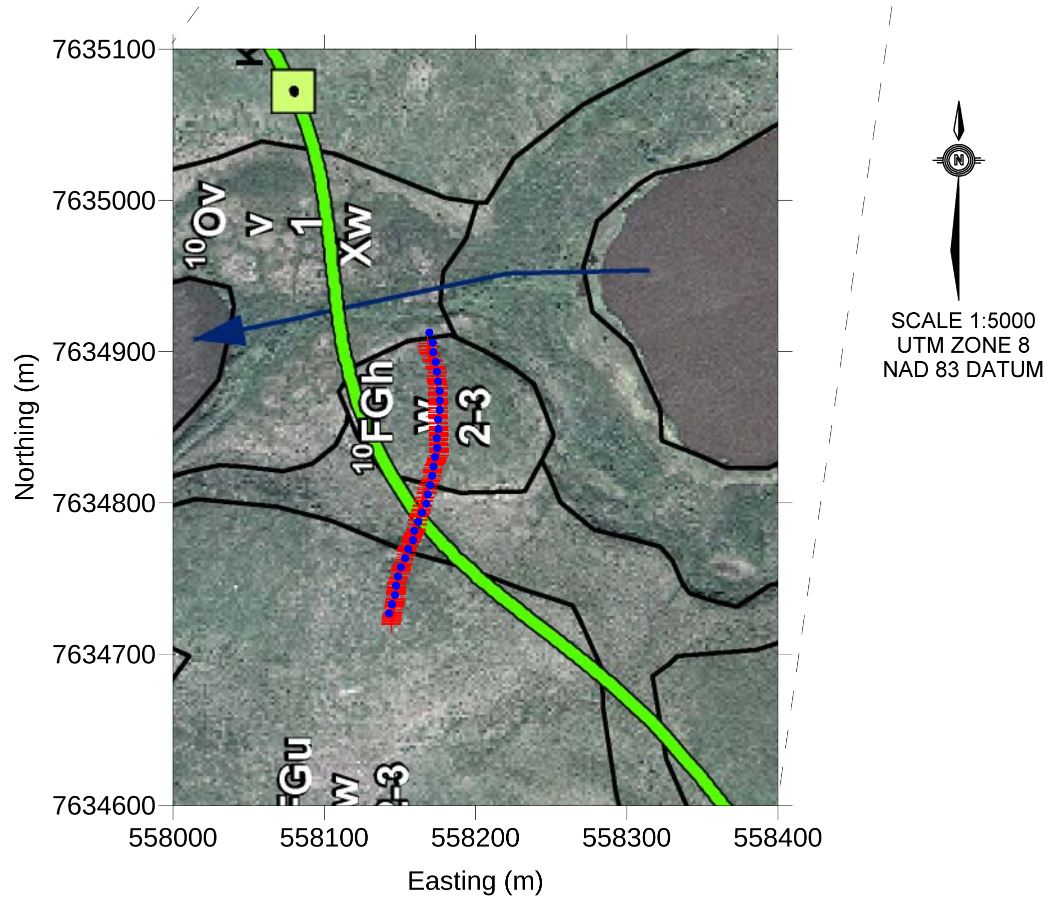
Figure 10





LEGEND

- Ground Penetrating Radar GPS Path
- Proposed Road Alignment
- OhmMapper GPS Path
- Expanded Map View Area

CLIENT: Stantec

KIGGIAK - EBA

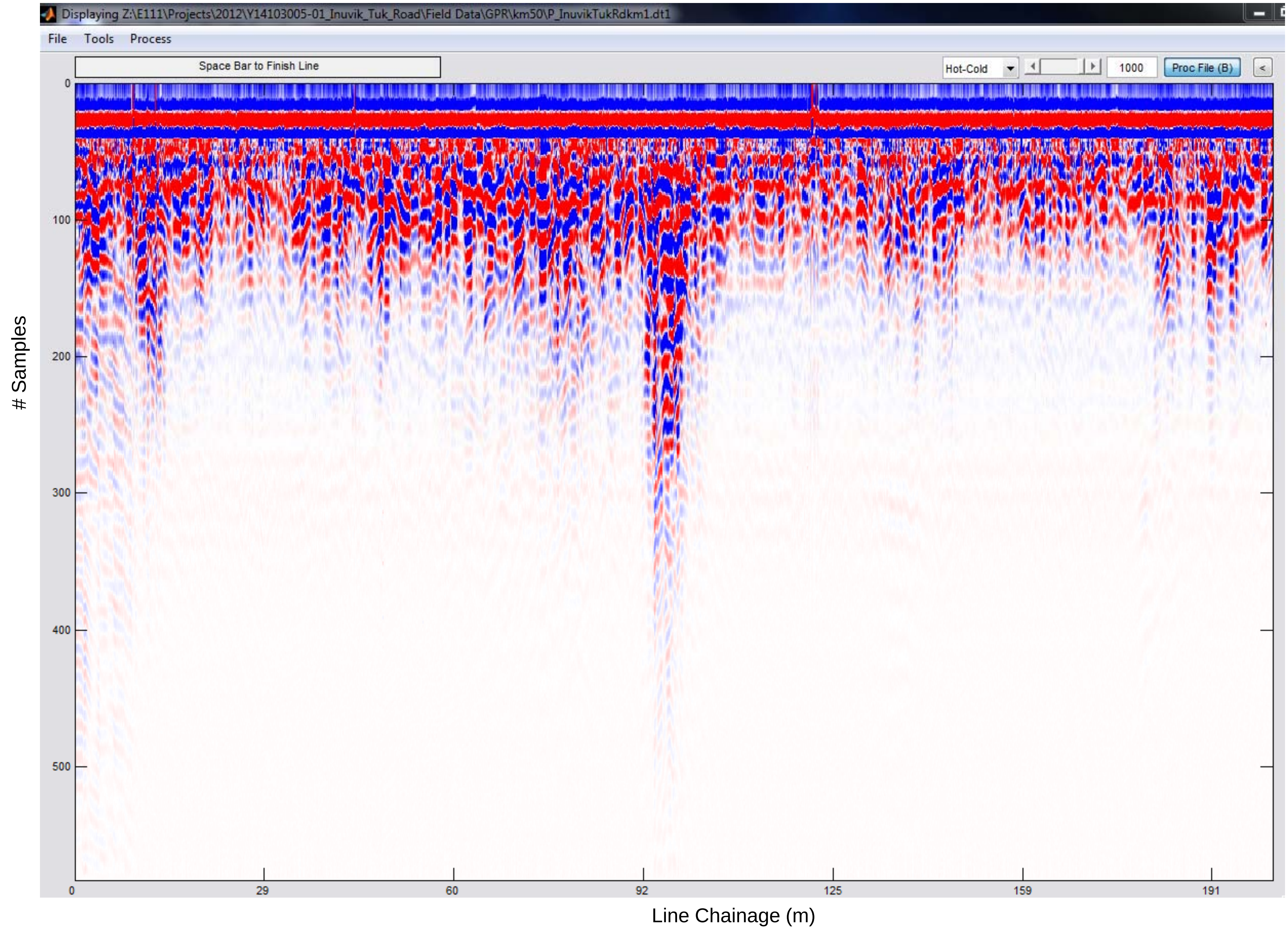
Inuvik to Tuktoyaktuk Highway
Terrain Assessment and Geophysical Investigation

GP5 KP50
Geophysical Data Overview Map

PROJECT NO.	DWN	CKD	APVD	REV
Y14103005-01	JA			000

OFFICE	DATE
EBA-EDM	August 28, 2012

Figure 11



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KIGGIAK - EBA

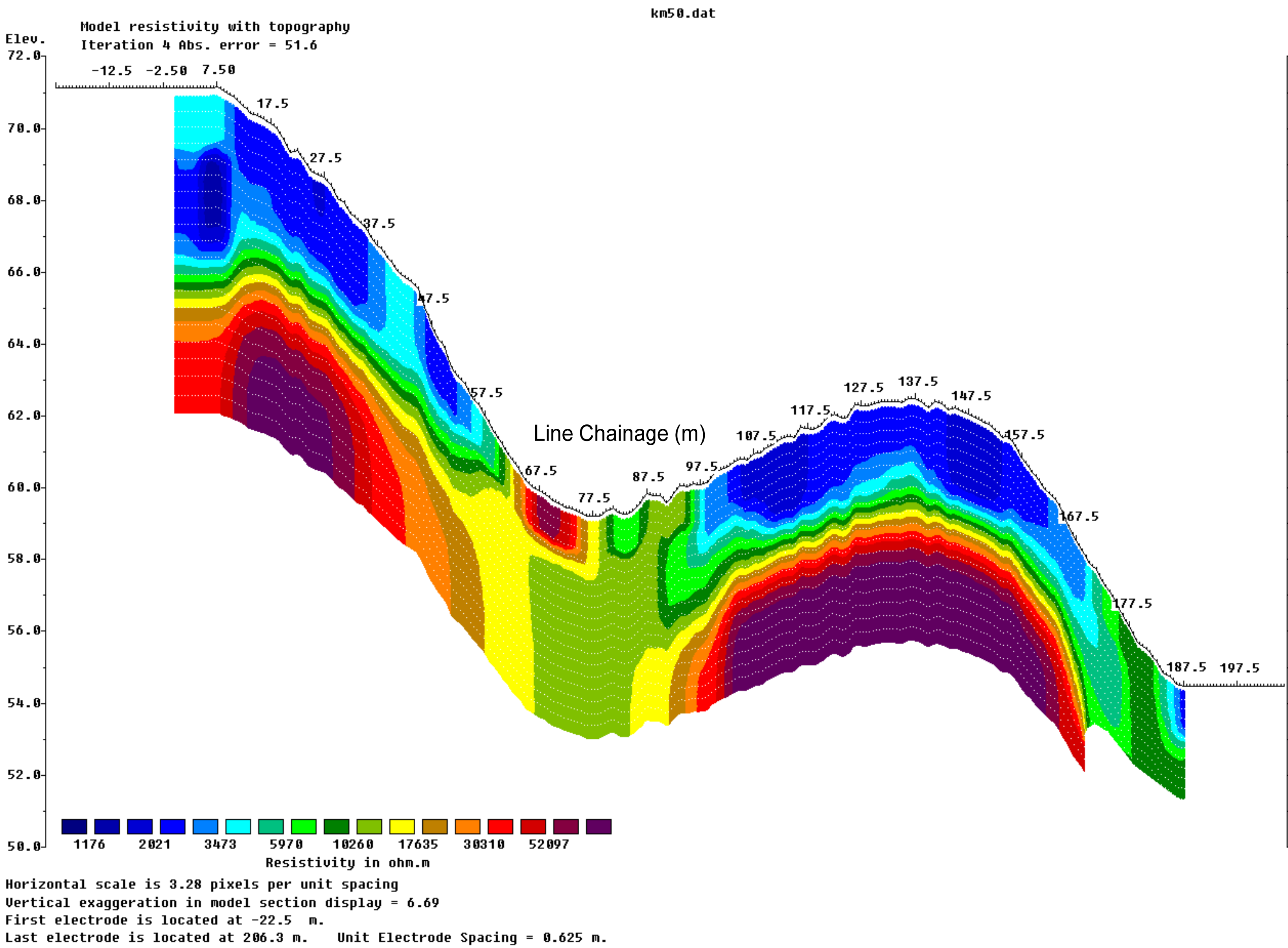
Inuvik to Tuktoyaktuk Highway
Terrain Assessment and Geophysical Investigation

GP5 KP50
GPR Profile
Granular Area

PROJECT NO.	DWN	CKD	APVD	REV
Y14103005-01	JA			000

OFFICE	DATE
EBA-EDM	August 28, 2012

Figure 12



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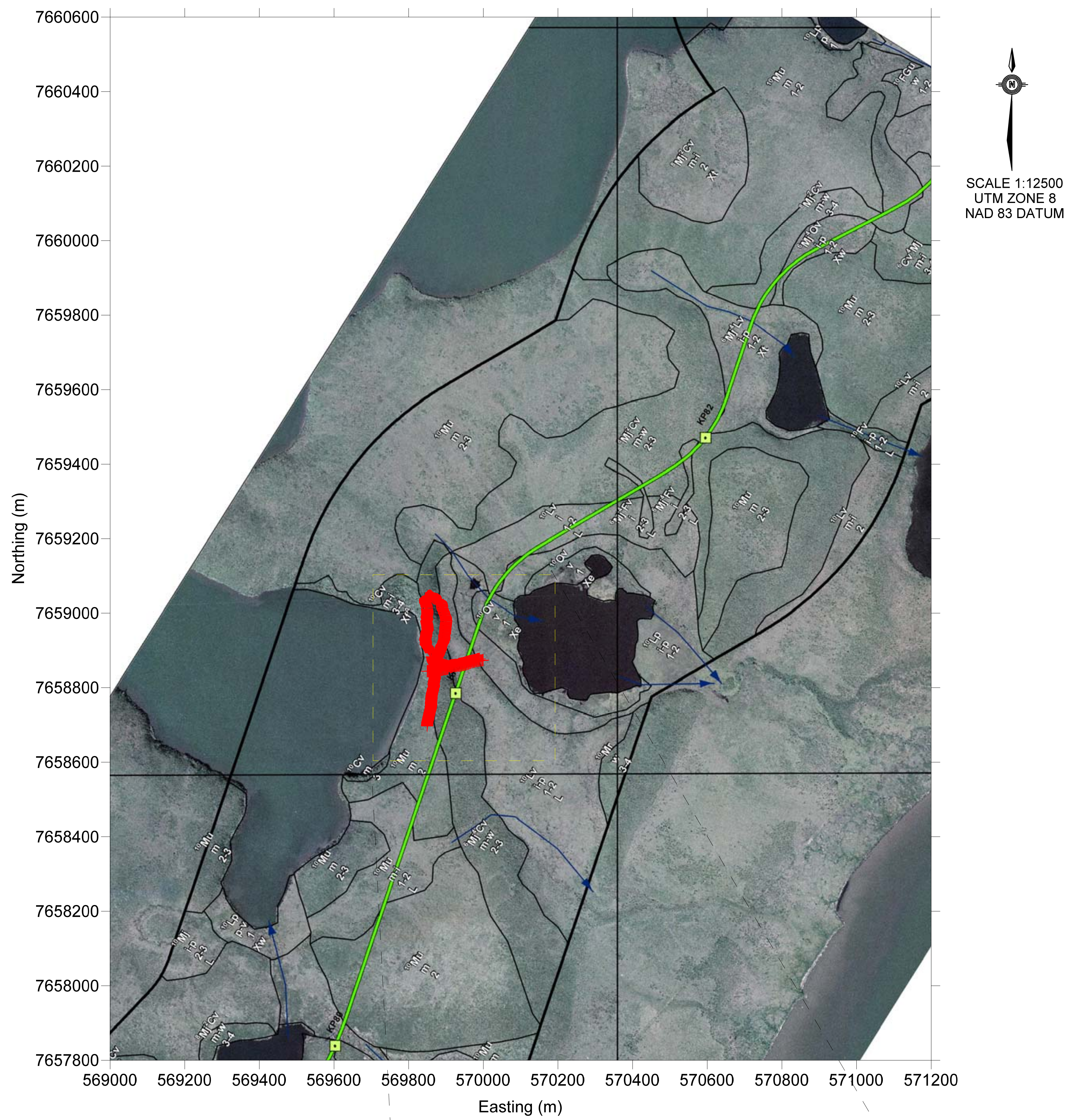
KIGGIAK - EBA

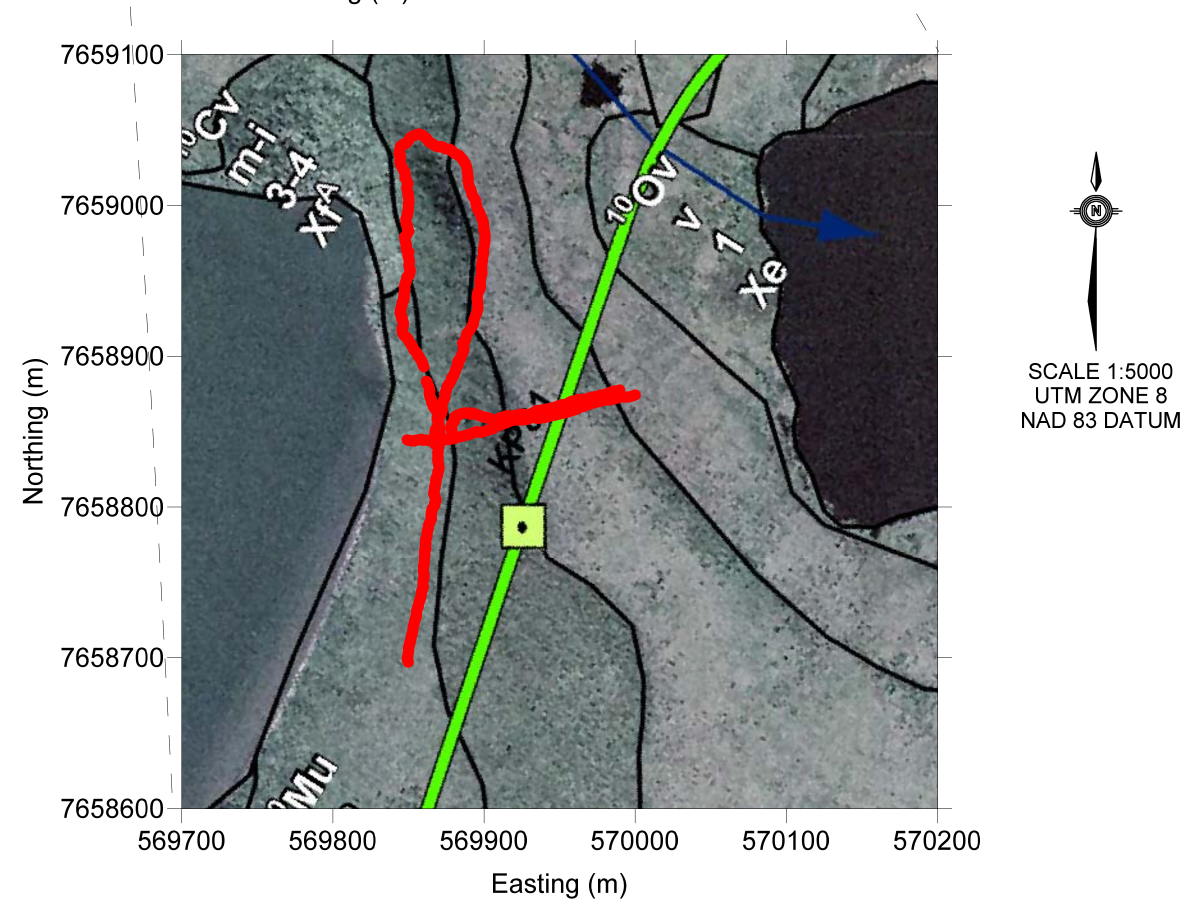
Inuvik to Tuktoyaktuk Highway
Terrain Assessment and Geophysical Investigation

GP5 KP50
Modelled Resistivity Profile
Granular Area

PROJECT NO.	DWN	CKD	APVD	REV
Y14103005-01	JA			000
OFFICE	DATE			
EBA-EDM	August 28, 2012			

Figure 13





LEGEND

- Ground Penetrating Radar GPS Path
- Proposed Road Alignment
- Expanded Map View Area

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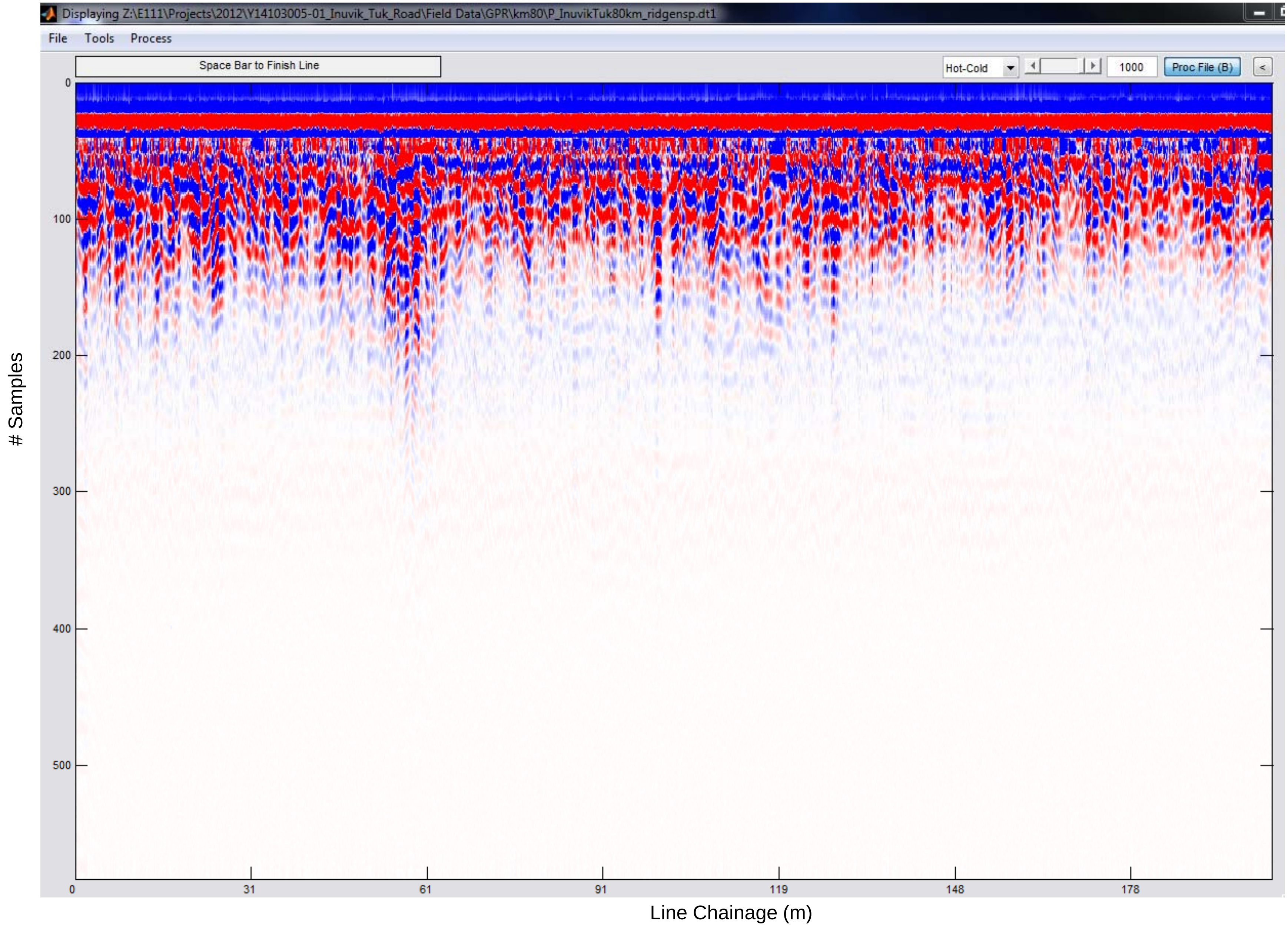
KIGGIAK - EBA

Inuvik to Tuktoyaktuk Highway
Terrain Assessment and Geophysical Investigation

GP6 KP81
Geophysical Data Overview Map

PROJECT NO.	DWN	CKD	APVD	REV
Y14103005-01	JA			000
OFFICE	DATE			
EBA-EDM	August 28, 2012			

Figure 14



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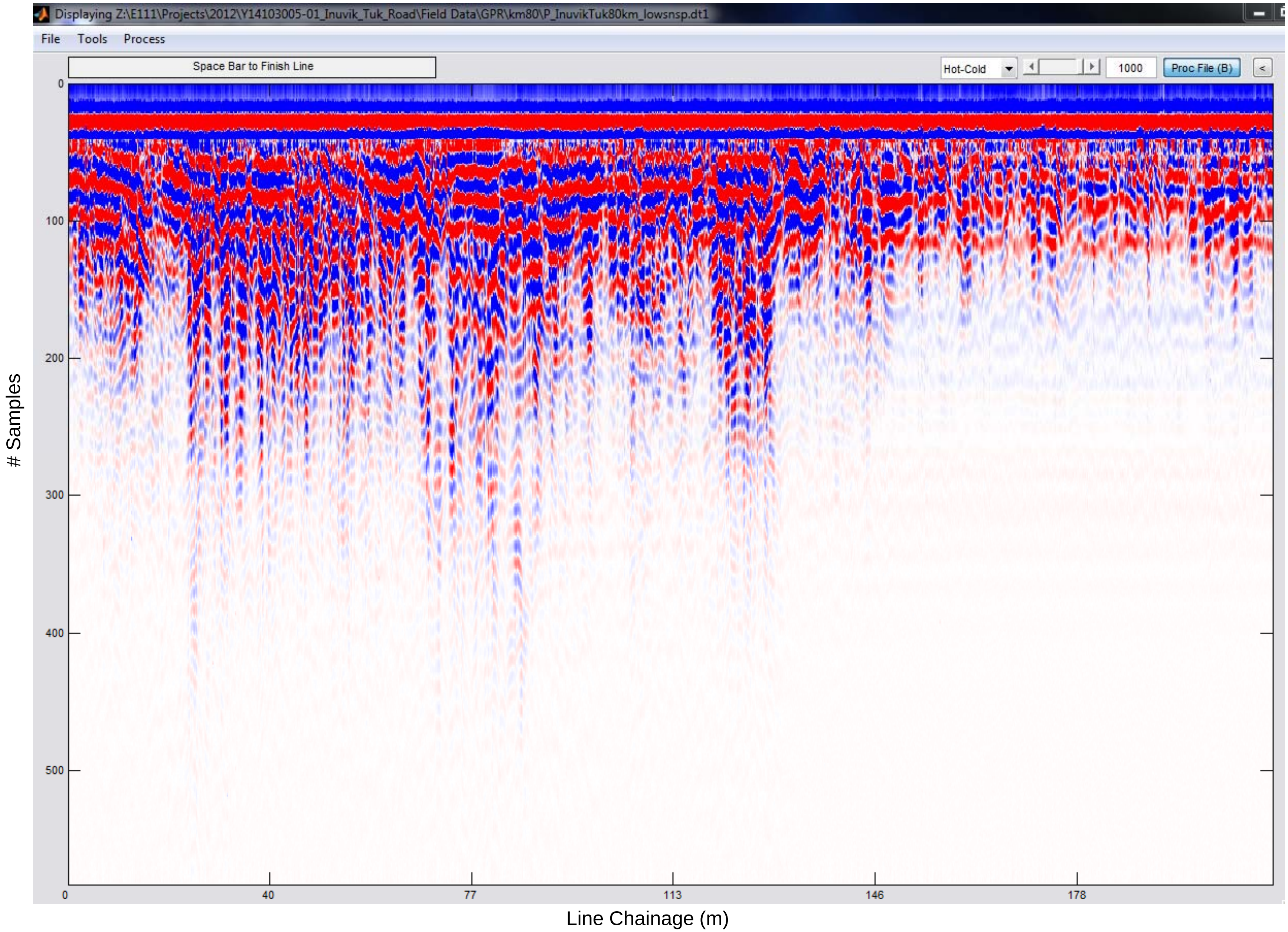
KIGGIAK - EBA

Inuvik to Tuktoyaktuk Highway
Terrain Assessment and Geophysical Investigation

GP6 KP81
GPR Profile
Along Ridge Line

PROJECT NO.	DWN	CKD	APVD	REV
Y14103005-01	JA			000
OFFICE	DATE			
EBA-EDM	August 28, 2012			

Figure 15



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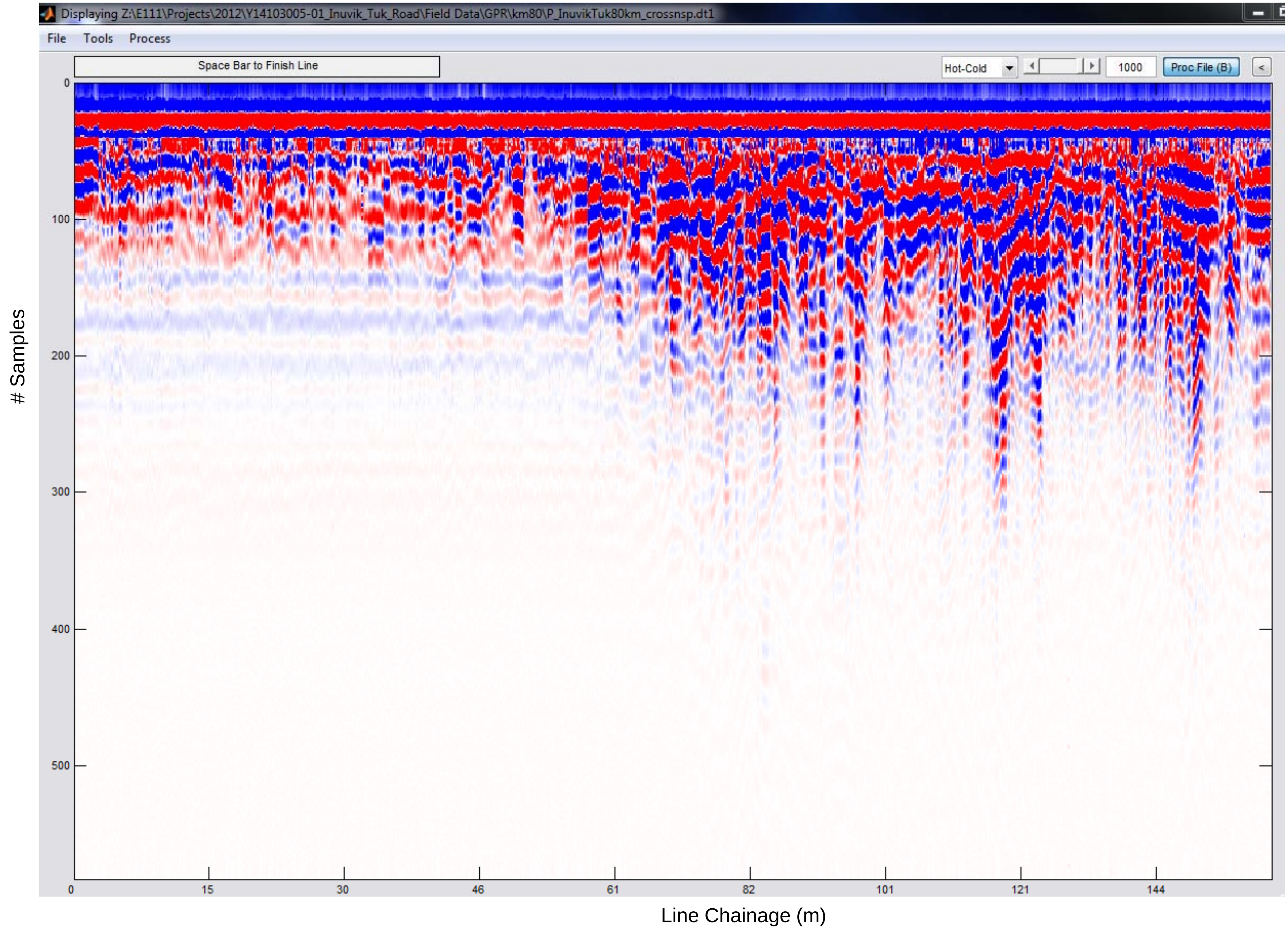
KIGGIAK - EBA

Inuvik to Tuktoyaktuk Highway
Terrain Assessment and Geophysical Investigation

GP6 KP81
GPR Profile
Tow of Ridge

PROJECT NO.	DWN	CKD	APVD	REV
Y14103005-01	JA			000
OFFICE	DATE			
EBA-EDM	August 28, 2012			

Figure 16



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KIGGIAK - EBA

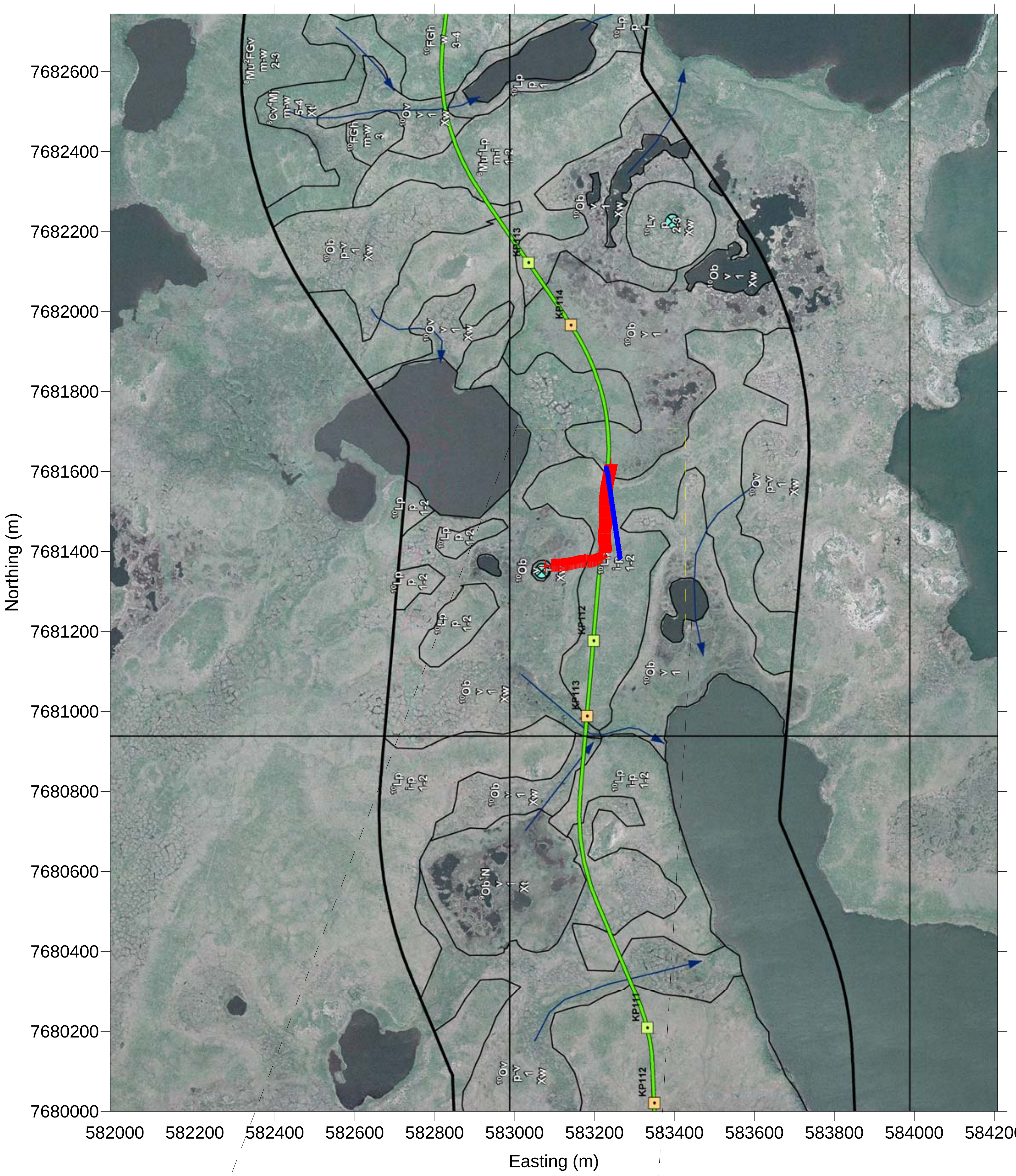
Inuvik to Tuktoyaktuk Highway
Terrain Assessment and Geophysical Investigation

GP6 KP81
GPR Profile
Perpendicular to Ridge Line

PROJECT NO.	DWN	CKD	APVD	REV
Y14103005-01	JA			000

OFFICE	DATE
EBA-EDM	August 28, 2012

Figure 17



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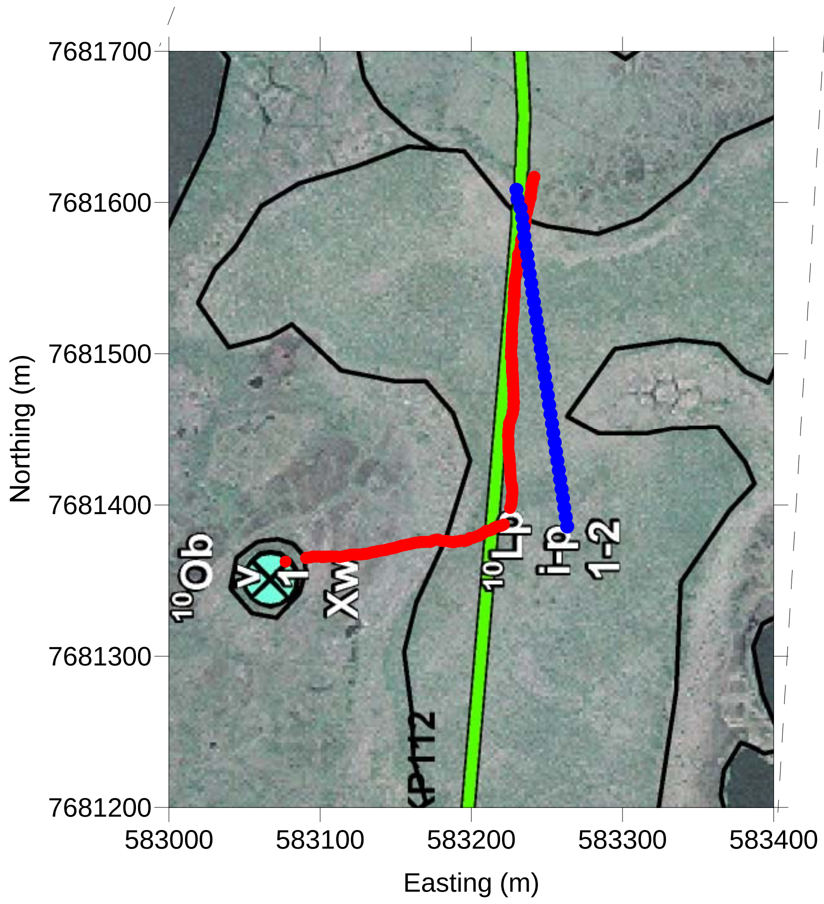
UTM ZONE 8
NAD 83 DATUM



SCALE 1:5000
UTM ZONE 8
NAD 83 DATUM

LEGEND

- Ground Penetrating Radar GPS Path
- Proposed Road Alignment
- OhmMapper GPS Path
- Expanded Map View Area

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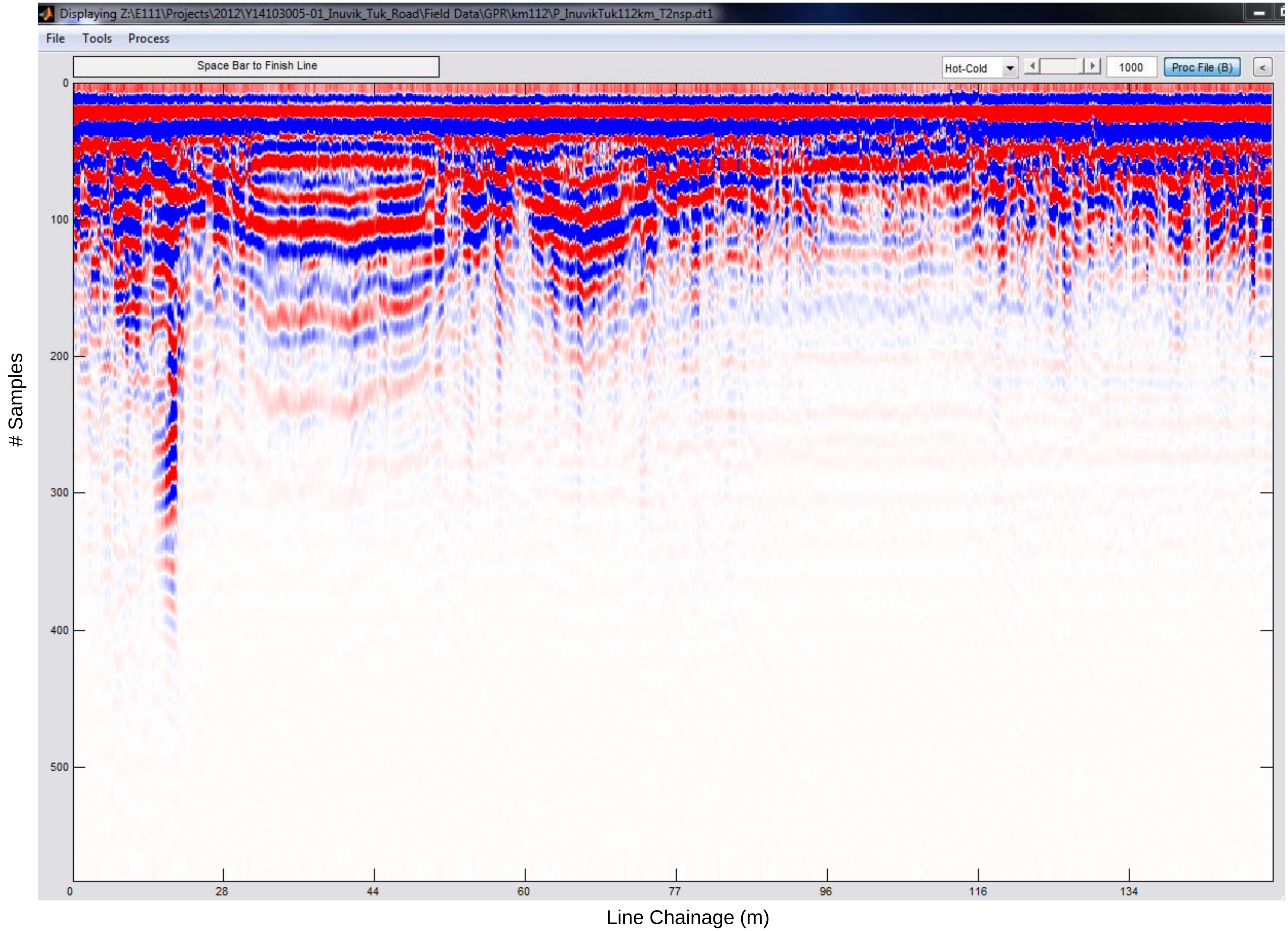
KIGGIAK - EBA

Inuvik to Tuktoyaktuk Highway
Terrain Assessment and Geophysical Investigation

GP7 KP112
Geophysical Data Overview Map

PROJECT NO.	DWN	CKD	APVD	REV
Y14103005-01	JA			000
OFFICE	DATE			
EBA-EDM	August 28, 2012			

Figure 18



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KIGGIAK - EBA

Inuvik to Tuktoyaktuk Highway
Terrain Assessment and Geophysical Investigation

GP7 KP112
GPR Profile
Ice Wedge Polygon Zone

PROJECT NO.	DWN	CKD	APVD	REV
Y14103005-01	JA			000
OFFICE	DATE			
EBA-EDM	August 28, 2012			

Figure 19