Seismic Imaging of crystalline crust in Canada's Superior Archean province: Progress with the Metal Earth project

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METAL EARTH

A new Canadian research initiative funded by Canada First Research Excellence Fund.

CANADA FIRST RESEARCH EXCELLENCE FUND

Canada

Laurentian University / Université Laurentienne
HARQUAIL SCHOOL OF EARTH SCIENCES / ÉCOLE DES SCIENCES DE LA TERRE

MERC
Mineral Exploration Research Centre

Introduction

- **Metal Earth** is an applied research and development program led by Laurentian University with $104 million funding from the Canada First Research Excellence Fund and federal/provincial/industry partners.
- By focusing on the **Precambrian Era**, Metal Earth aims to answer fundamental questions related to **differential metal endowment** in both space and time.
- The project intends to determine the **geological, geochemical, and geophysical differences** between metal endowed, less endowed, and barren areas with seemingly equivalent geological settings.
- Metal Earth geophysical data includes **reflection seismic, MagnetoTelluric (MT), gravity, and passive seismic** surveys along several transects in the Archean Superior geological province of Canada, with an overall length of more than 1000 km extending from southeastern Quebec to north-western Ontario.

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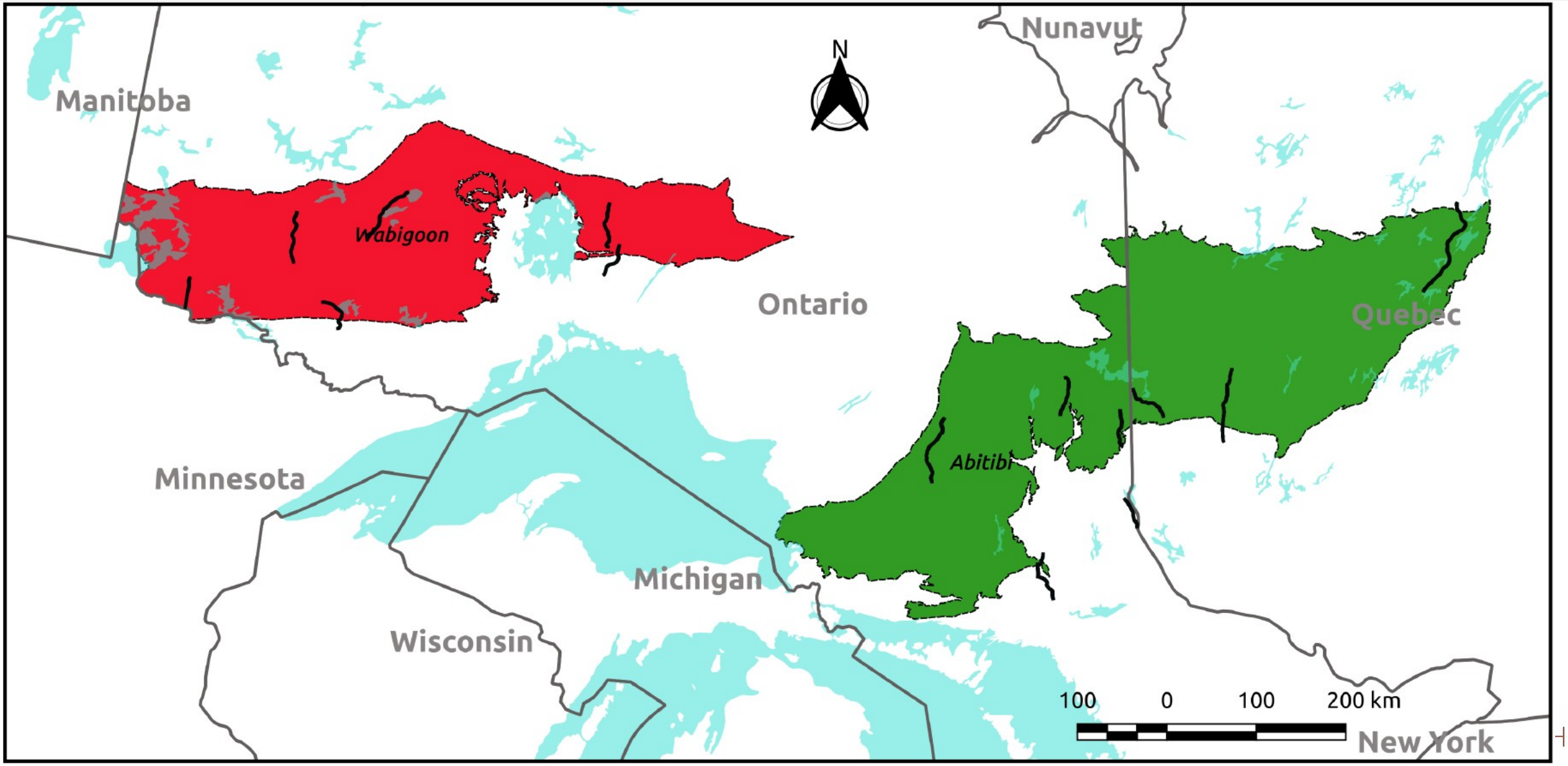
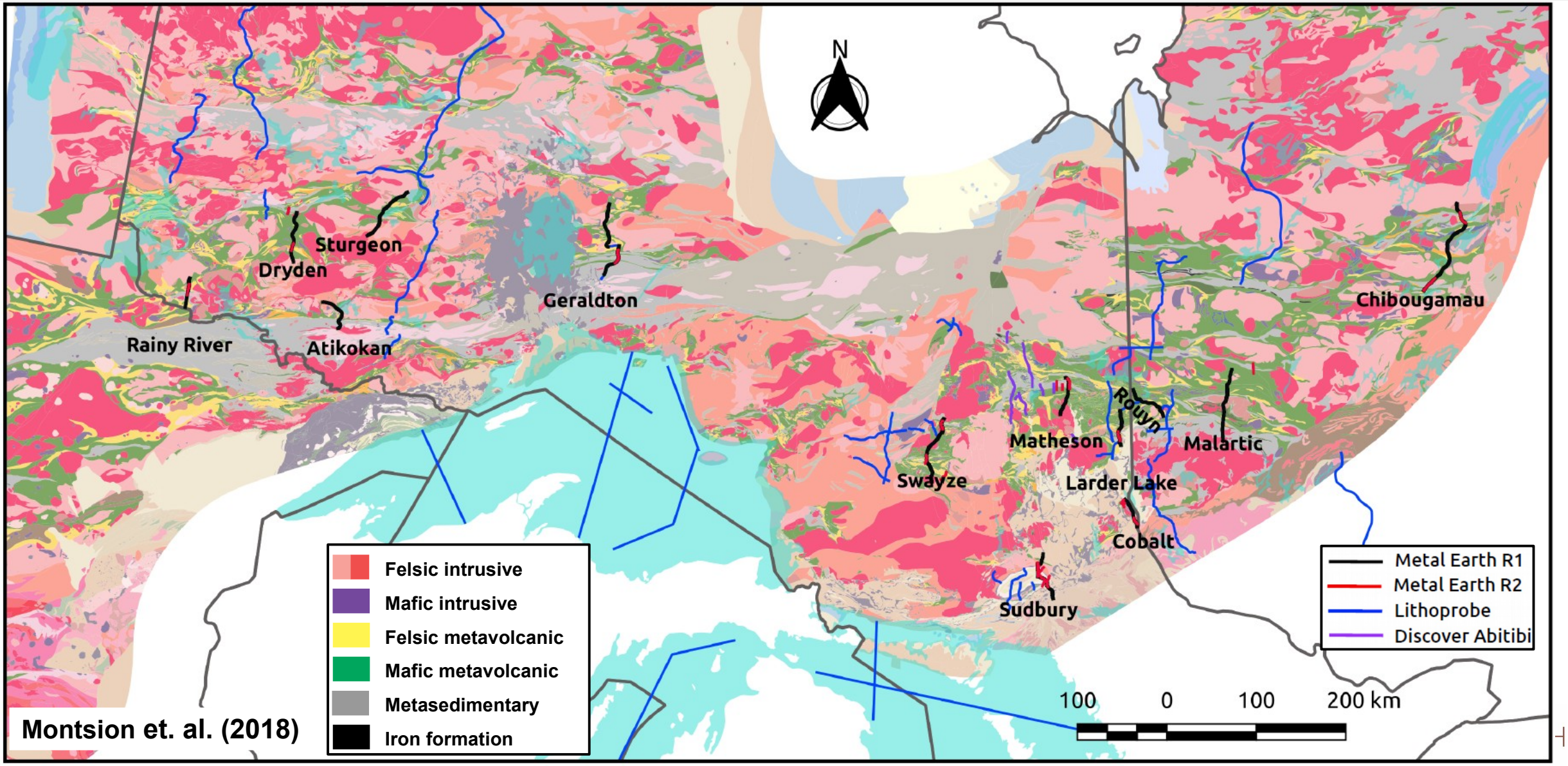
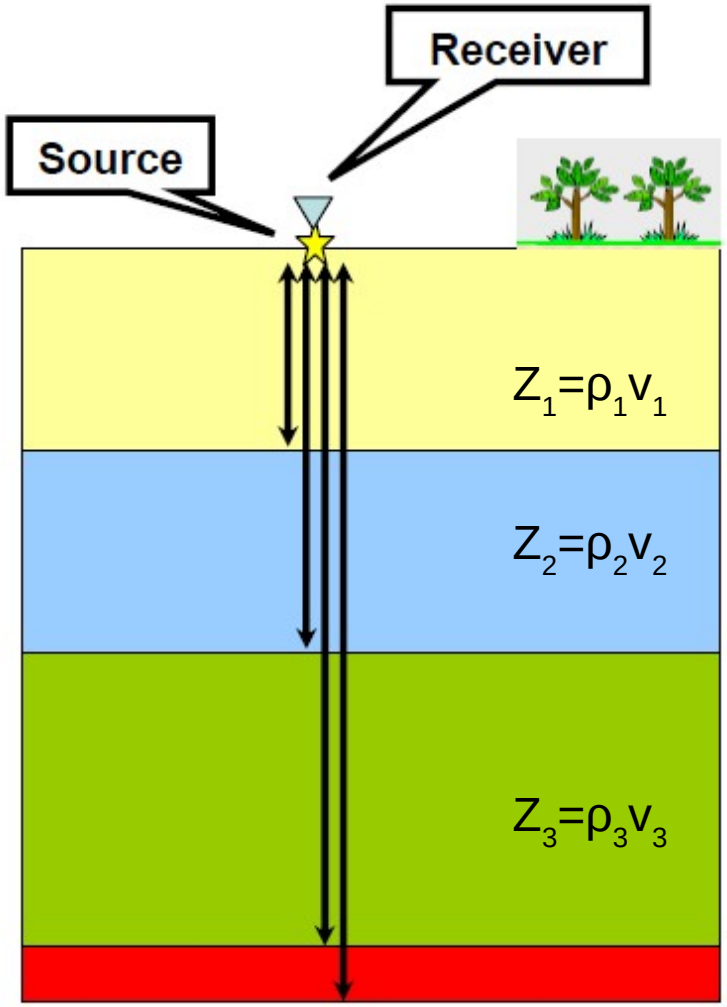
Abitibi and Wabigoon Subprovince of Superior



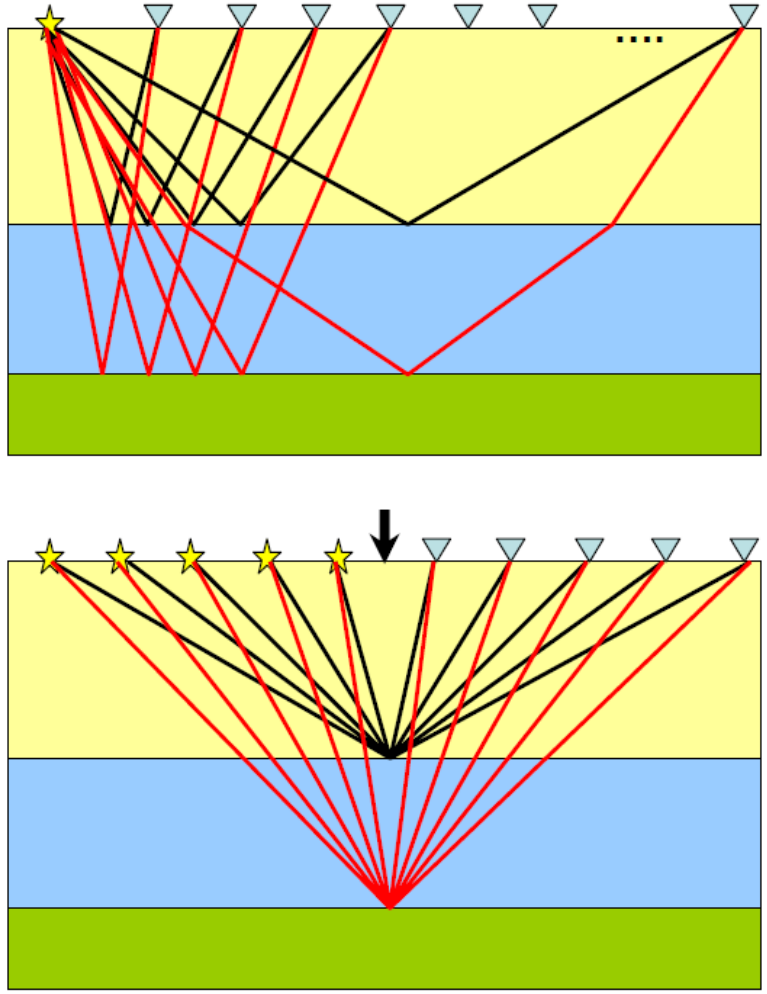
Lithological Map of Superior Province and Seismic Transects



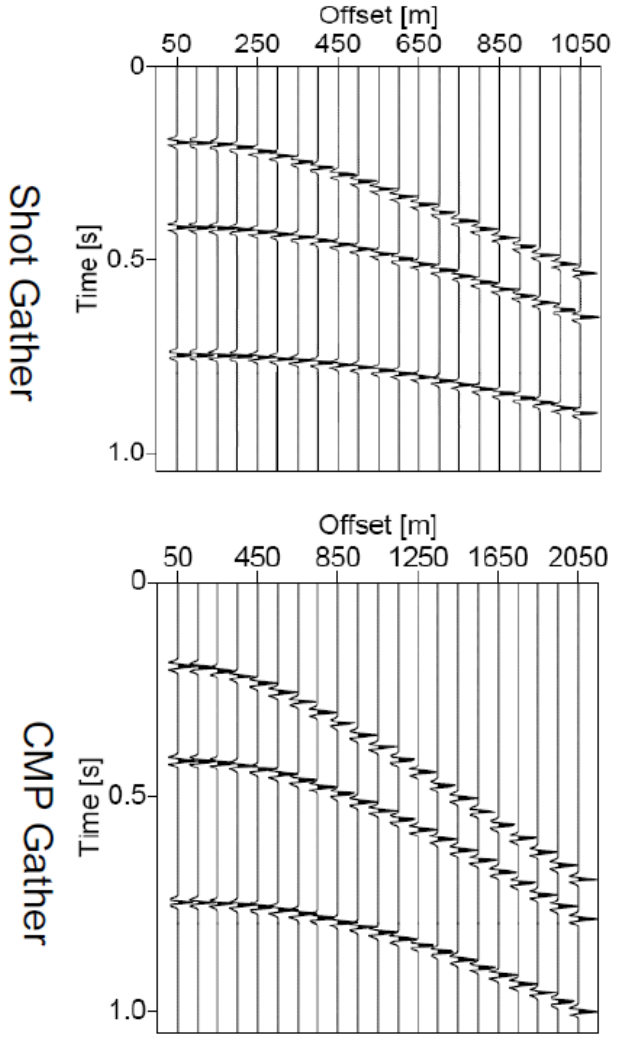
2D Seismic Data Acquisition



Ideal Reflection Seismic Survey



Practical Reflection Seismic Survey



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Metal Earth Seismic Transects -- Acquisition

Parameter	Regional (R1) mode	High-Resolution (R2) mode
Record length	12 or 16 s	12 s
Sample rate	2 ms	2 ms
Spread size	15 km-0-15 km	All live (10-20 km)
Roll on/off	Yes	Yes
Source interval	50 m (4 sweeps); 12.5 m (1 sweep)	25 m (4 sweeps); 6.25 m (1 sweep)
Receiver interval	25 m	12.5 m
Vibrator sweep	28 s, 2-96 Hz linear; 4 vibs;	28 s, 5-120 Hz +3db/octave; 3 vibs;

Metal Earth Seismic Acquisition Parameters

Transect Name	Length, km	Acquisition Modes	Comment
Chibougamau	129.85	R1, R2 × 2	No vibrator move-up
Malartic	84.775	R1, R3	Major gap near Malartic Mine/Town
Rouyn-Noranda	84.775	R1, R3	Crooked line; coincident with Lithoprobe AG-21
Larder Lake	49	R1, R2, R3	coincident with Lithoprobe AG-23
Cobalt	46.375	R1, R2	
Matheson	53.95	R1, R2	R1, R2 offset
Swayze	89.35, 11.8	R1, R2 × 3	
Geraldton	60.2125	R1 × 2, R2	Coincident with Lithoprobe WS-3a
Sturgeon Lake	73.475	R1	
Atikokan	54.1	R1	Crooked line
Dryden	74.4	R1, R2 × 2	
Rainy River	33.15	R1, R2	
Sudbury	39, 17, 16, 10	R1 × 3, R2 × 2, R3	Grid of lines

Metal Earth Seismic Transects

Naghizadeh et. al. (2019)

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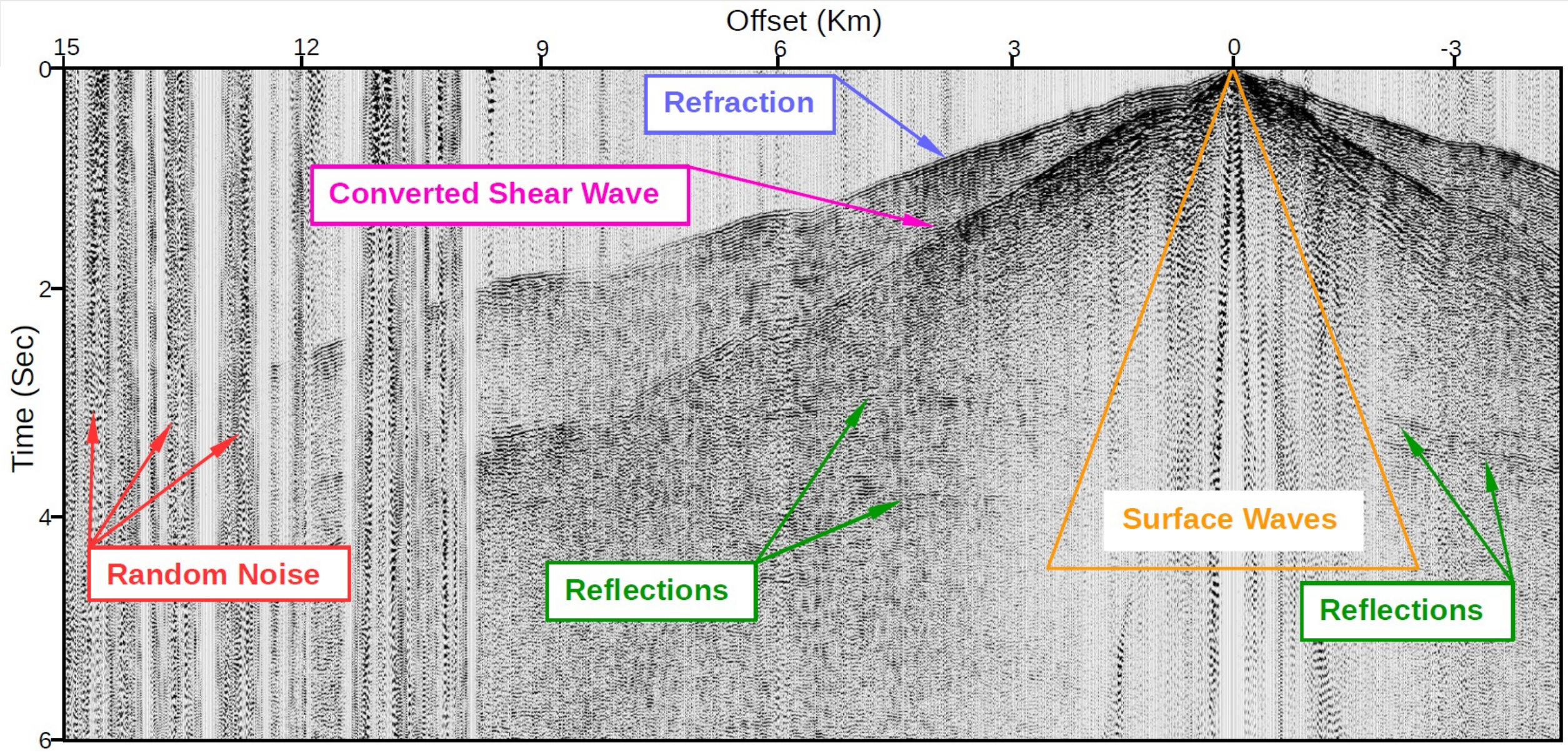
A Seismic Shot Gather from Malartic Transect



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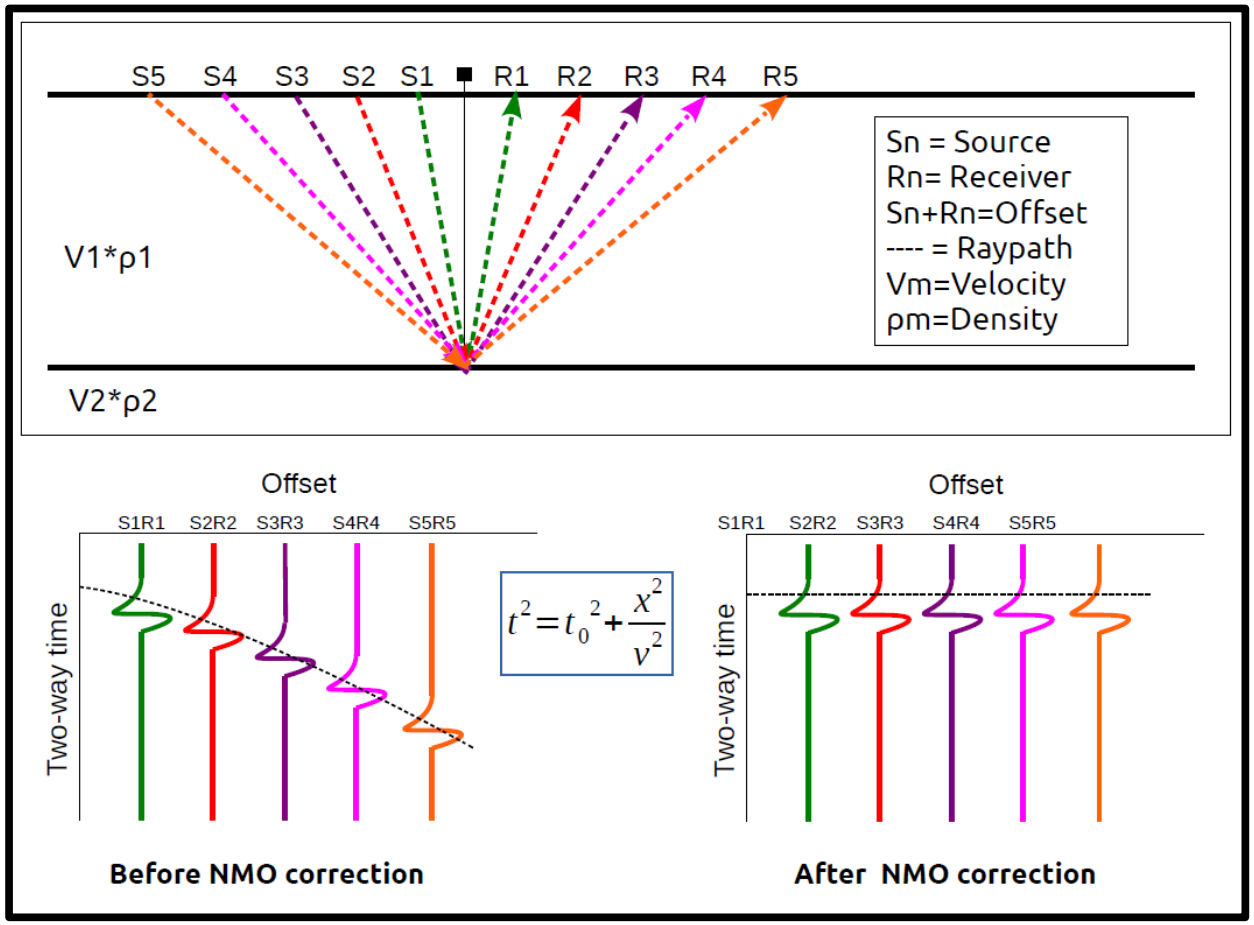
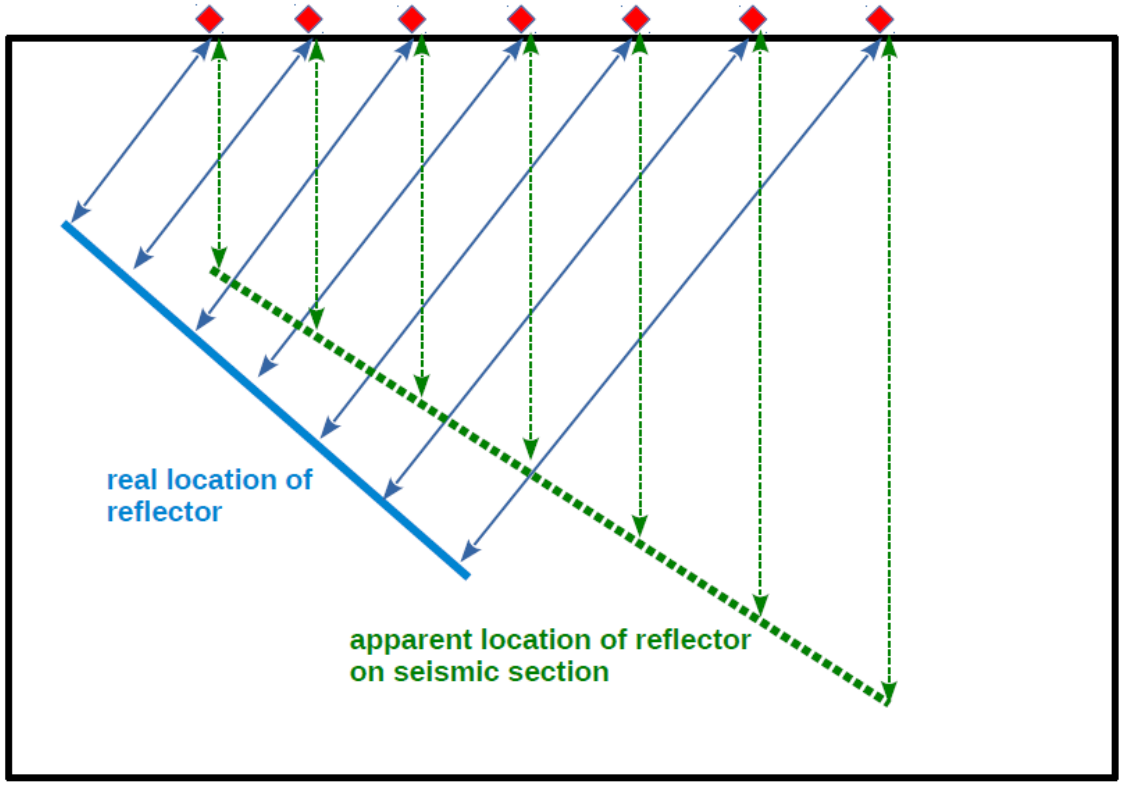
Two Important Steps of Seismic Data Processing



Normal Move-Out (NMO) correction



Seismic Migration

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Metal Earth Seismic Data Processing

Processing Step	Parameters Used	Comment
Trace Kills and Reversals Min Phase Conversion Ensemble Balance, Amplitude Recovery Surface Conistent Scaling Linear and Erratic Noise Attenuation	Time power correction + 1.5	
Surface-Consistent Deconvolution	Operator: 160 ms Prewhitening: 0.1 %	Design window: 171-10000 ms at 38 m offset 3347-10000 ms at 15000 m offset
Anomalous Frequency Suppression	Outband: 5-100 Hz Signal band: 15-50 Hz	
Refraction Statics	Datum:500 m Replacement Velocity: 5600 m/s	Tomography
Linear and Erratic Noise Attenuation		
TE Mean window		Design window: 171-10000ms at 38 m offset 3347-10000 ms at 15000 m offset
Velocity Analysis		Every 1.0 km
Surface Consistent Residual Statics	Max shift 64 ms Window: 2000-9000 ms	
Velocity Analysis2		Every 500 m
Surface Consistent Residual Statics	Max shift 48 ms Window: 1000-9000 ms	

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Metal Earth Seismic Data Processing (cont.)

Post-Stack Time migration		
Velocity Analysis Normal Move-out & Mute CDP stack		
Time Migration	Kirchhoff Summation	Migration Angle: 65 degrees Max Aperture: 15000 meters
Pre-Stack Time migration (PSTM)		
Velocity Analysis (PSTM)	Kirchhoff Summation	CMP/CDP Distance: $\leq$ 500 meters
Trace Equalization window	Rolling Window: 1000 ms Overlap 50%	
Pre Stack Time Migration (PSTM)	Kirchhoff Summation	Migration Angle: 65 degrees Max Aperture: 10000 meters
Front-End Muting	3/93 1067/758 3554/1871 8028/2778 (m/ms)	
CDP Stack		
Random Noise Attenuation		
TraceEqualization window	Rolling Window: 1000 ms Overlap 50%	

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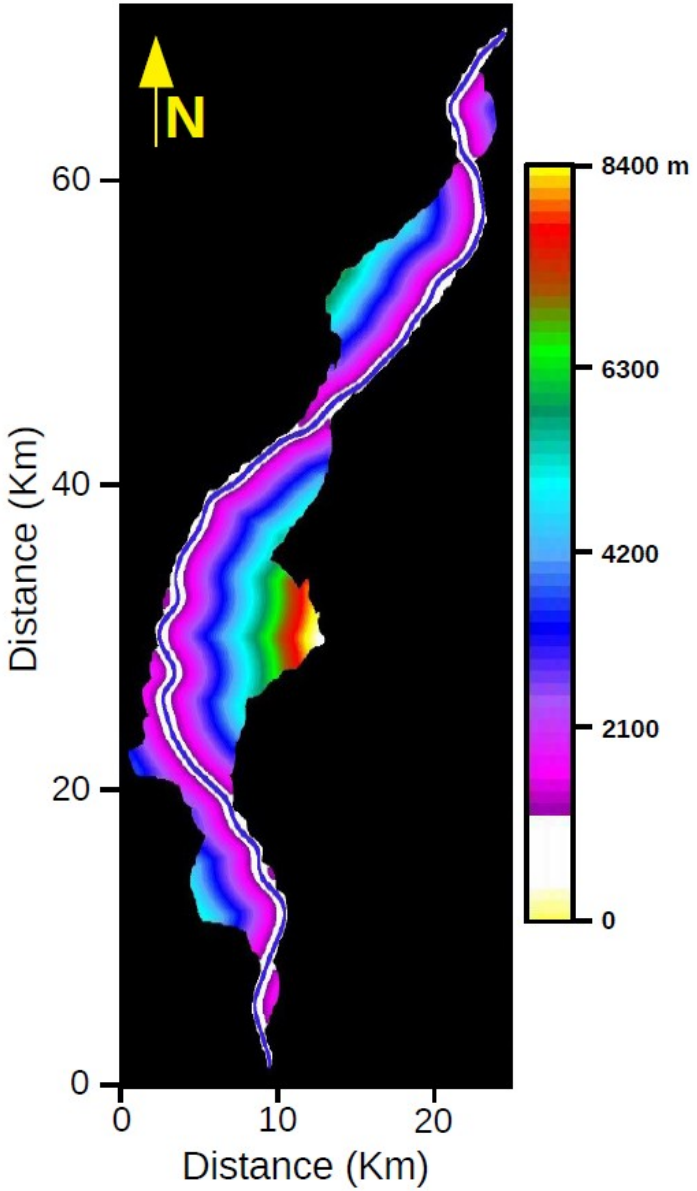
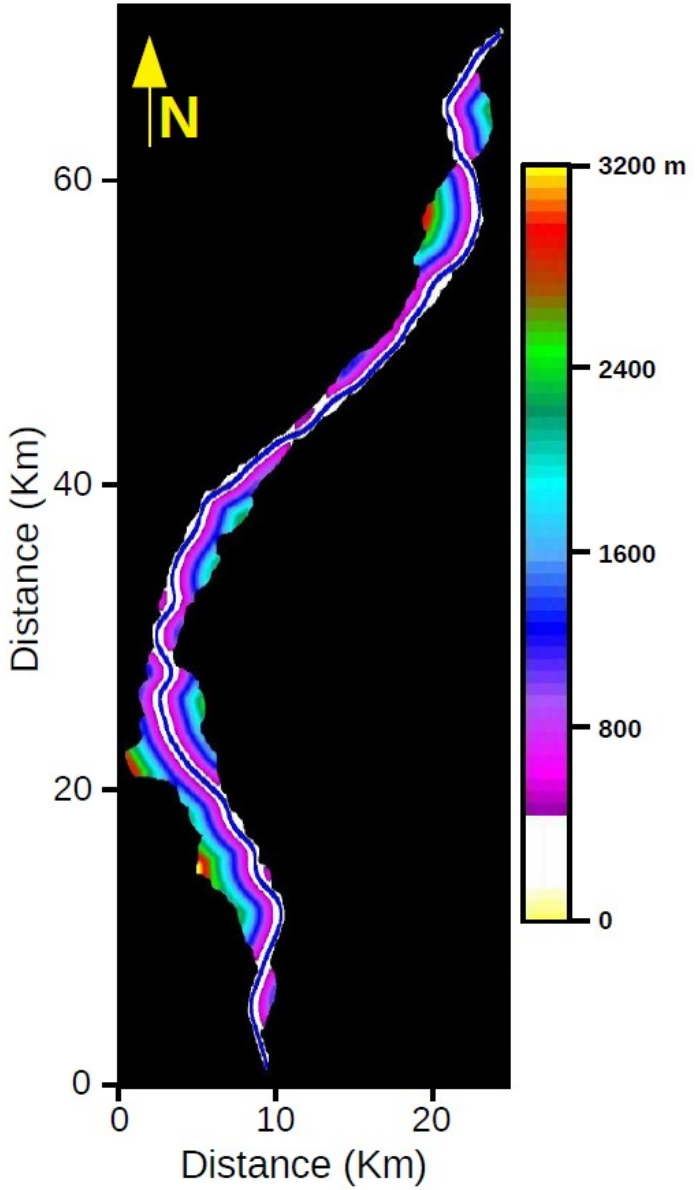
CMP to CMP-Line distance (Crooked Line) -- Swayze Transect

Full-Offset (~70 km)





Offset < 15 km

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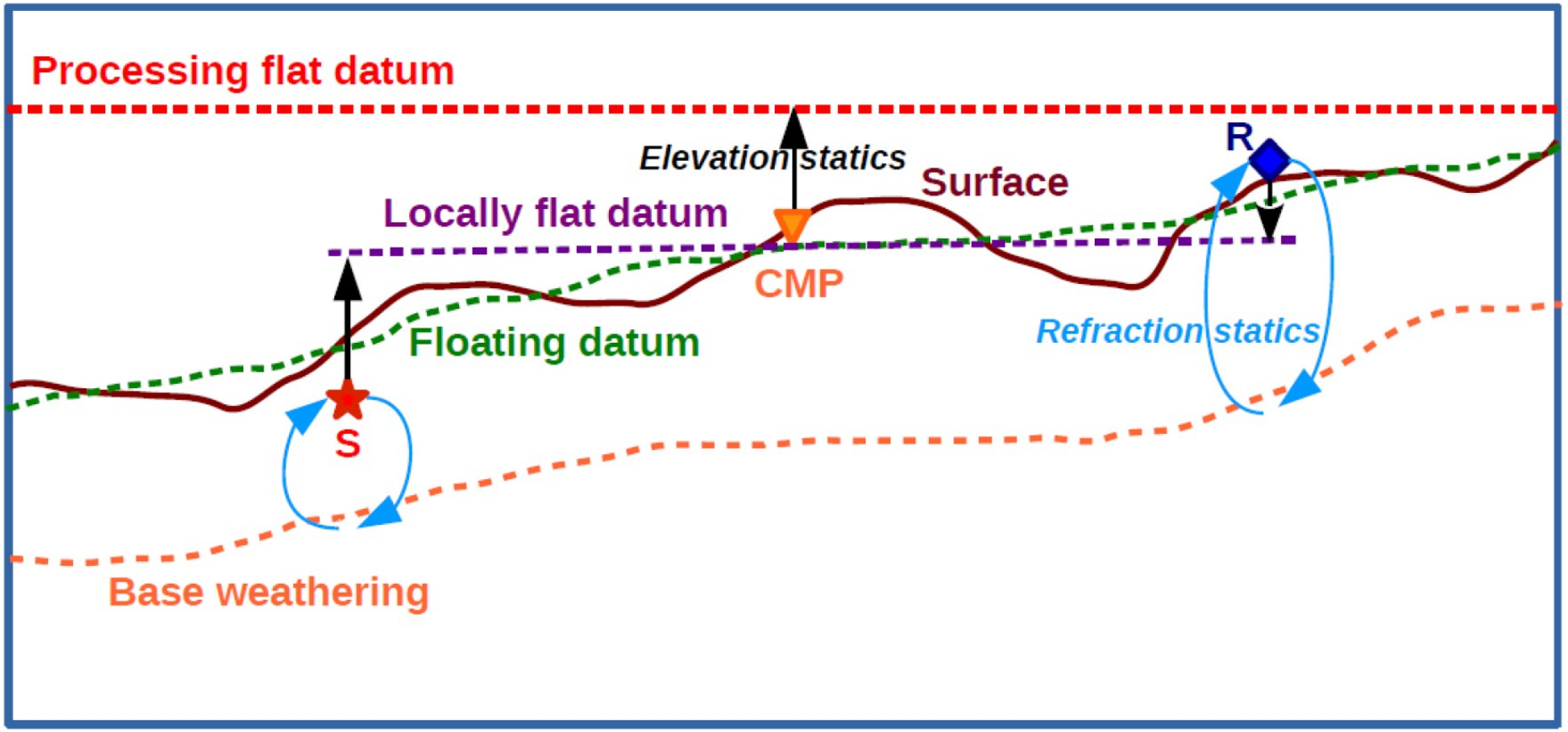
Statics Correction for Land Seismic Data



Elevation Statics: To remove the effect of topography
Refraction Statics: To remove the effect of near-surface velocity vatriations
Residual Statics: To remove any random jittered time-shifts in seismic events after correcting the elevation and refraction statics.

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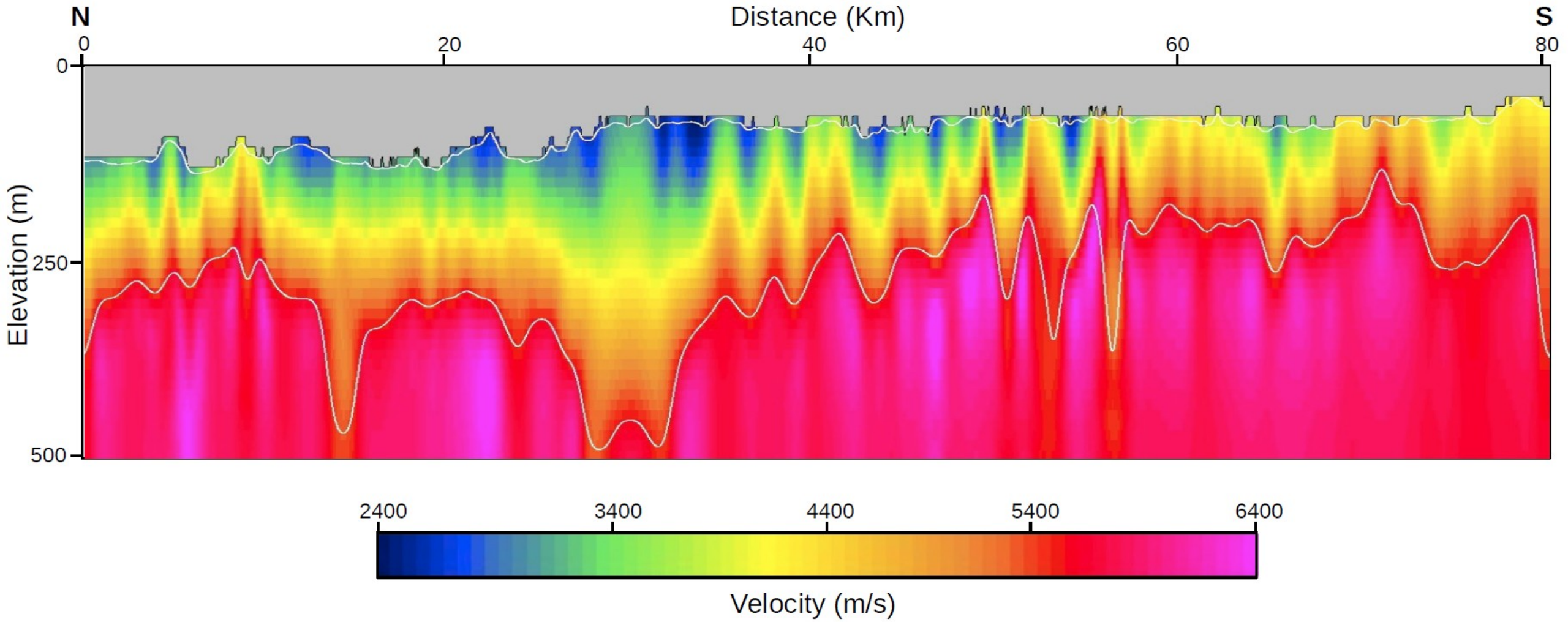
Near-Surface Refraction Velocity for Static Correction -- Swayze Transect



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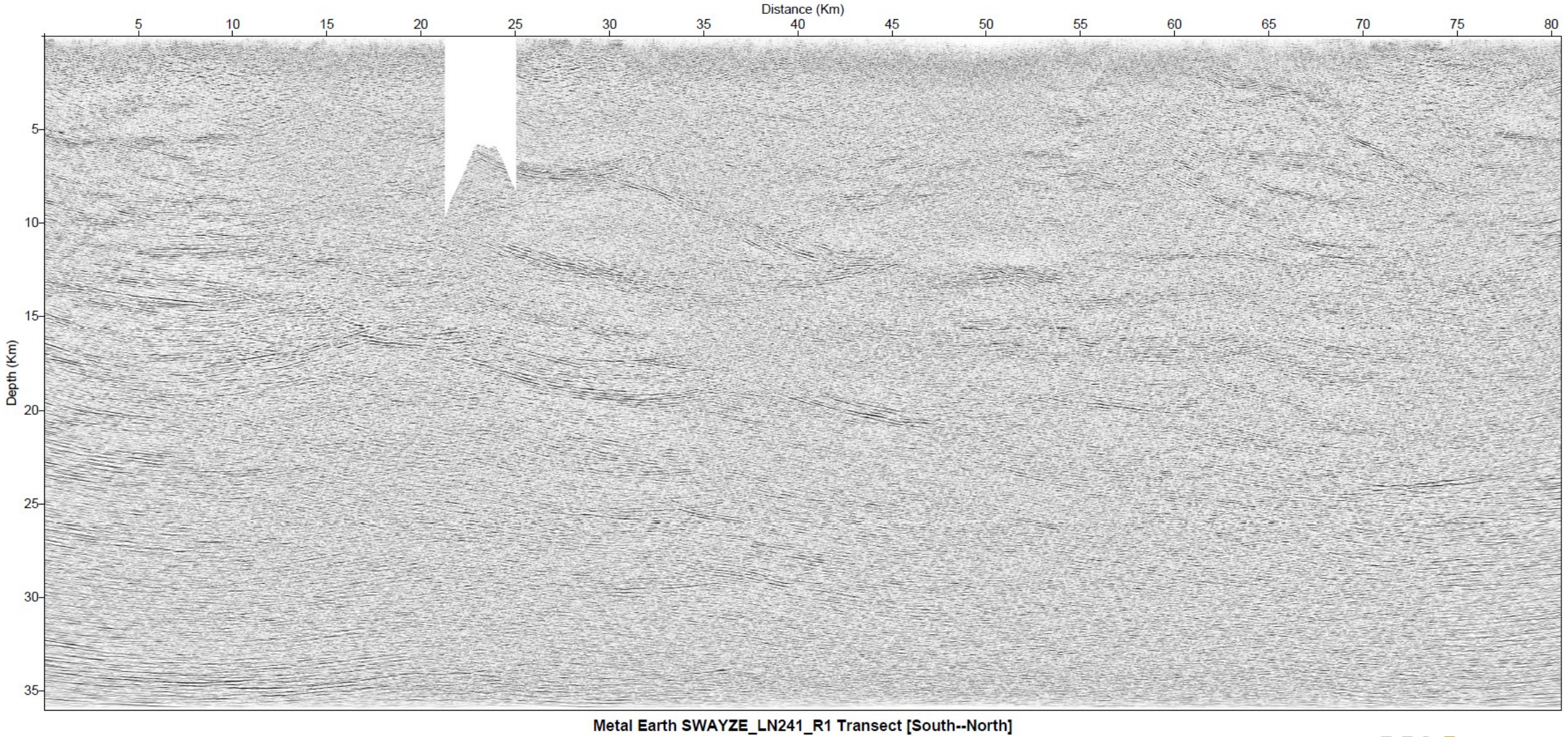
Pre-Stack Time Migrated Seismic Section -- Swayze Transect



Metal Earth SWAYZE_LN241_R1 Transect [South--North]

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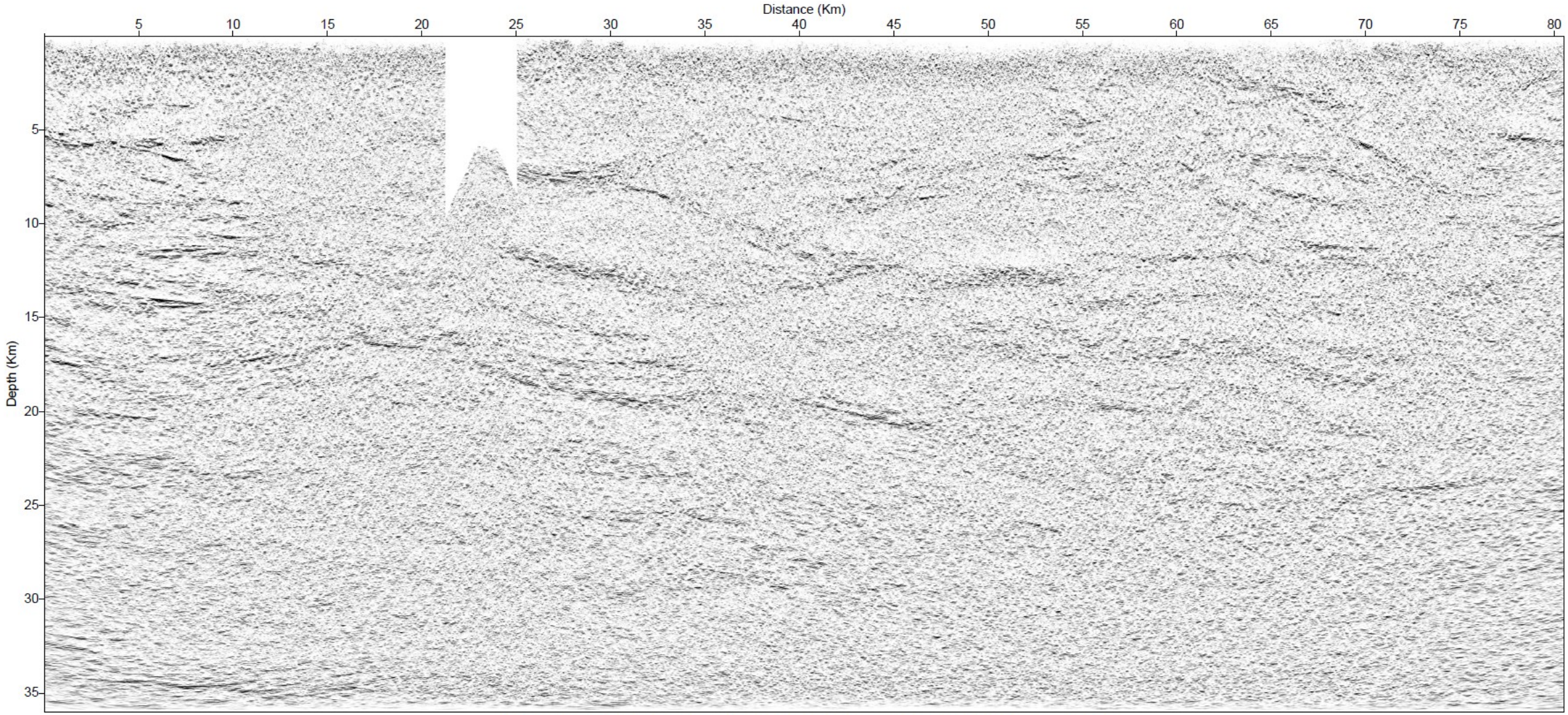
Hilbert Transform Envelope Seismic Section -- Swayze Transect



Metal Earth SWAYZE_LN241_R1 Seismic Transect Hilbert Envelope [South--North]

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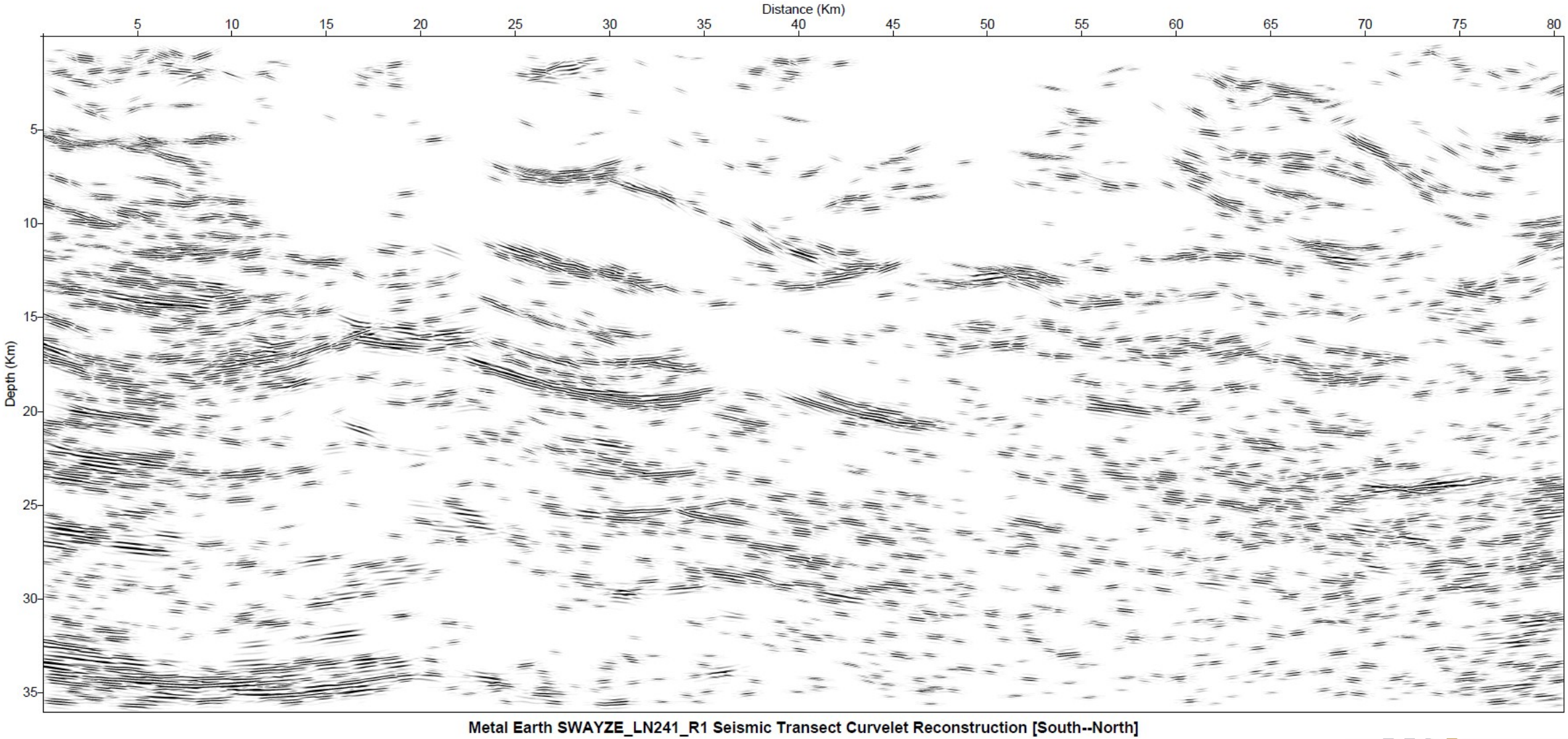
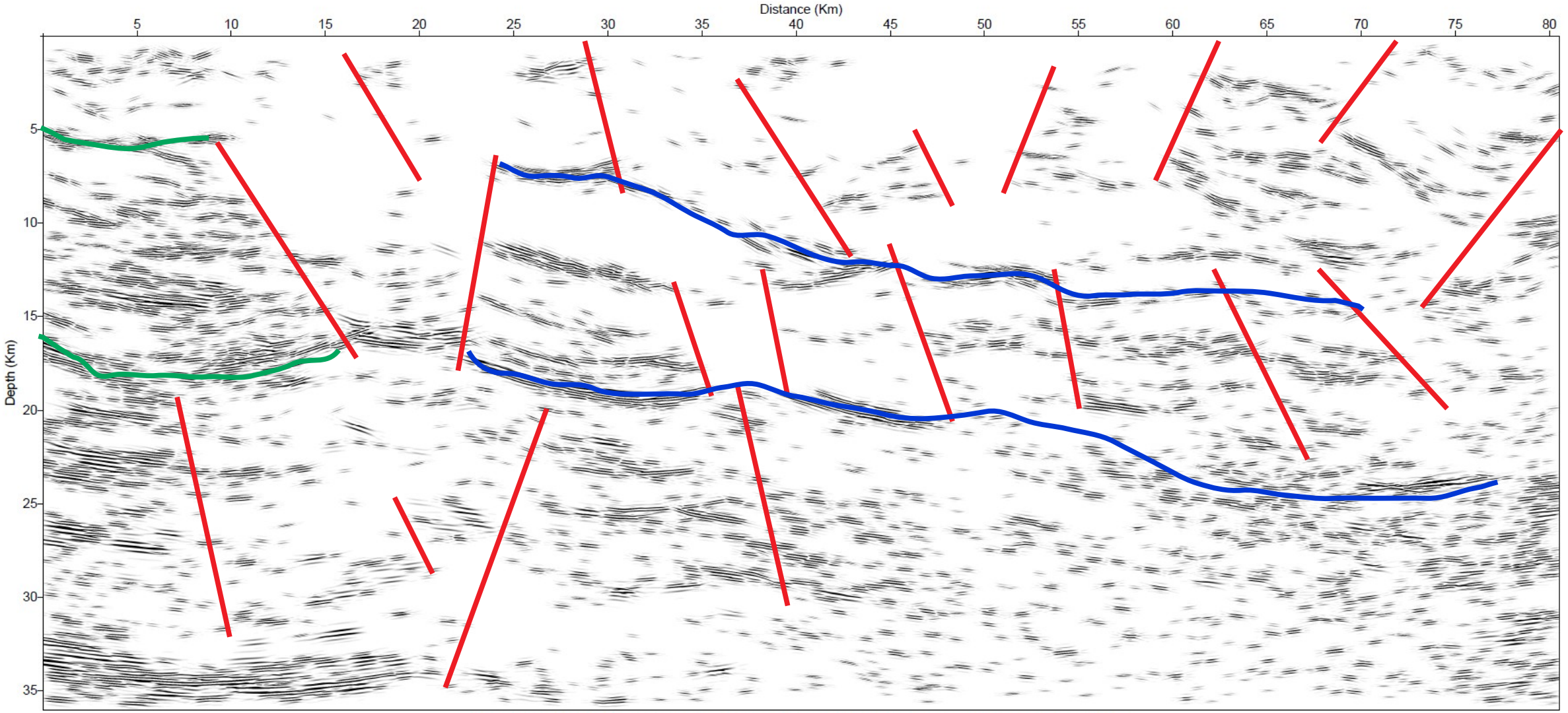
Dip Coherency Filtered Seismic Section –- Swayze Transect



Metal Earth SWAYZE_LN241_R1 Seismic Transect Curvelet Reconstruction [South--North]

METAL EARTH

Dip Coherency Filtered Seismic Section –- Swayze Transect



Metal Earth SWAYZE_LN241_R1 Seismic Transect Curvelet Reconstruction [South--North]

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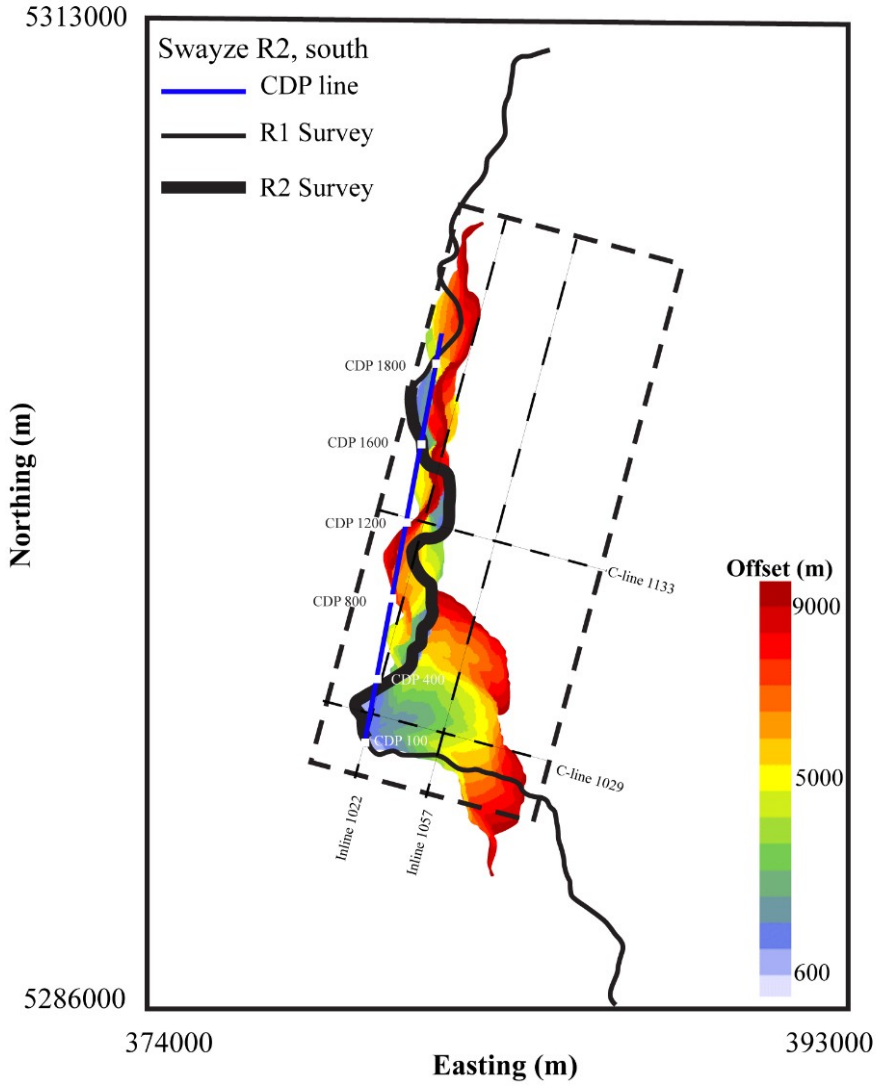
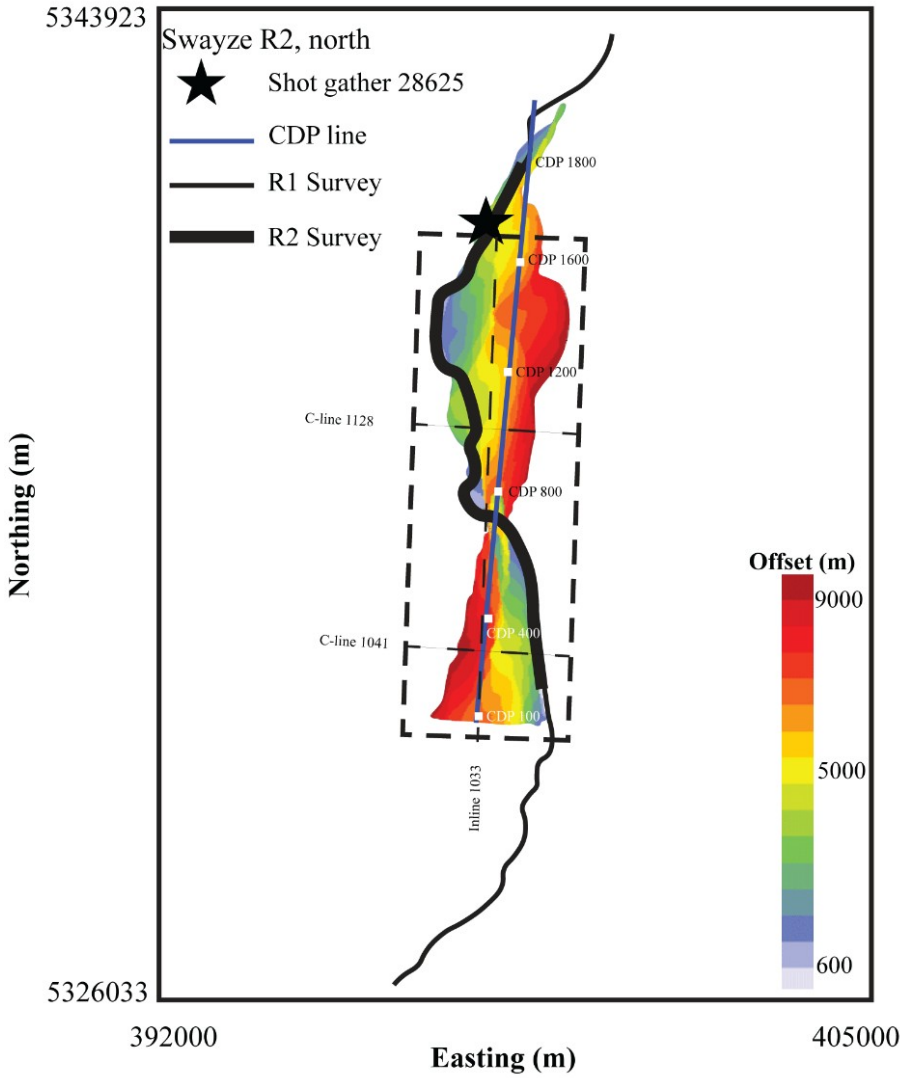
3D Swath processing of 2D Crooked Seismic Line - Swayze R2 surveys

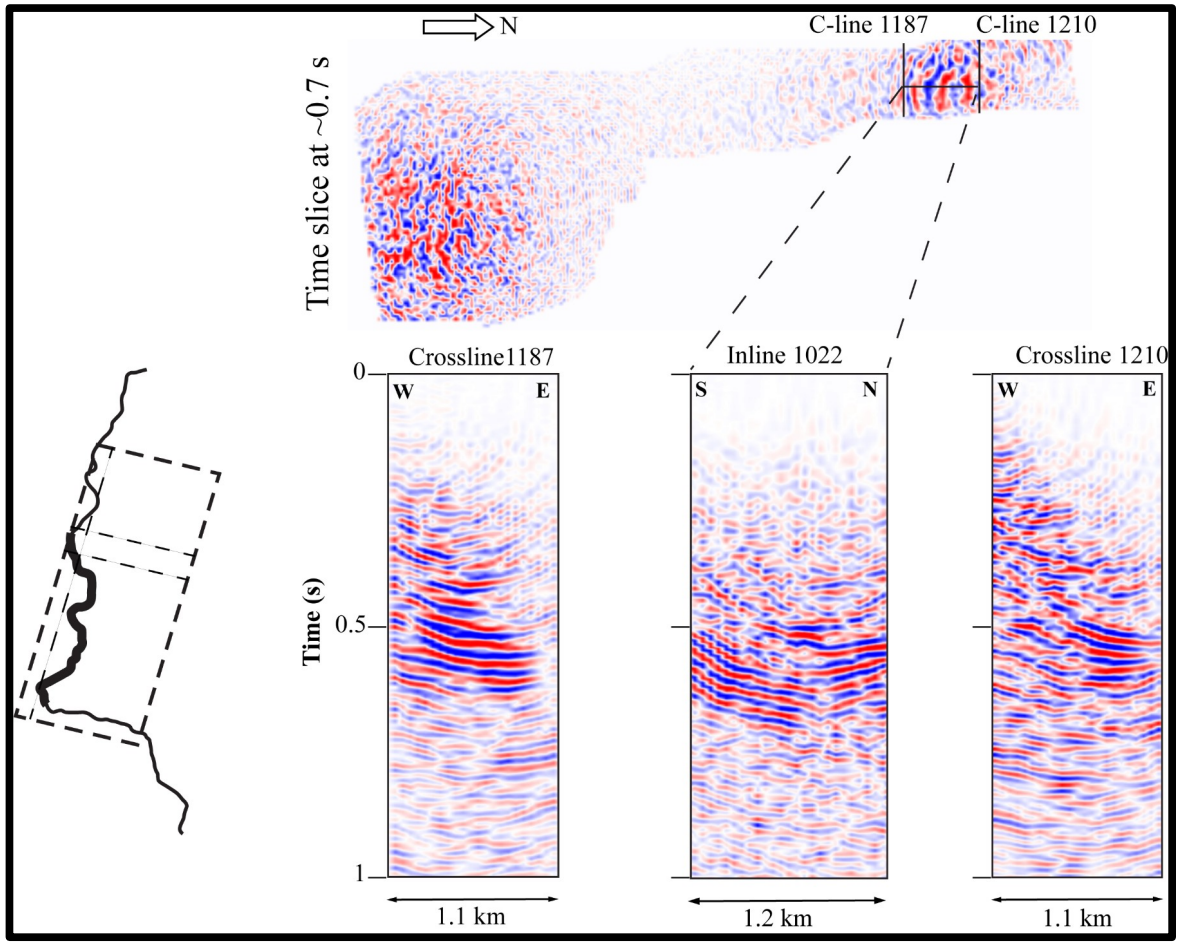


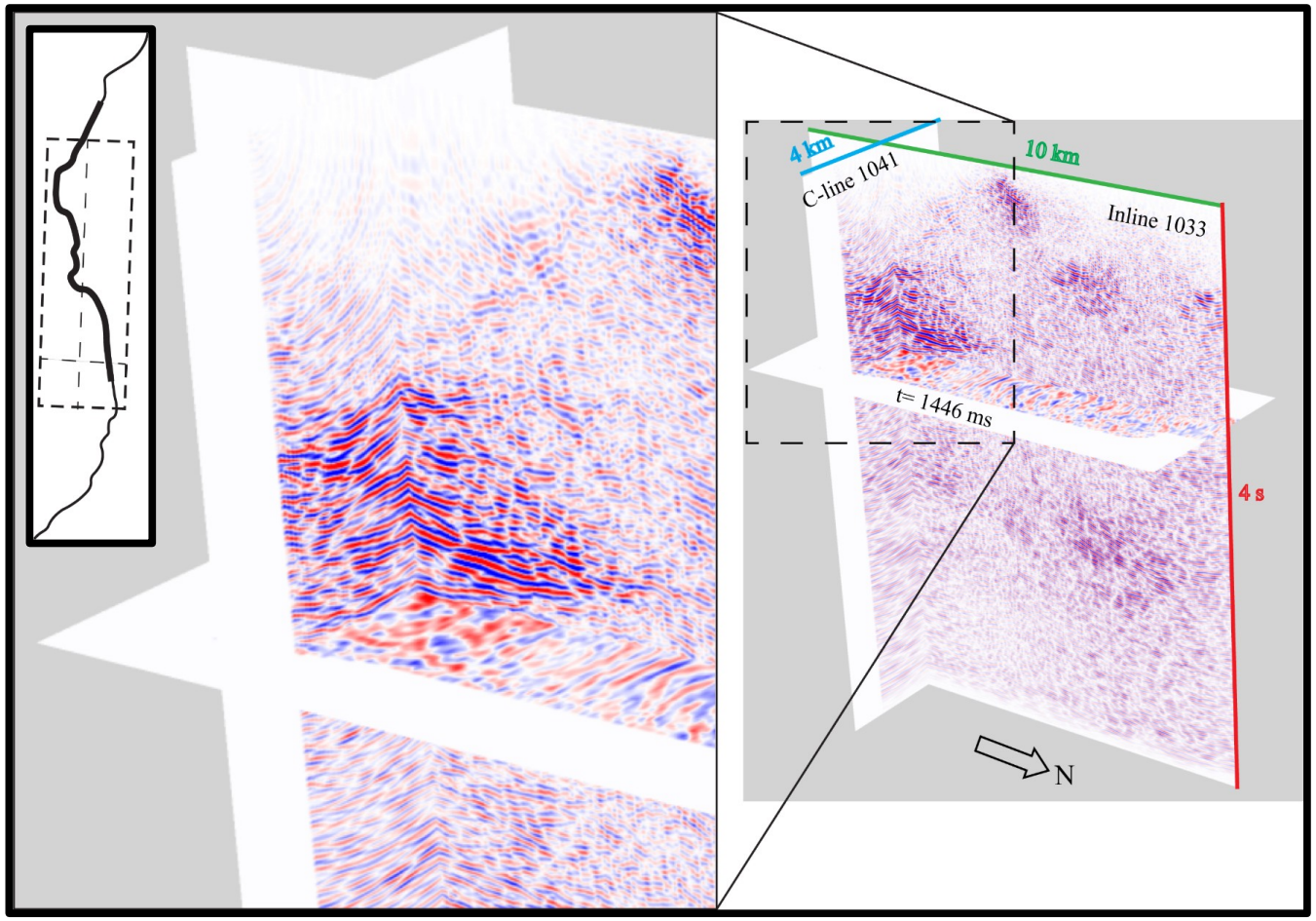


Processing is done by Saeid Cheraghi

METAL EARTH

3D Swath processing of 2D Crooked Seismic Line - Swayze R2 surveys





Processing is done by Saeid Cheraghi

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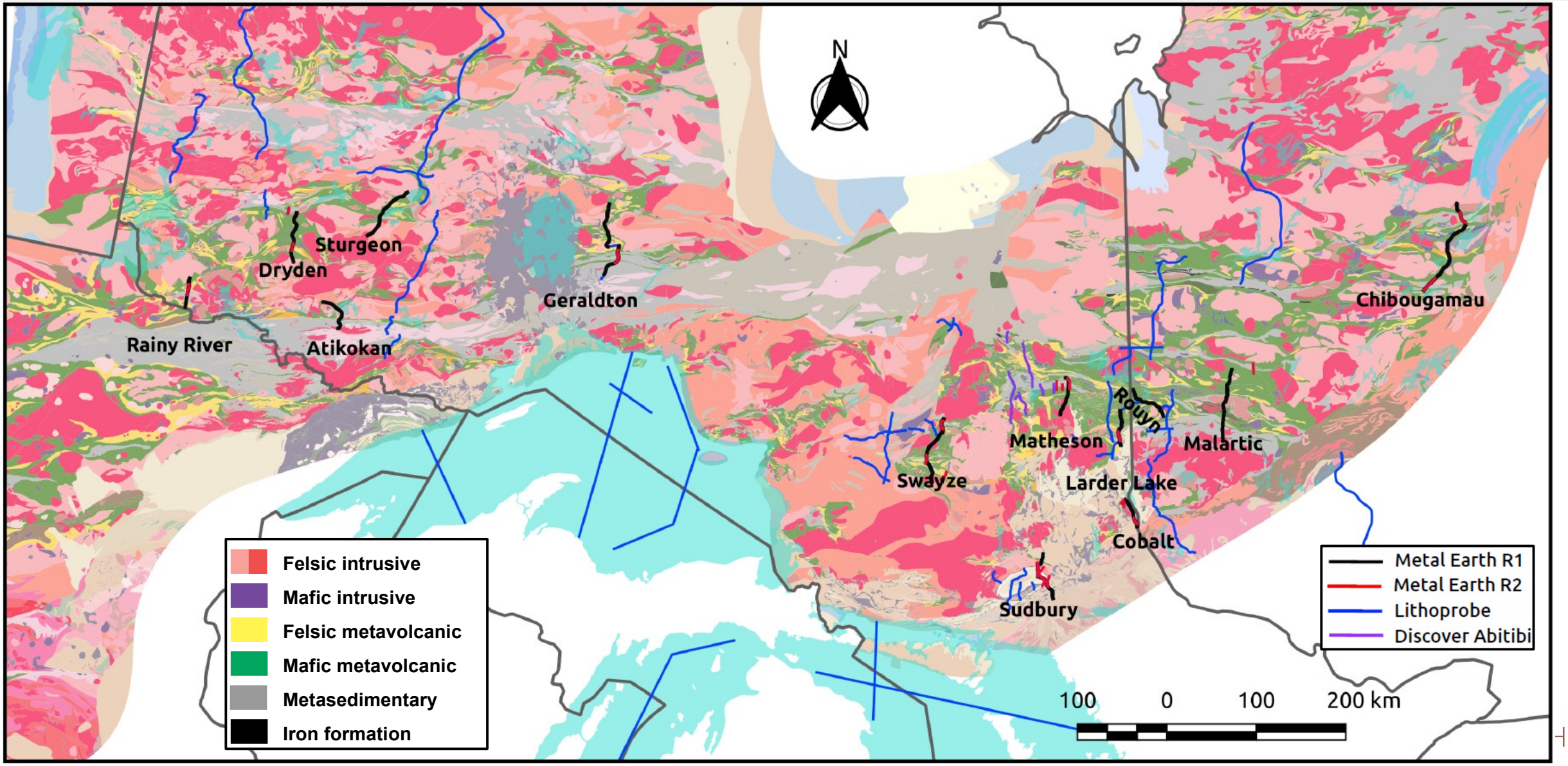
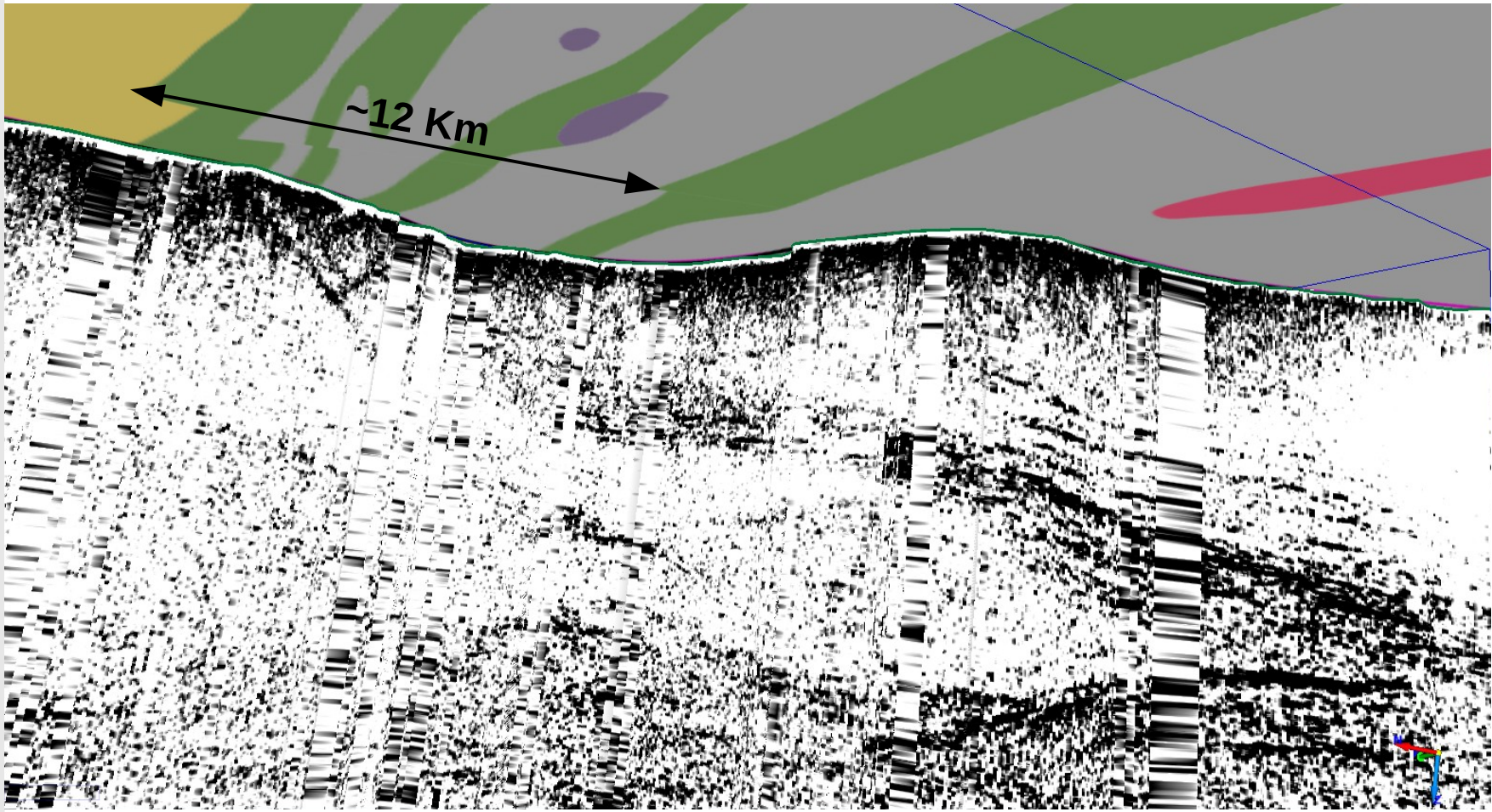
Seismic Transects of the Superior Province



Lithoprobe WS-3a Transect before cleaning up the coordinates

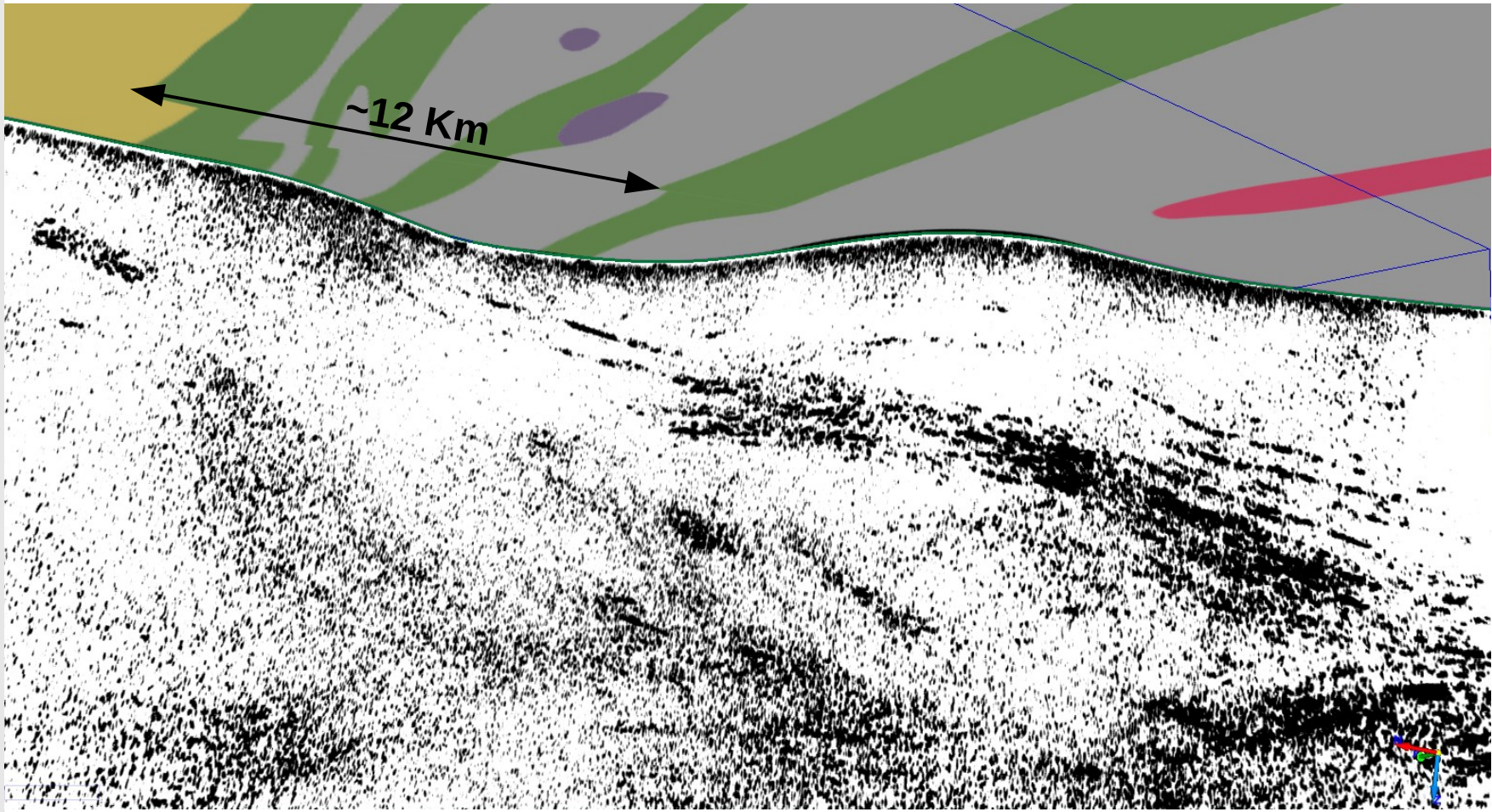
(downloaded from NRCAN website)



Horizontal to Vertical scale is 1:1

METAL EARTH

Lithoprobe WS-3a Transect after cleaning up the coordinates



Horizontal to Vertical scale is 1:1

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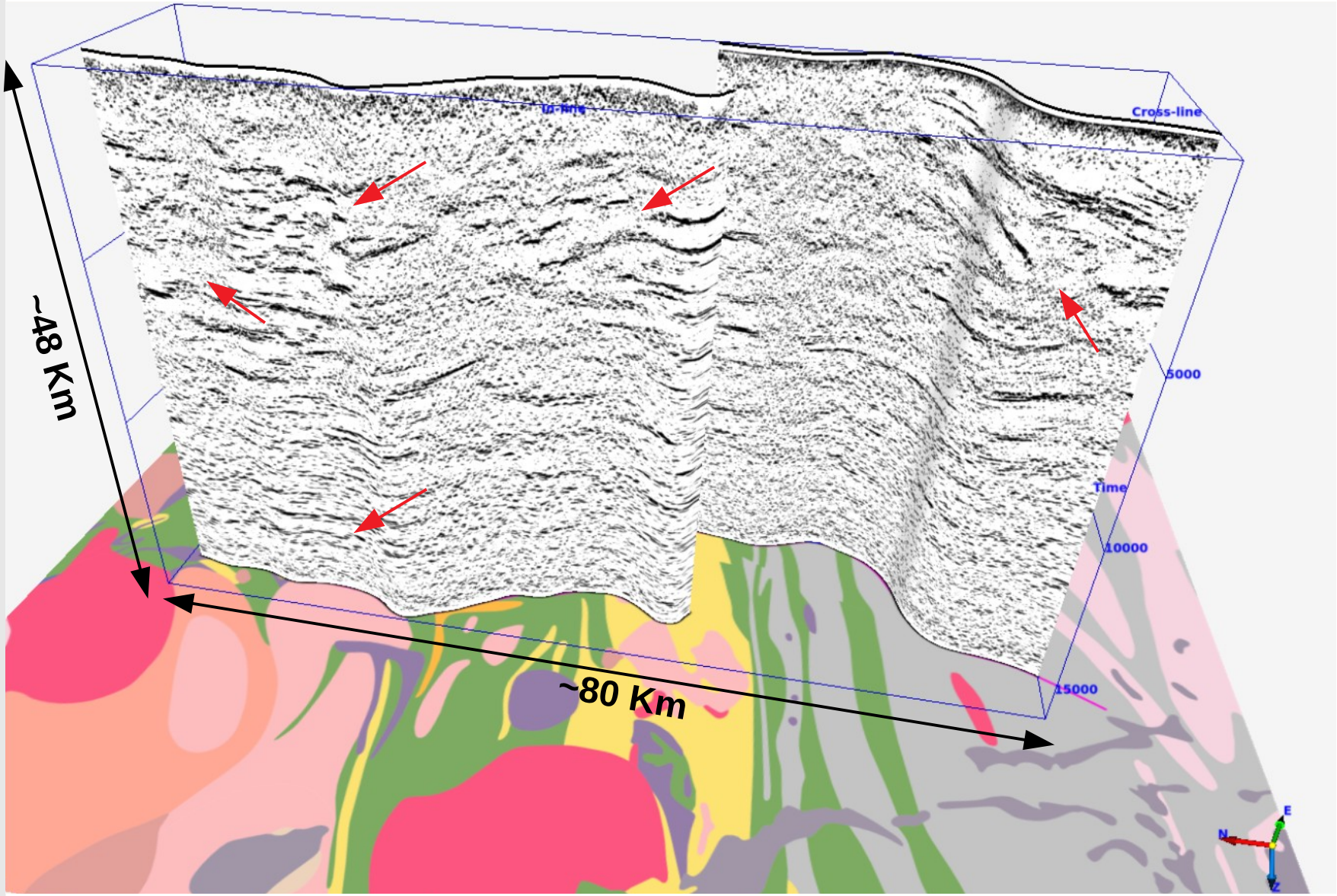
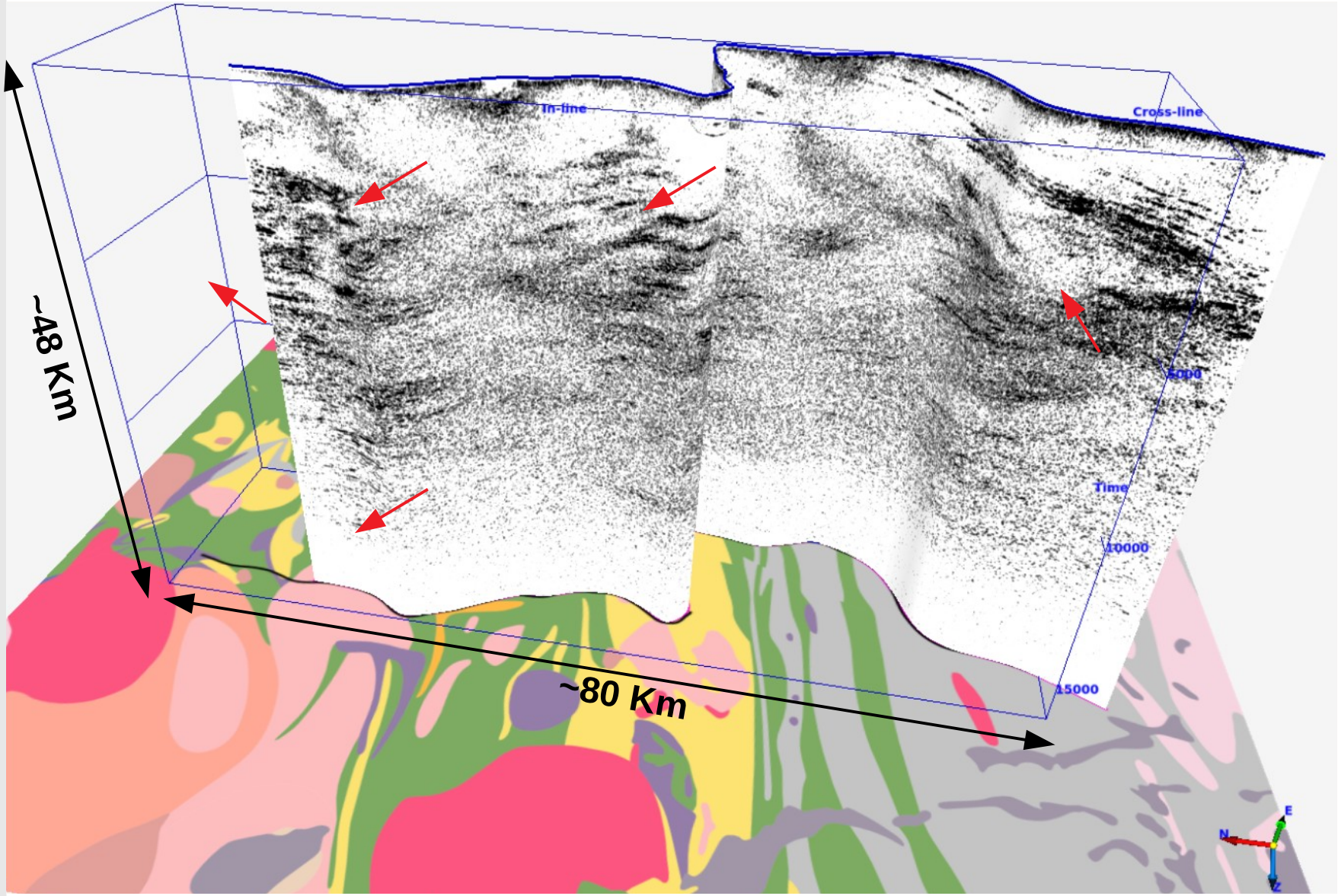
Metal Earth Geraldton Transect



METAL EARTH

Lithoprobe WS-3a Transect



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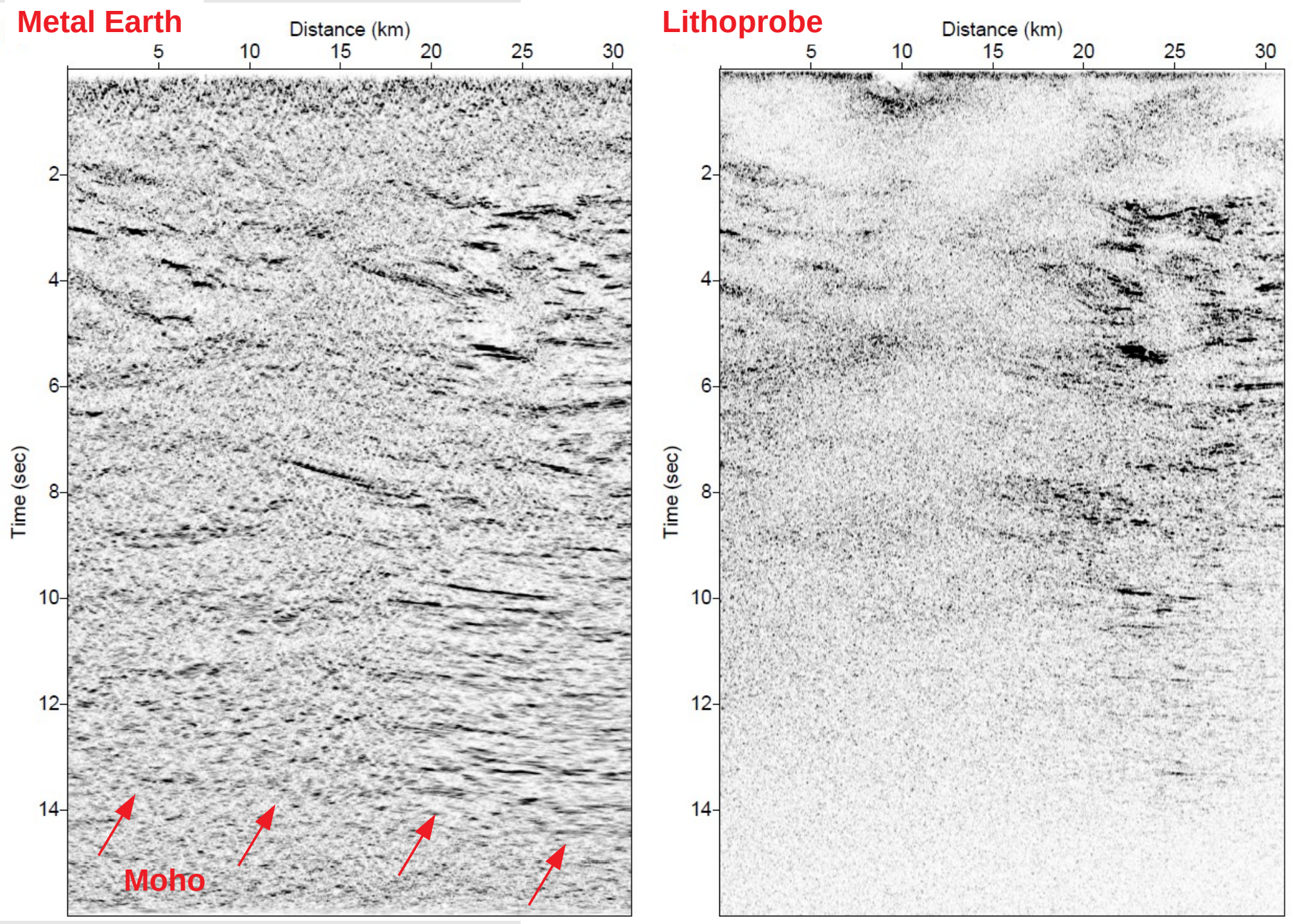

Lithoprobe WS-3a vs. Metal Earth Geraldton

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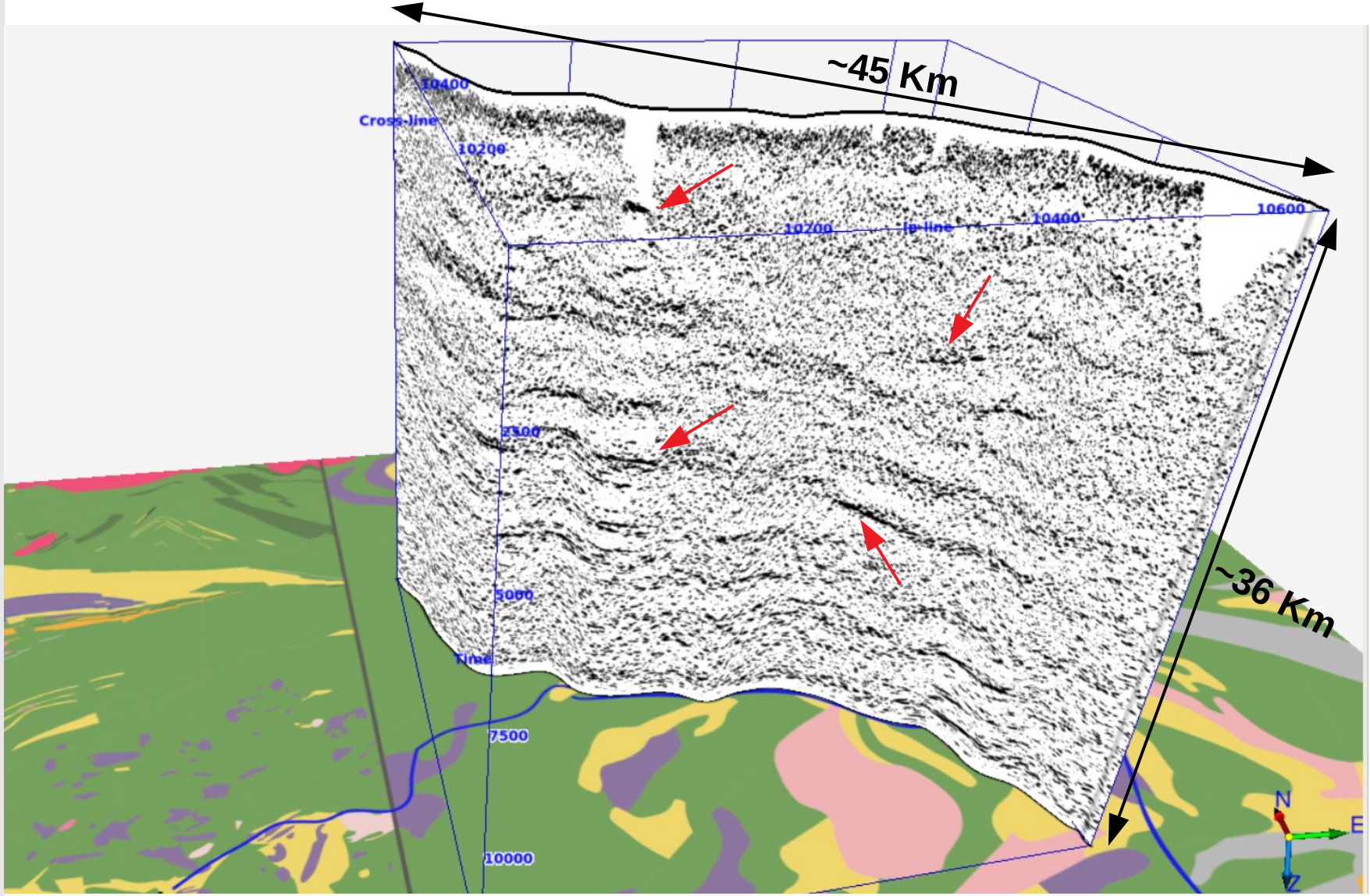
Metal Earth Rouyn Transect



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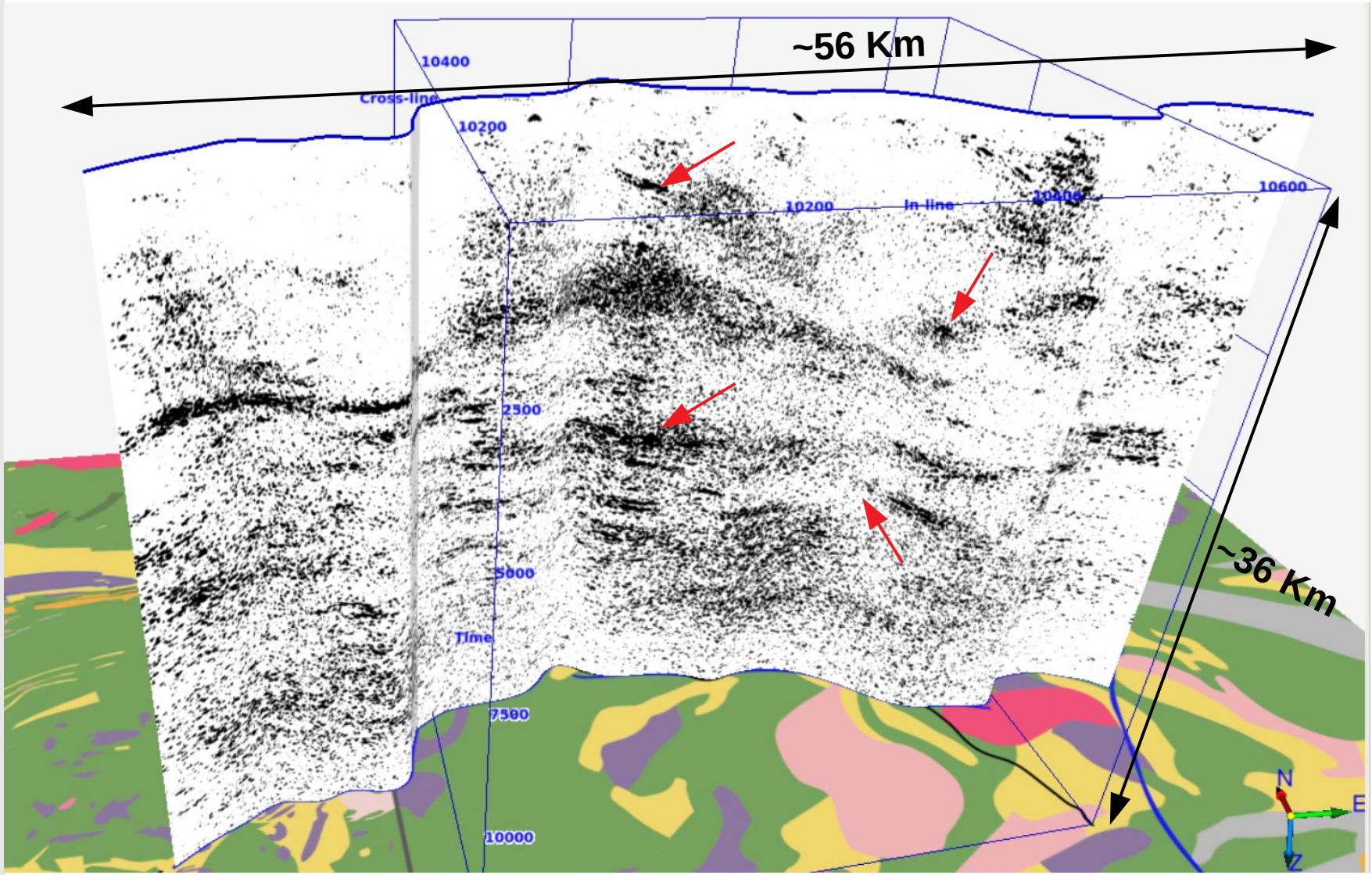
Lithoprobe AG-21 Transect



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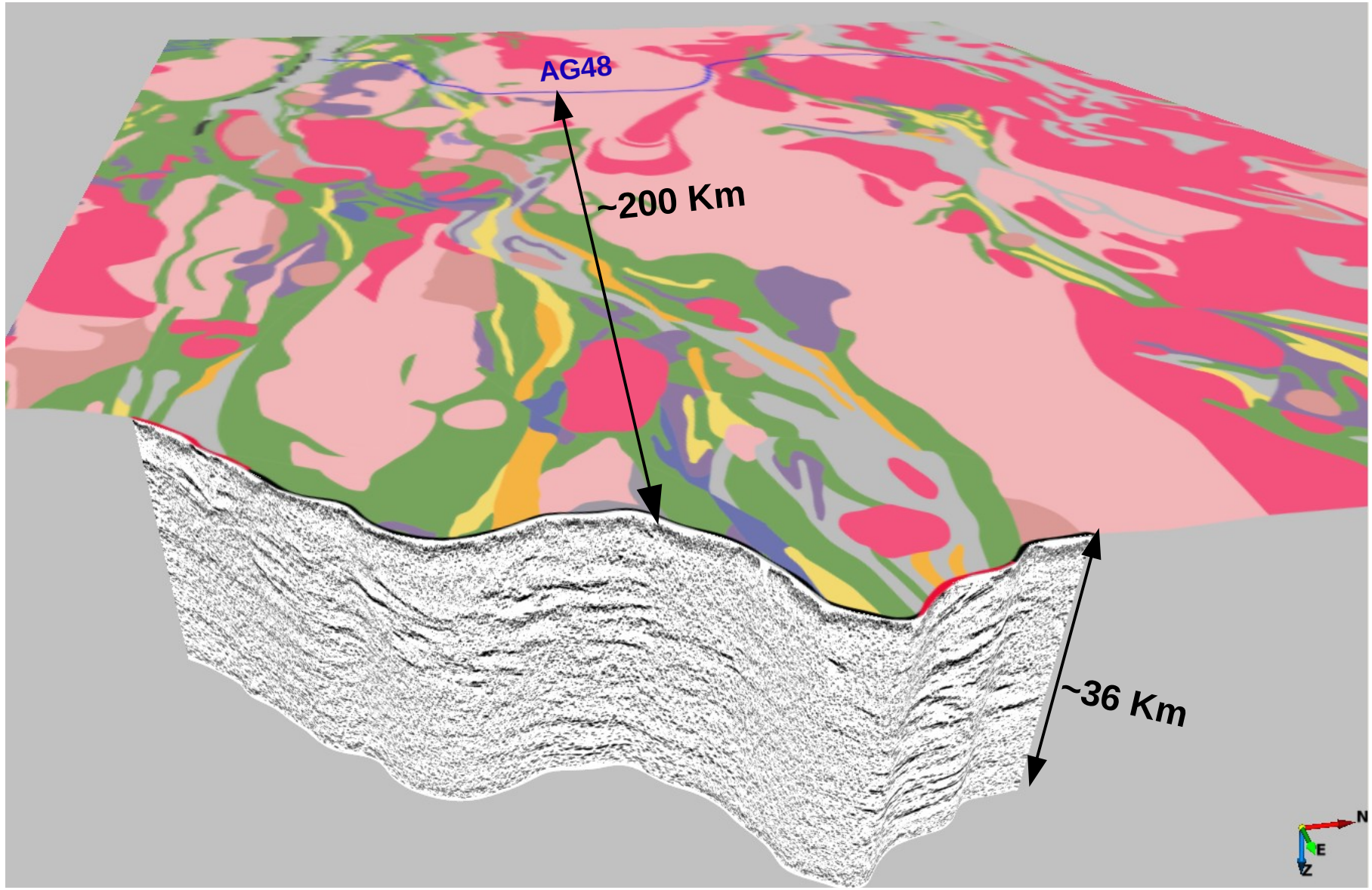
Metal Earth Chibougamau Transect



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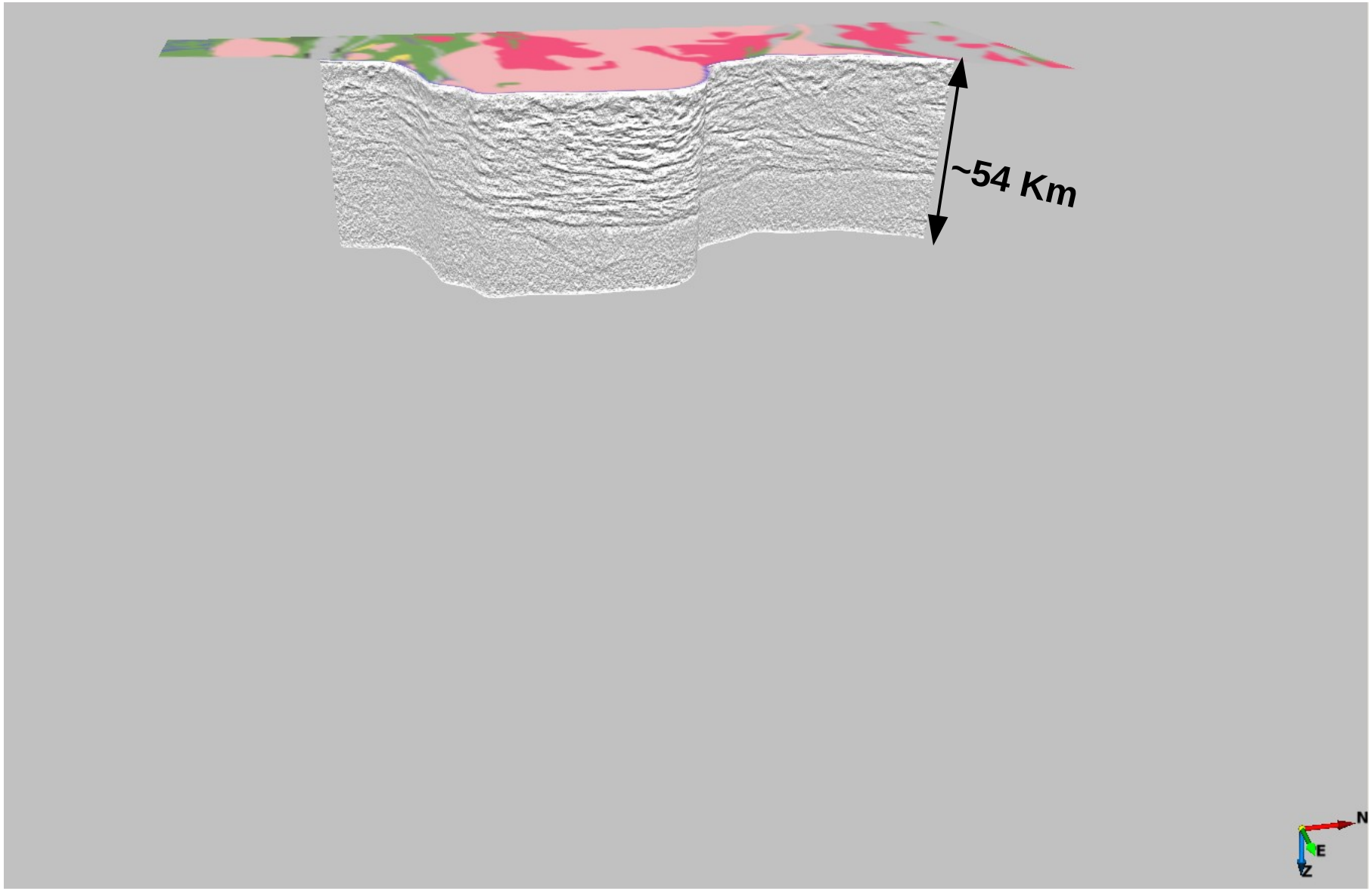
Lithoprobe AG-48 Transect



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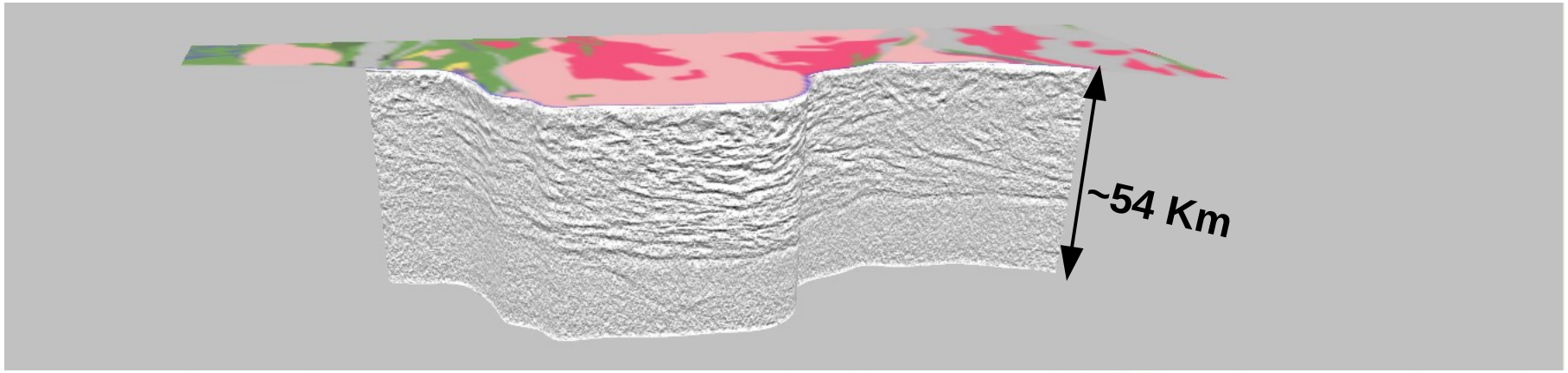
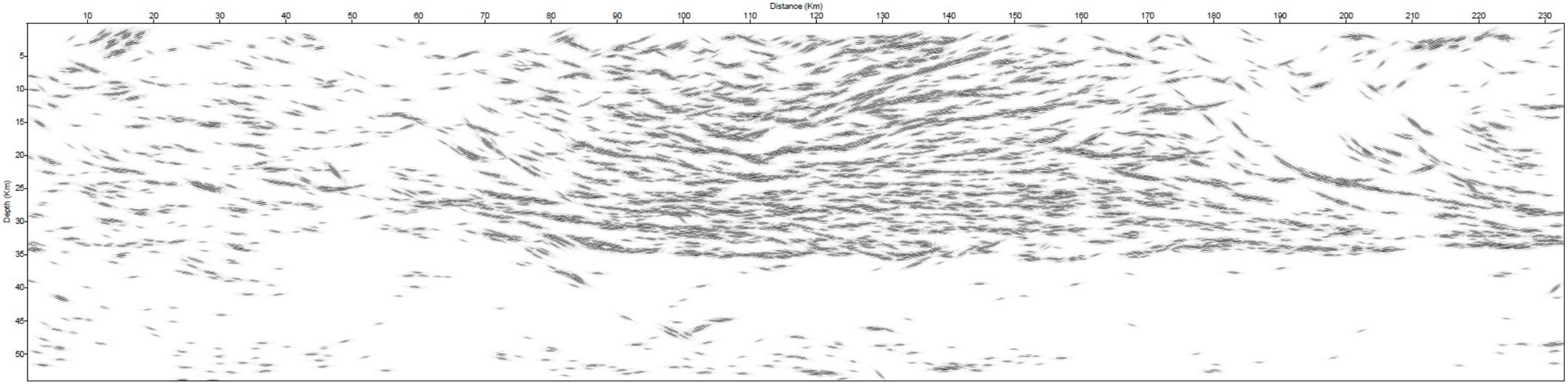
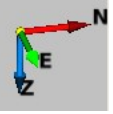
Lithoprobe AG-48 Transect







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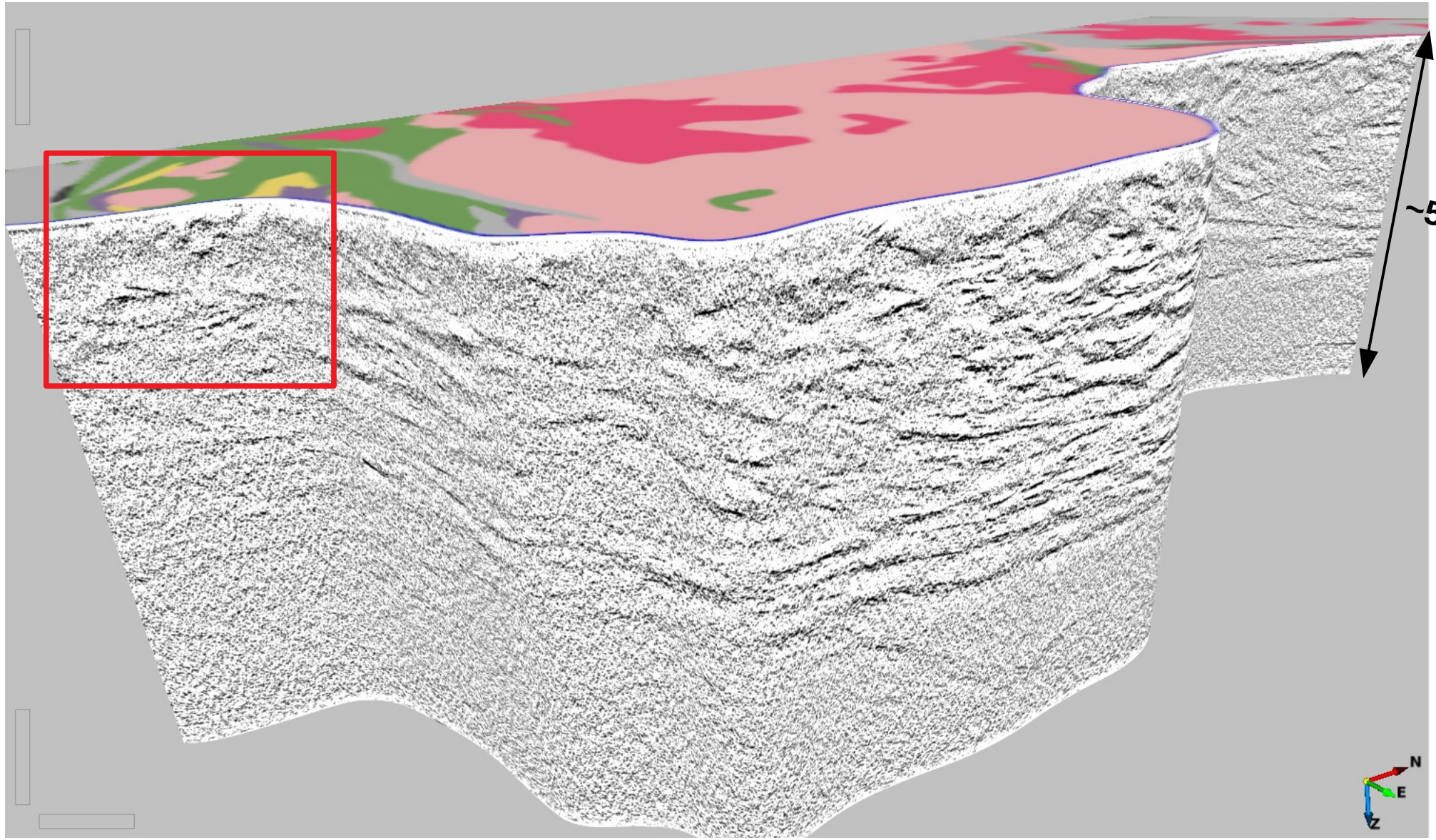
Lithoprobe AG-48 Transect



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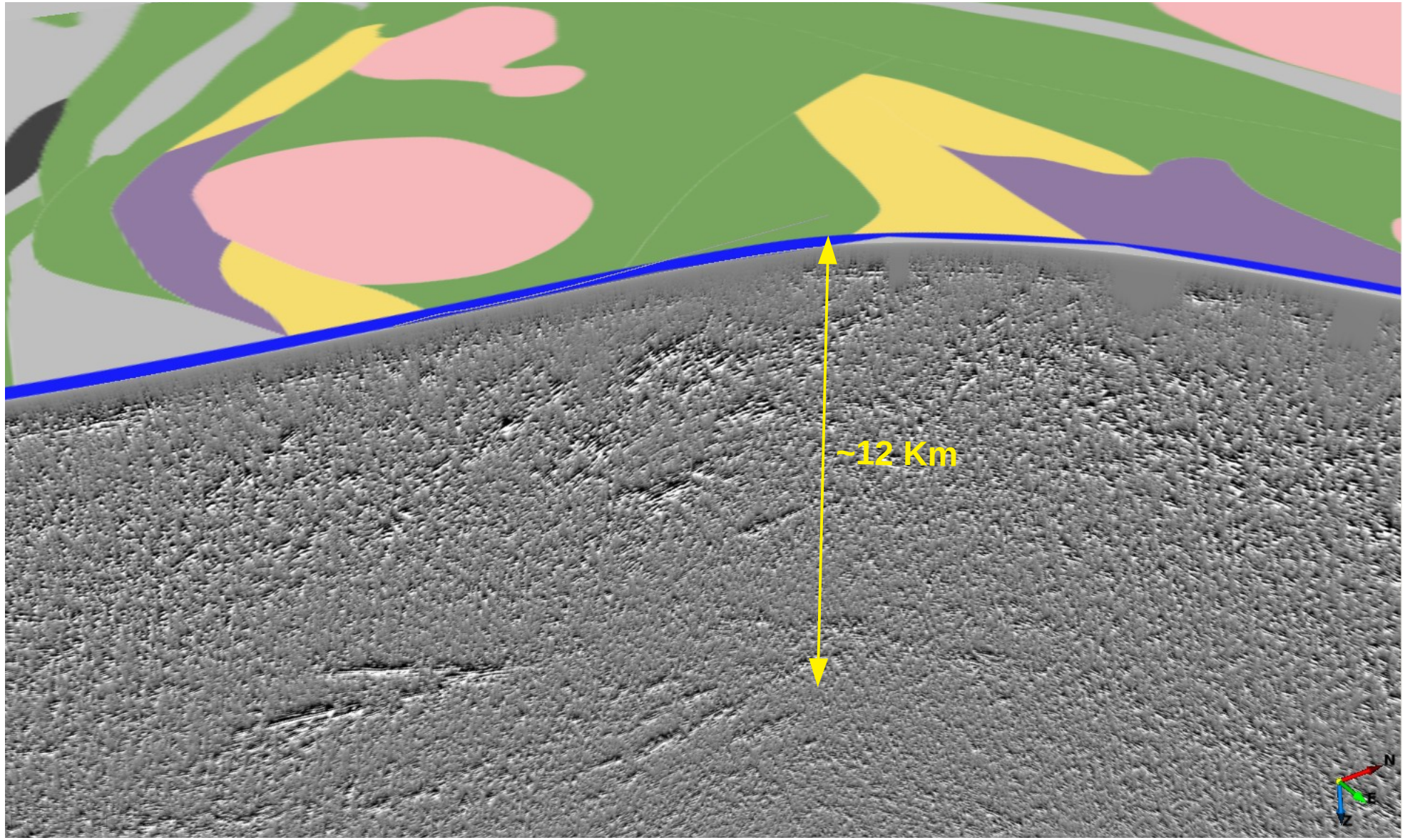
Southern part of Lithoprobe AG-48 Transect (Matagami)



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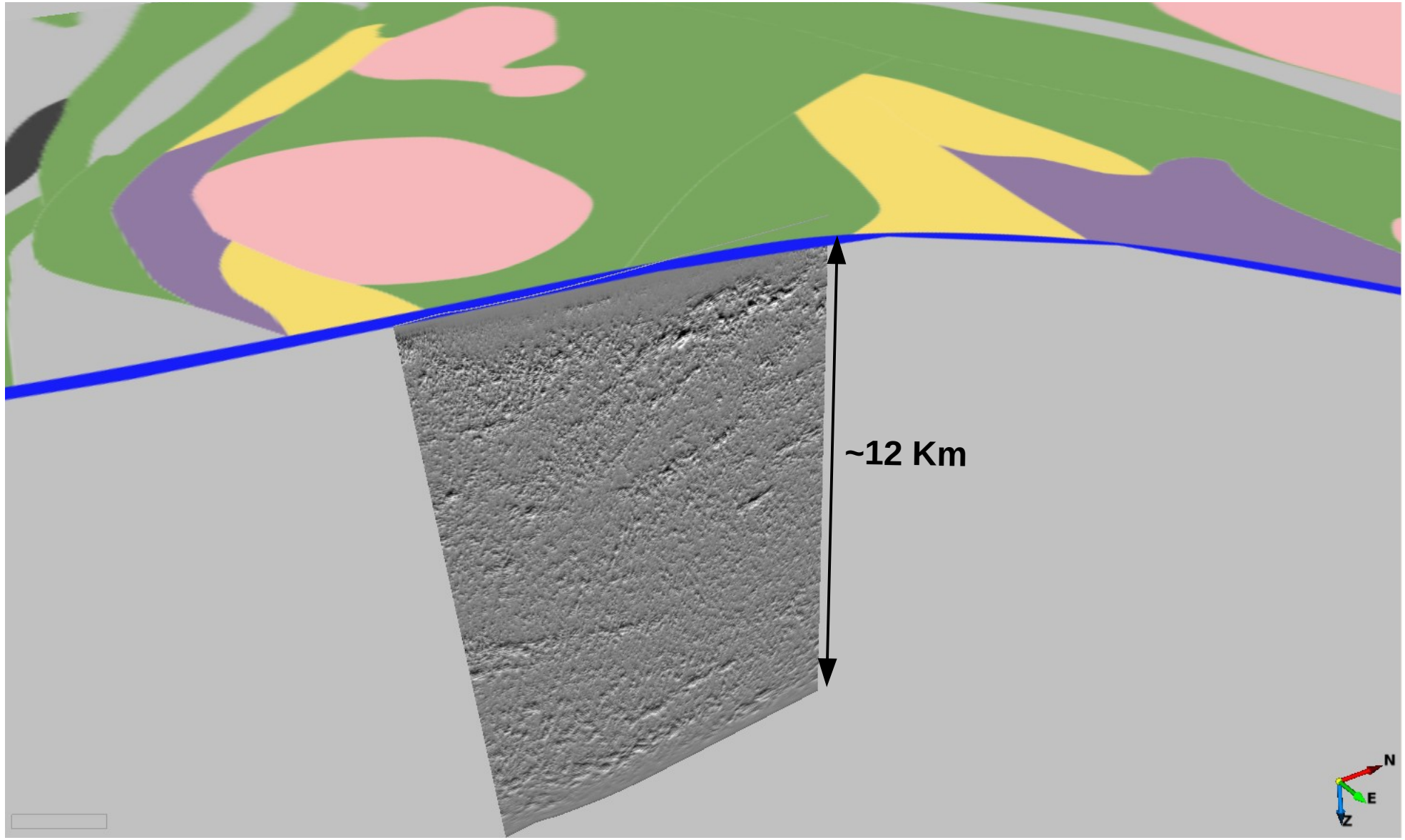
Lithoprobe High-Resolution AG-93a Transect (Matagami)



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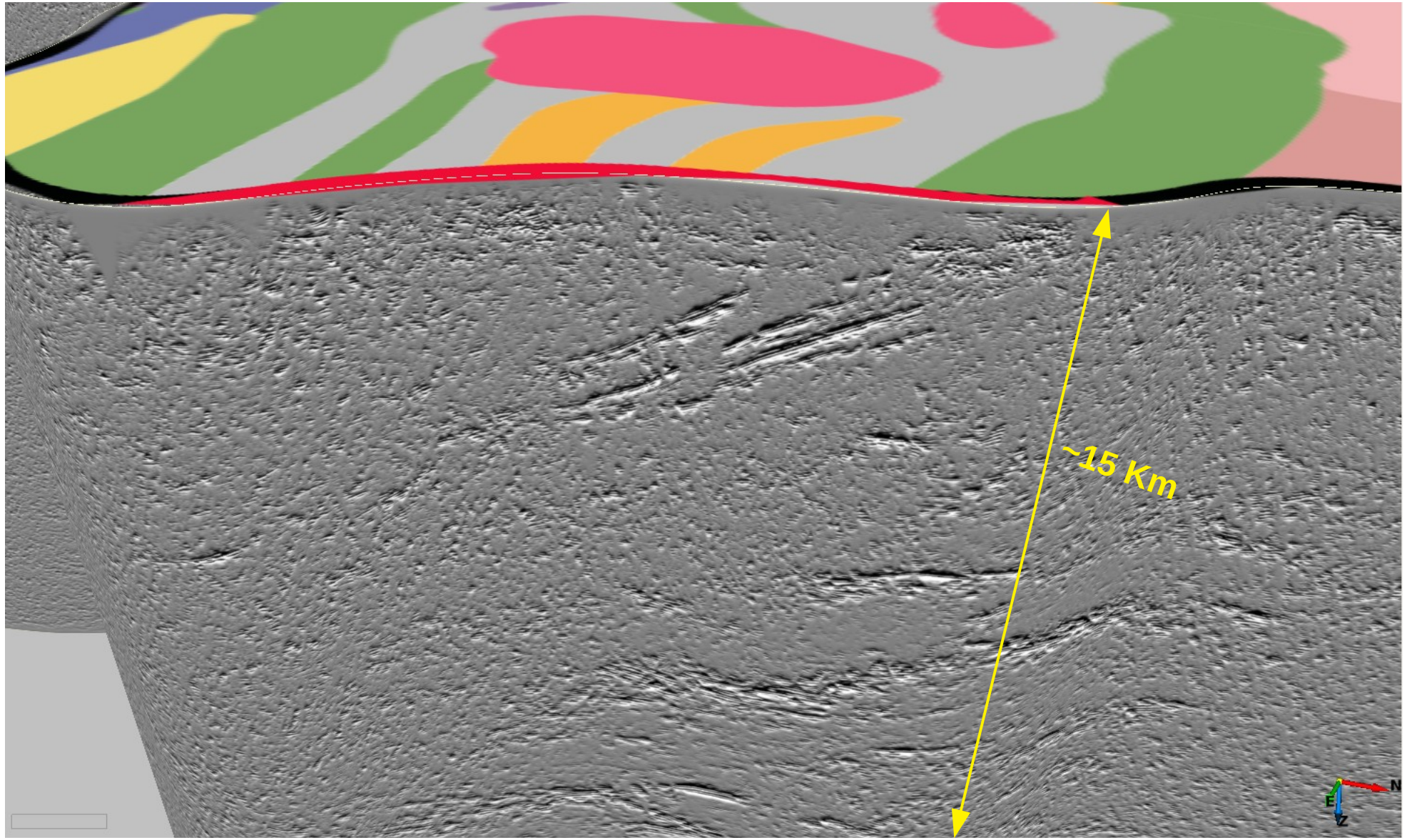
Northern part of Metal Earth Chibougamau R1 Transect



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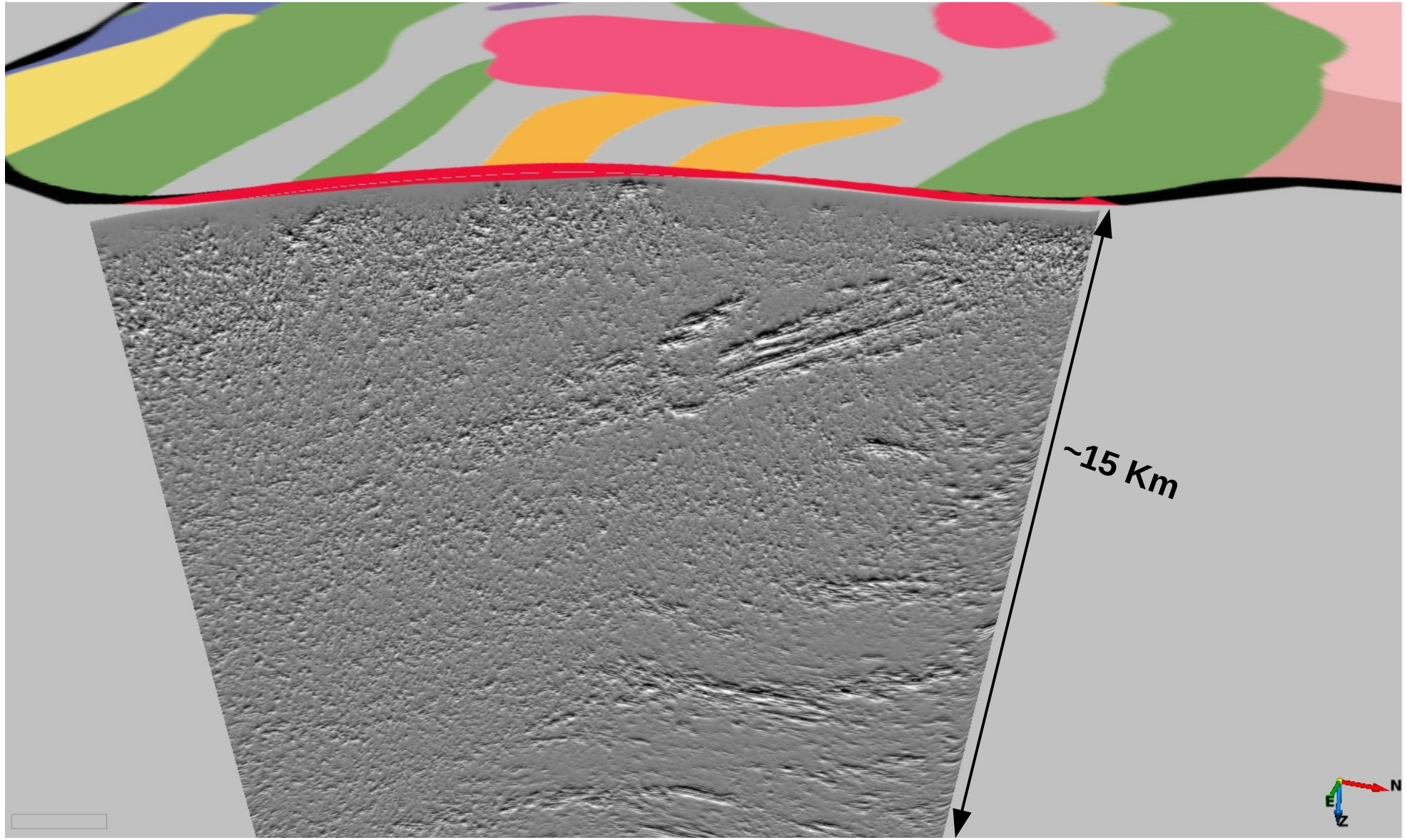
Metal Earth Chibougamau R2 Transect



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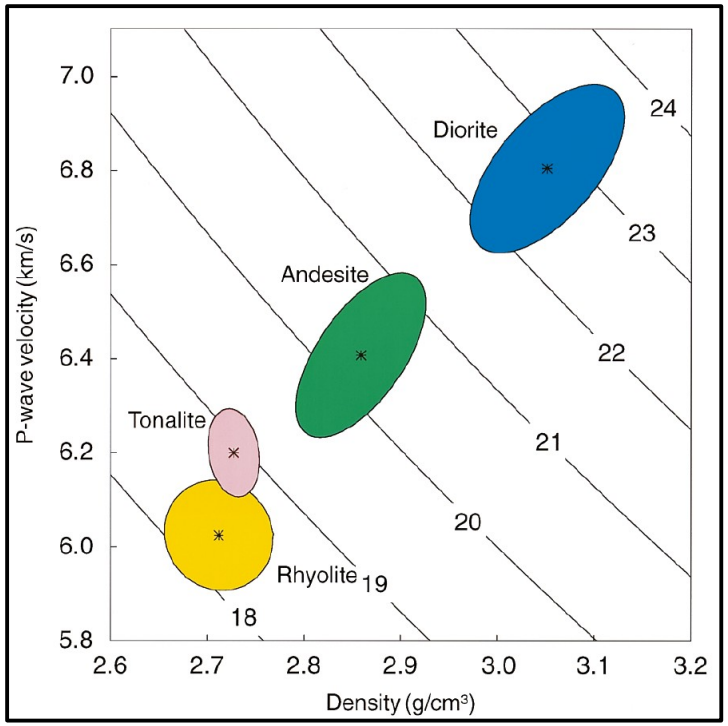
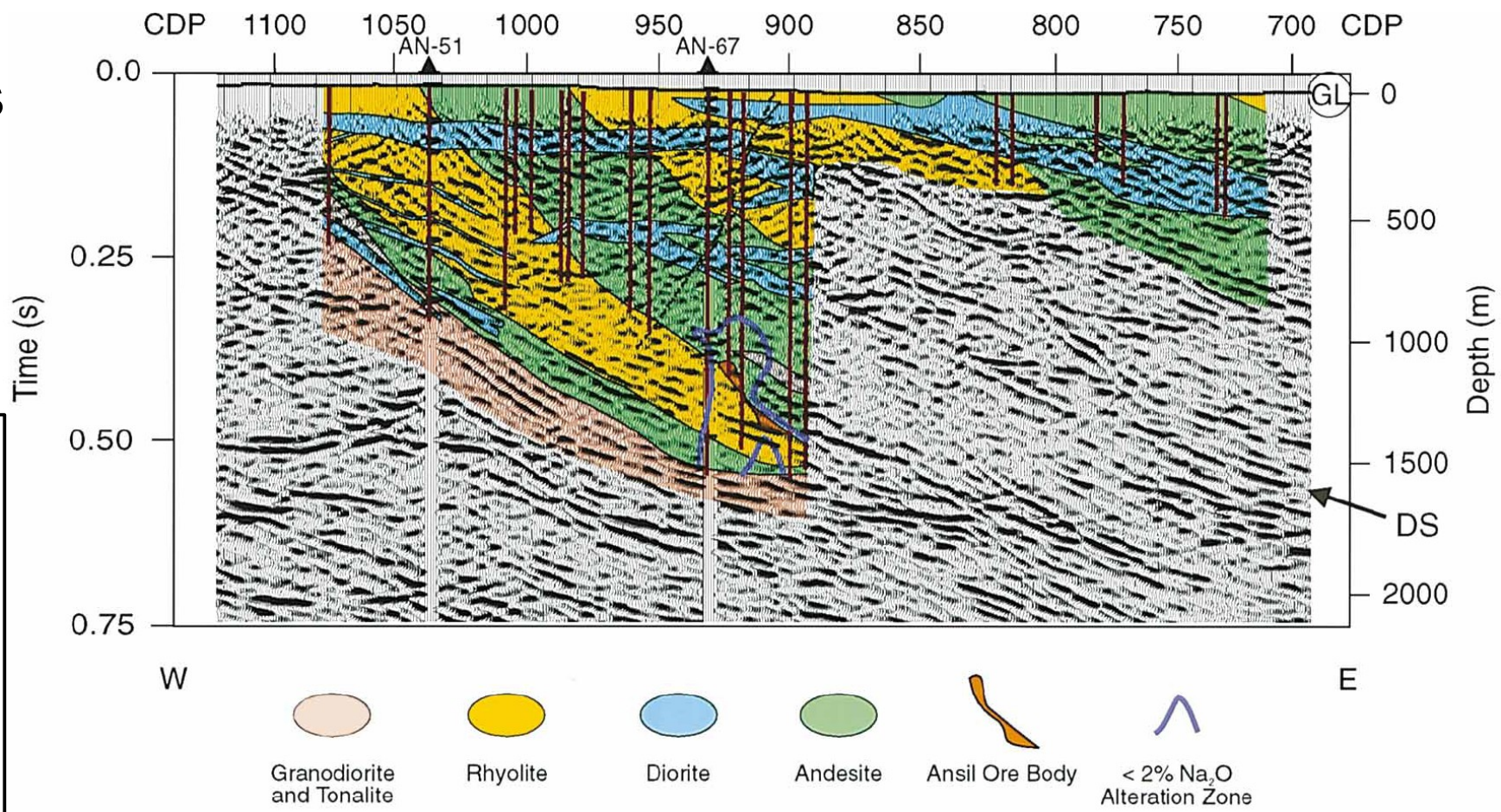
What is the nature of reflections in Superior?

- Lithological Boundaries
- Extensive Sills
- Deformation Zones
- …





High-resolution Seismic Imaging of Ansil (VMS) mining camp

Perron and Calvert (1998)

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Interpretation of Superior's Seismic Reflections (I)

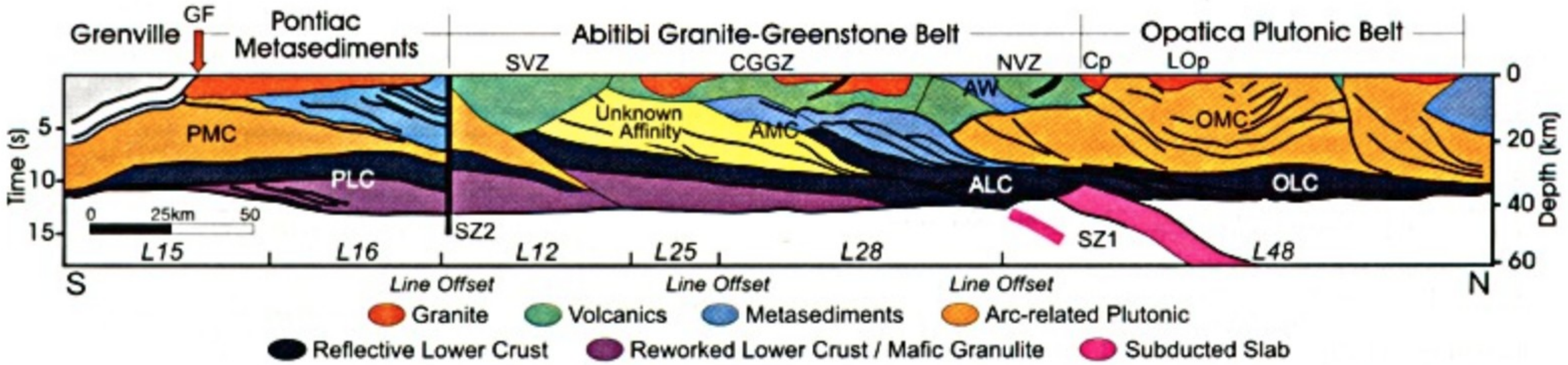

Figure 5. Composite interpretation of seismic sections across the Opatica plutonic belt, Abitibi granite-greenstone belt, Pontiac subprovince, and Grenville province; seismic line locations (L48, etc.) are shown in Figure 4. Irregular heavy black lines indicate seismic reflectors. ALC—Abitibi lower crust; AW—accreted wedge; CGGZ—central granite-gneiss zone; Cp—Canet pluton; GF—Grenville Front; LOp—Lac Ouescapis pluton; NVZ—northern volcanic zone; OMC—Opatica middle crust; OLC—Opatica lower crust; PMC—Pontiac middle crust; PLC—Pontiac lower crust; SVZ—southern volcanic zone; SZ1 and SZ2—suture zones 1 and 2.

Percival (2007)

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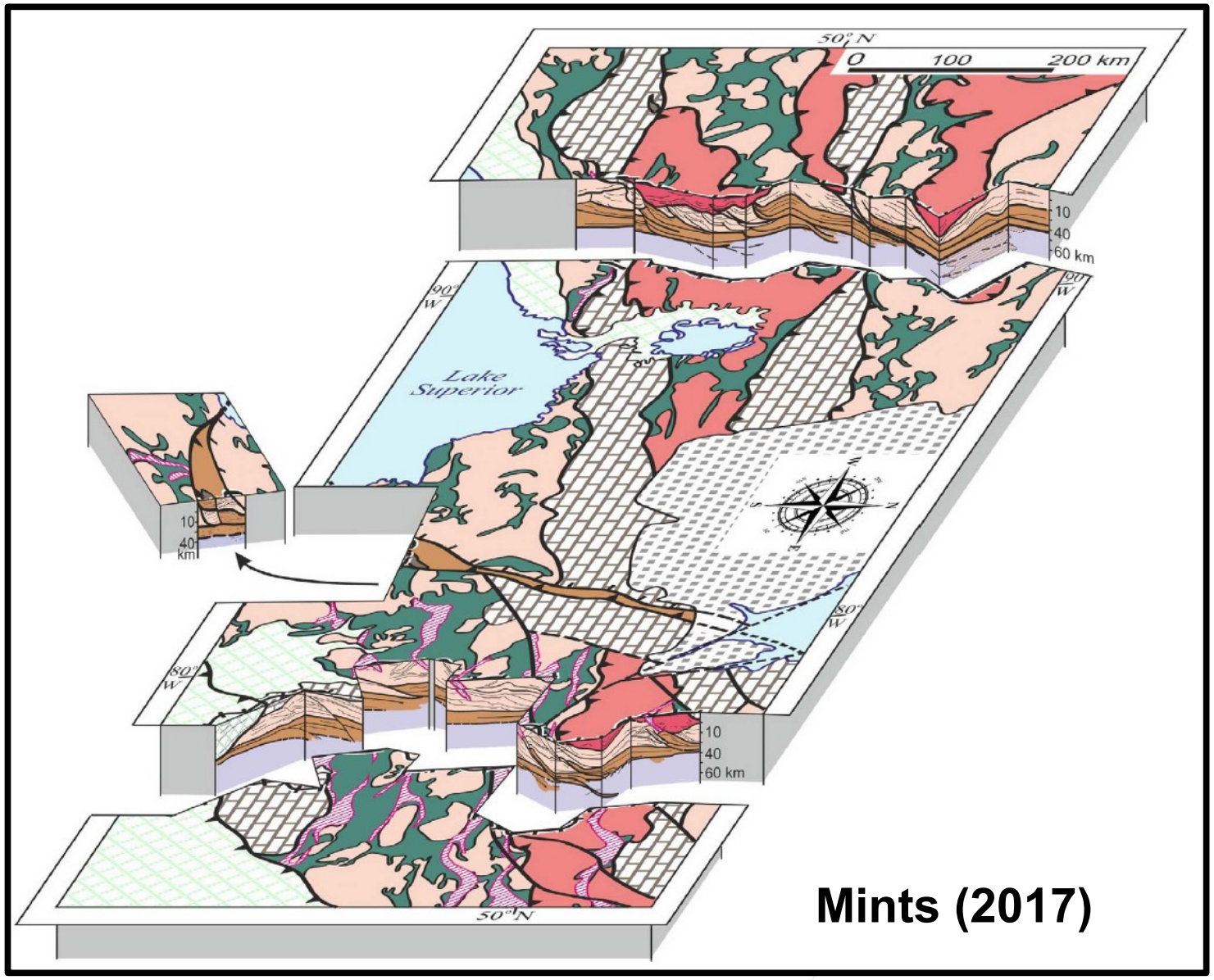
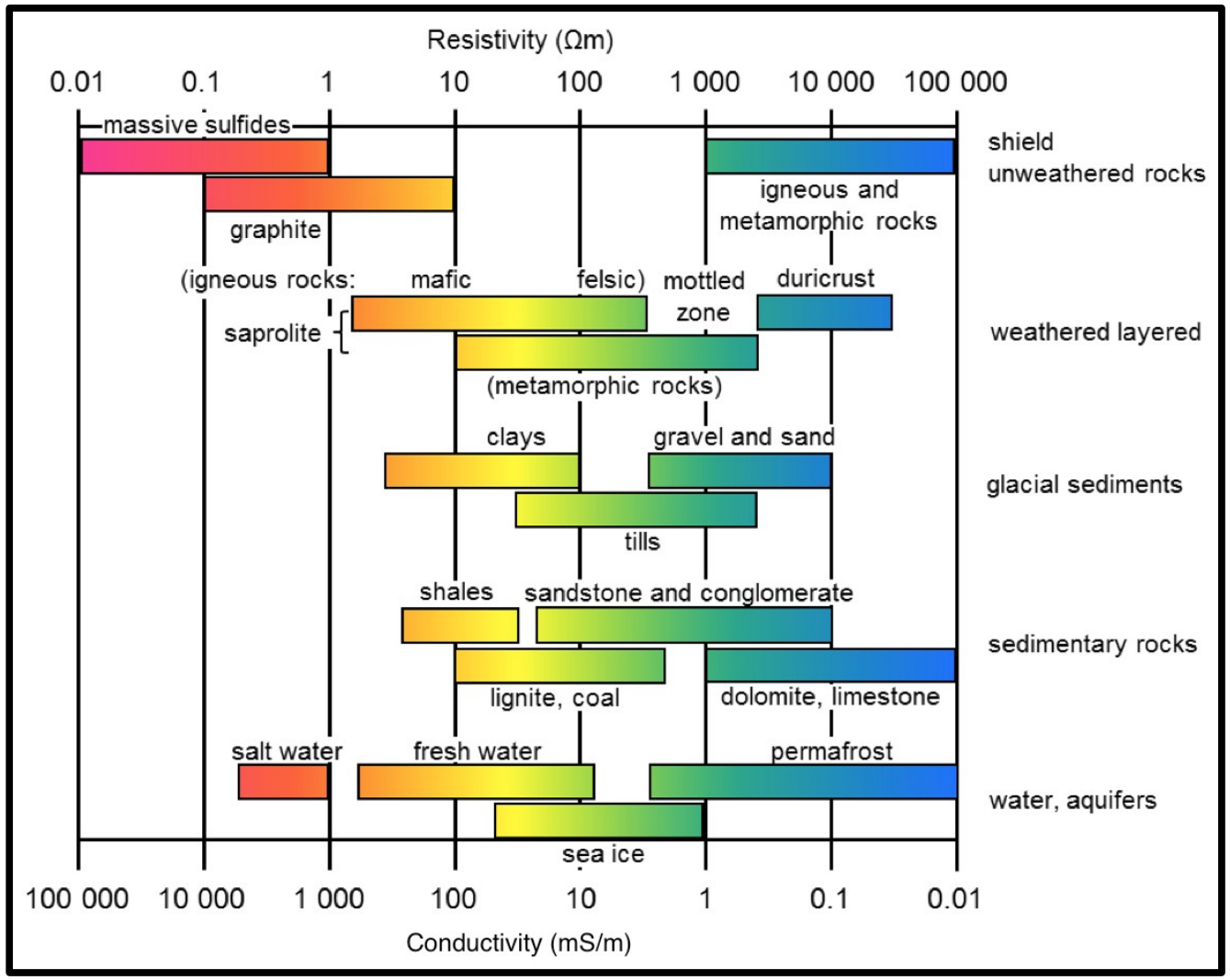
Interpretation of Superior's Seismic Reflections (II)

- **Upper Crust** (top 5 to 10 km) is mostly **non-reflective** except across meta-sedimentary belts.
- **Middle Crust** reflections are often gently dipping layers with variable thickness of 10 to 20 km. The boundaries of these layers should have a **tectonic origin** as there are variations of slope and cross-cutting of the layers. The **reverse–thrust displacement** of tectonic planes toward the surface is an indication of the relative lateral displacement of the planes.
- **Lower Crust** layers show zones of **intense and parallel reflections** near the base of the crust. The thickness of this zone in Abitibi is around 10 km while in Wabigoon (western Superior) it doubles to 20 km.

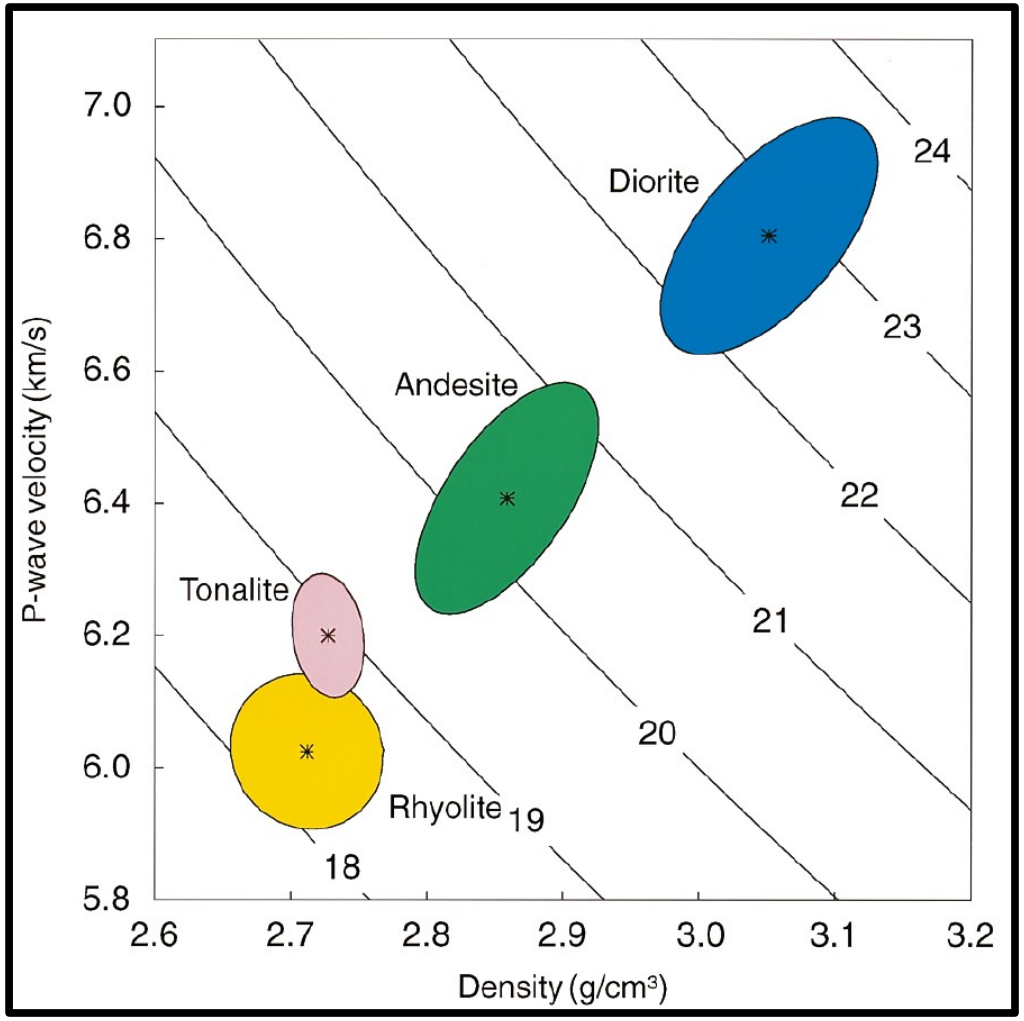


Mints (2017)

Density, Seismic Velocity, and Electrical Resistivity of Rocks



Palacky (1987)



Perron and Calvert (1998)

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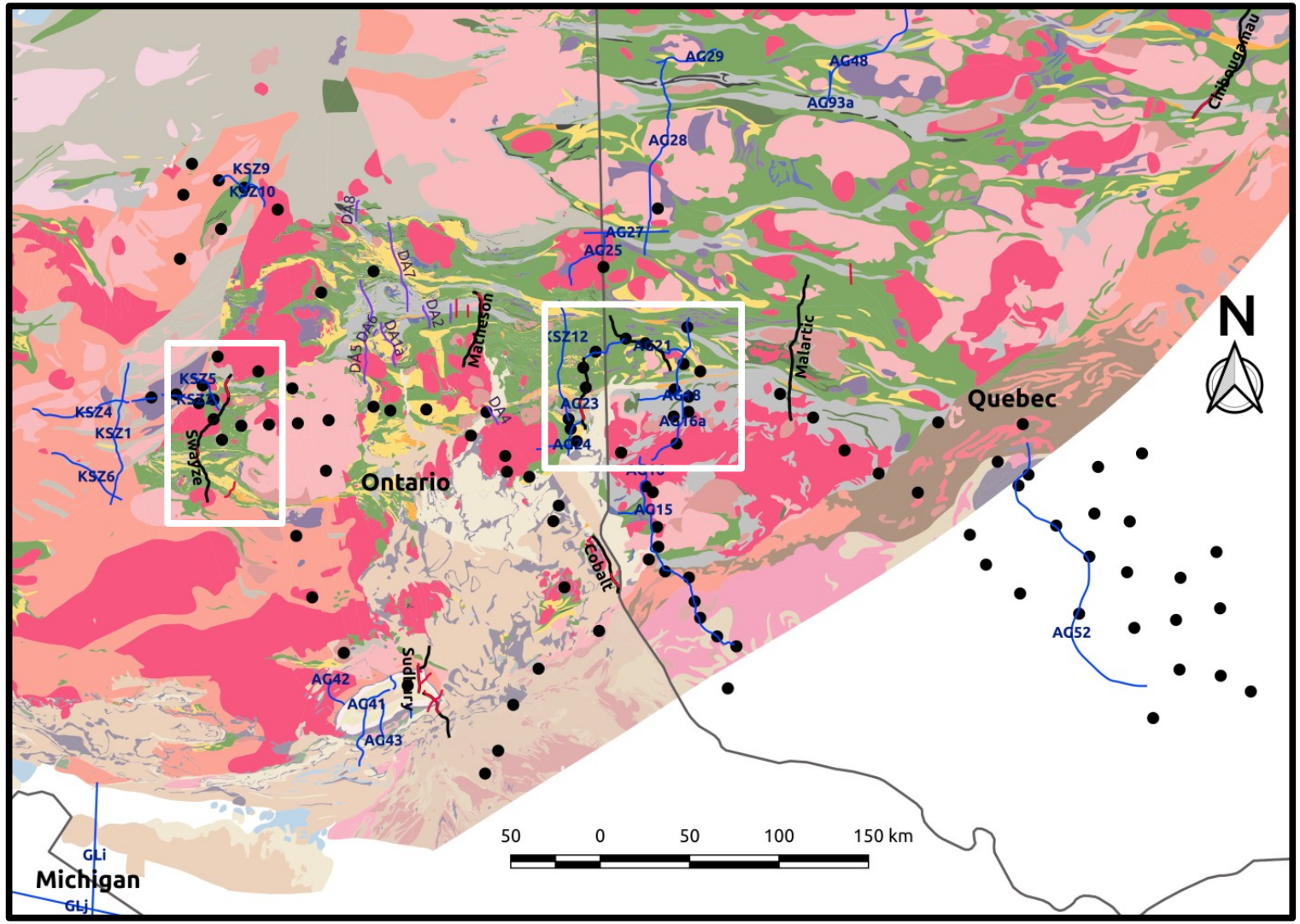
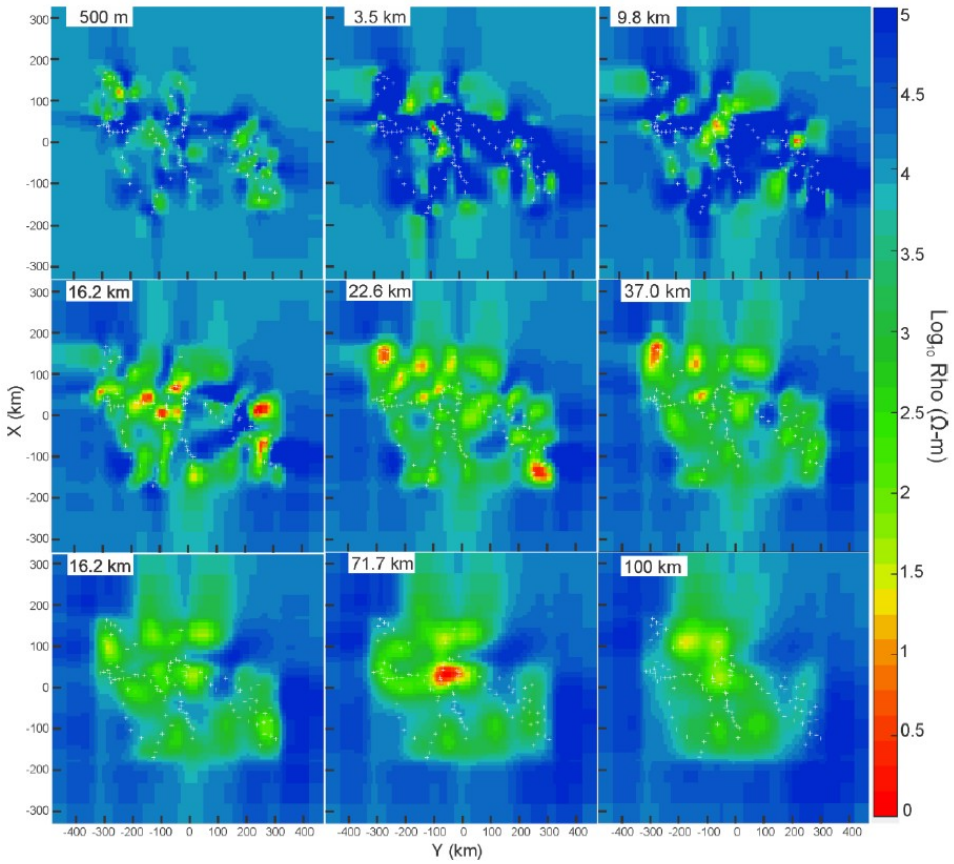
3D Resistivity Model inverted from Lithoprobe MT data





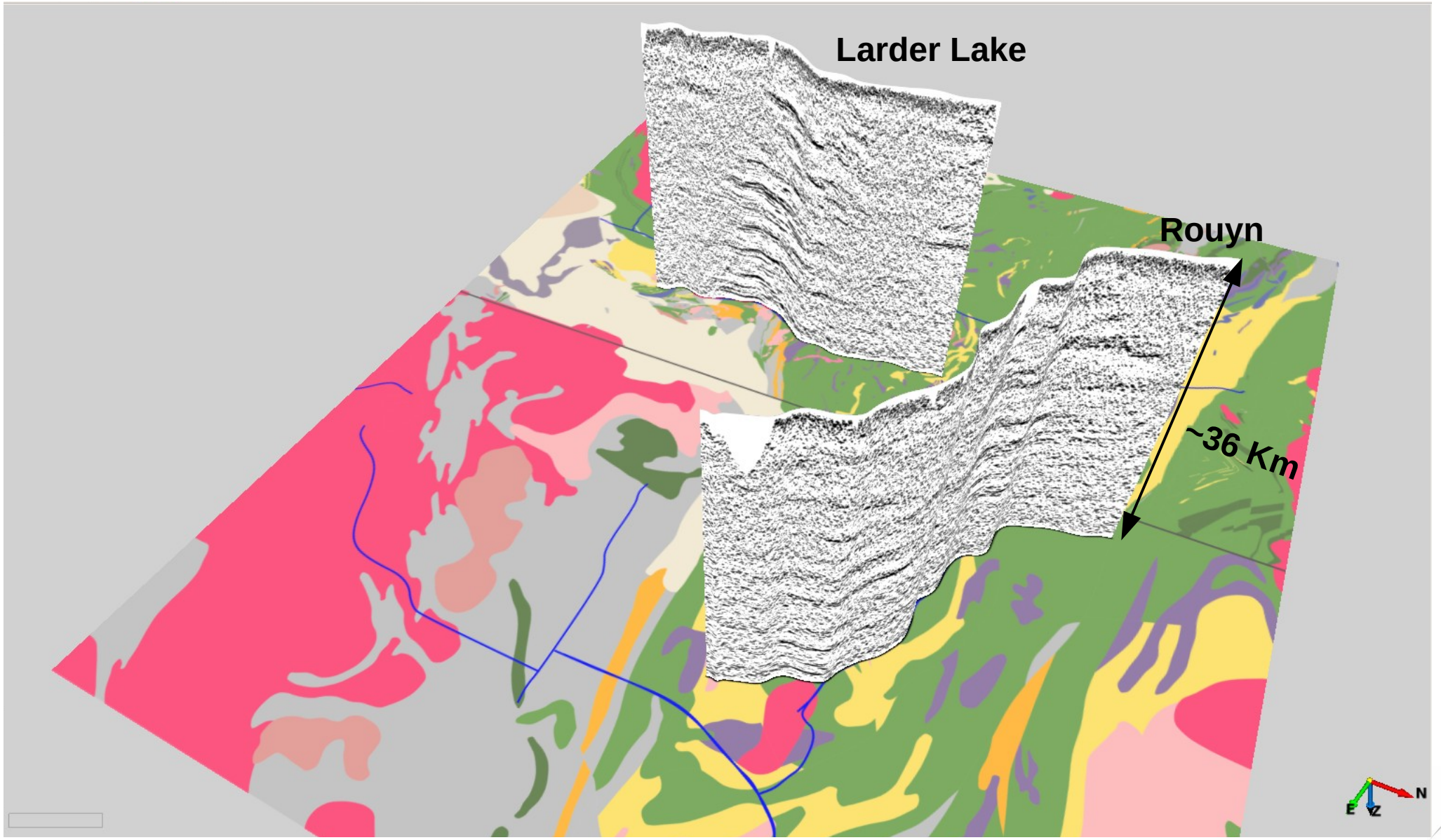
Inverted 3D MT Resistivity Model

Roots and Craven (2017)

- Lithoprobe MT stations used for 3D MT inversion

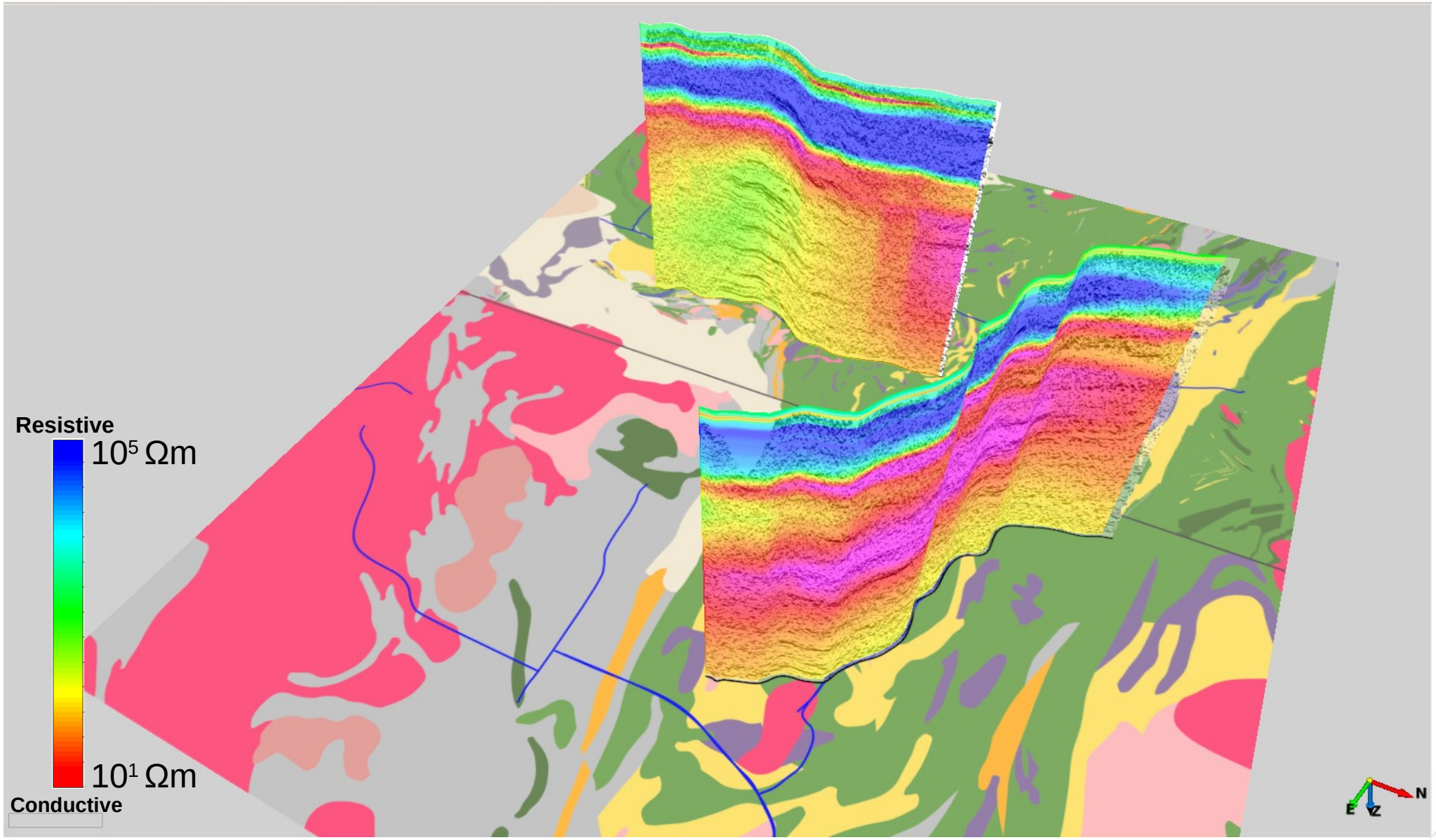
METAL EARTH

Metal Earth Rouyn and Larder Lake Seismic Transects



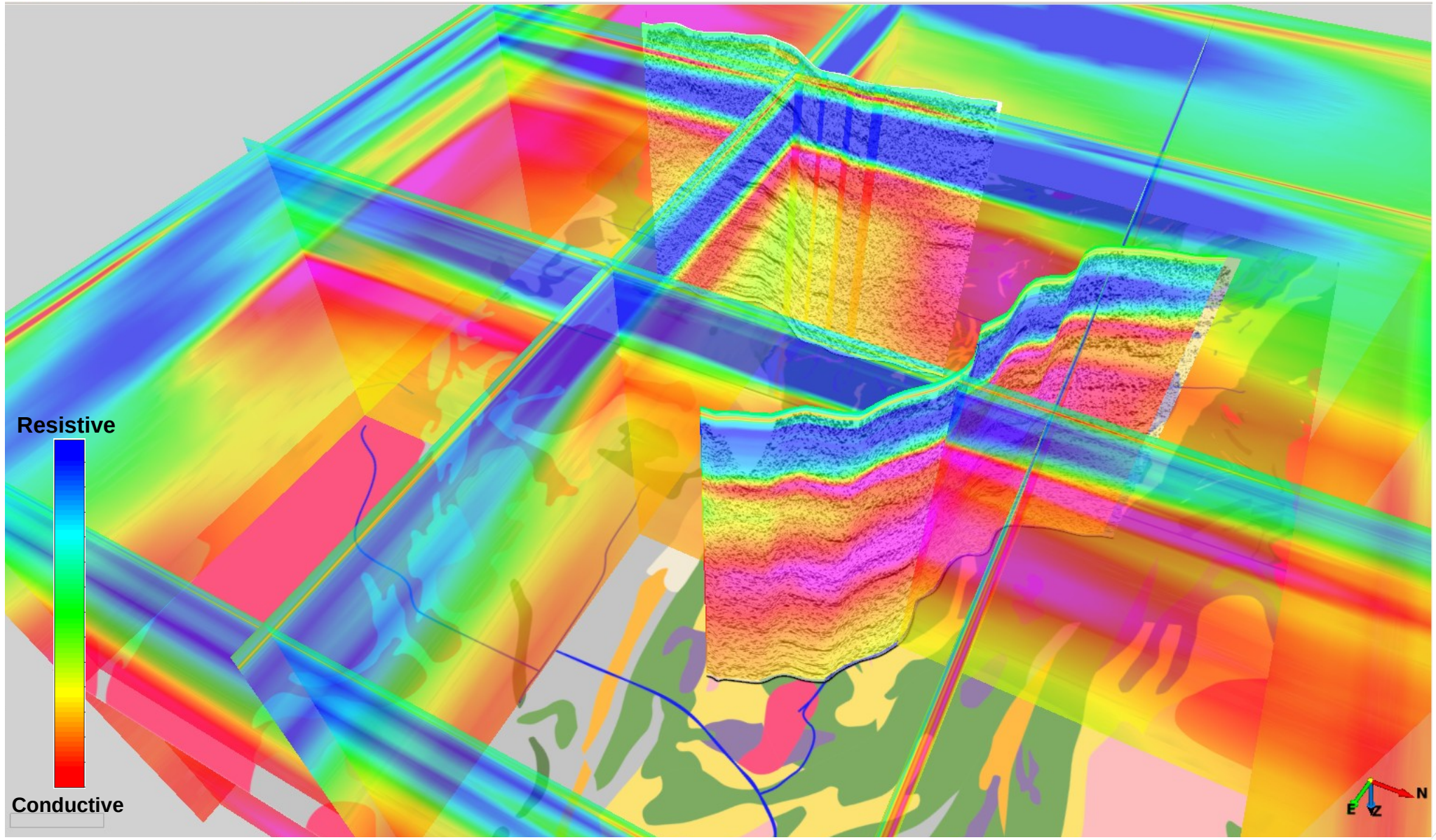
METAL EARTH

Projected Electrical Resistivity along Seismic Transects



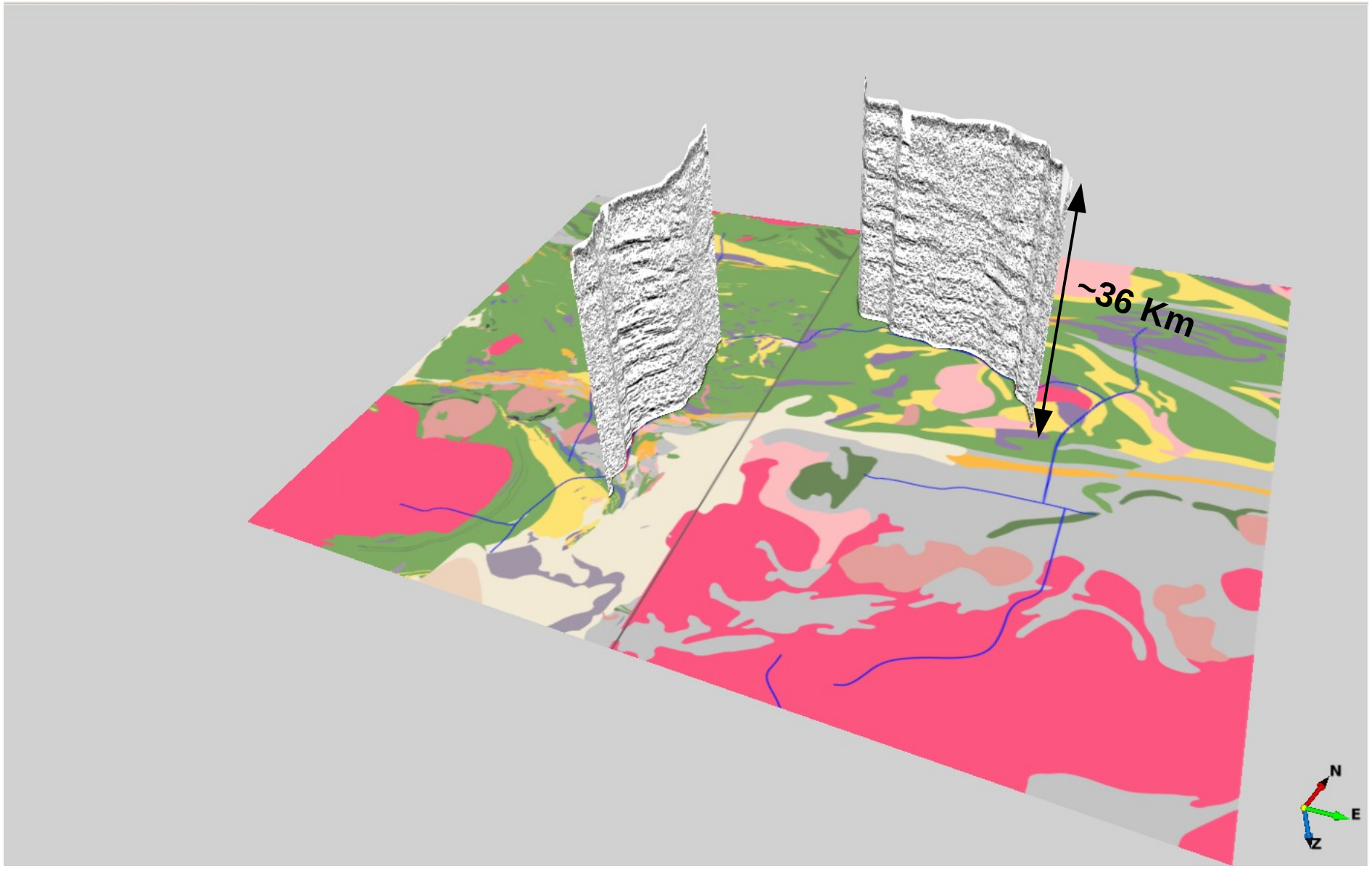
METAL EARTH

3D Electrical Resistivity Model



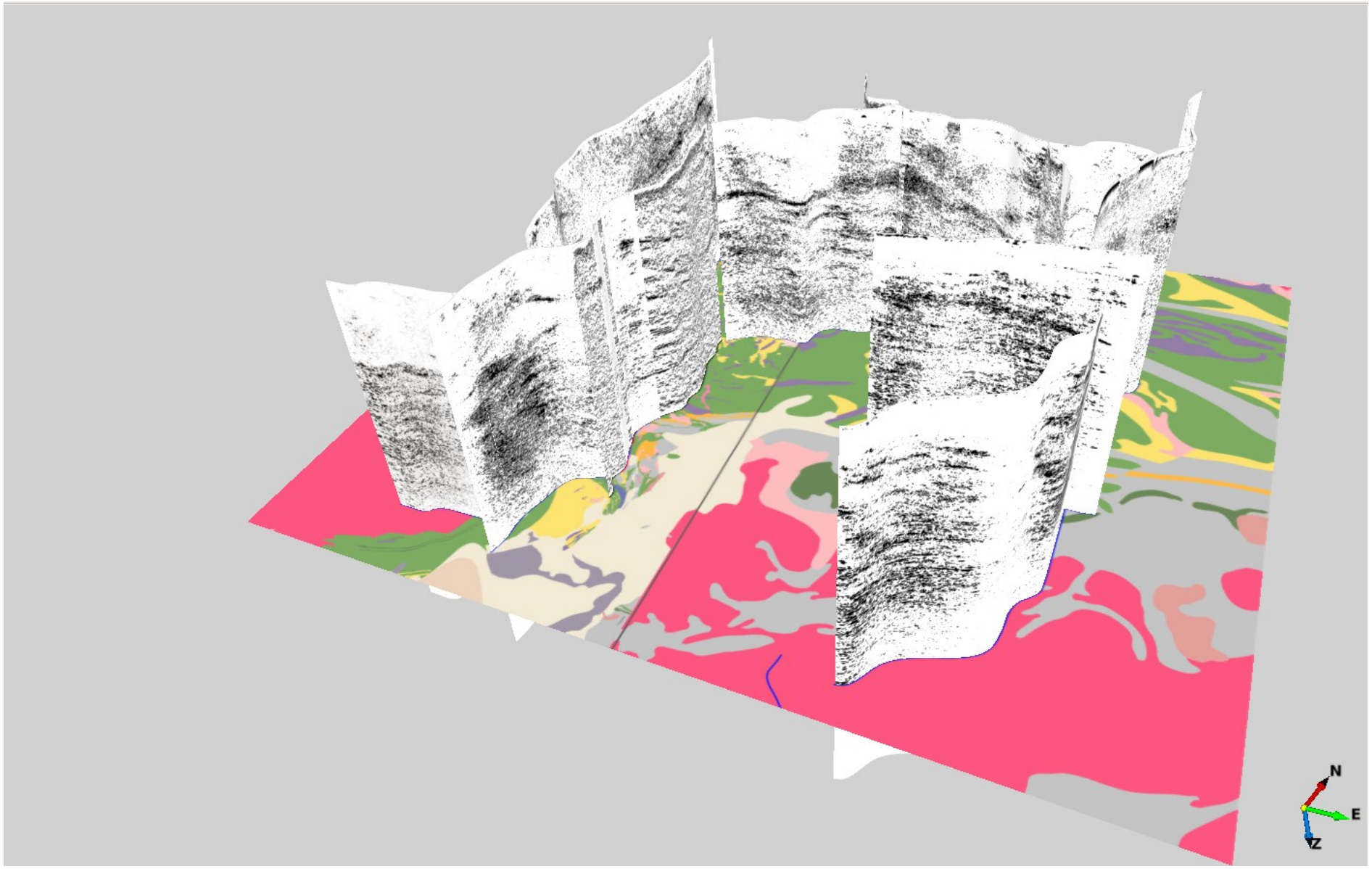
METAL EARTH

Metal Earth Rouyn and Larder Lake Seismic Transects



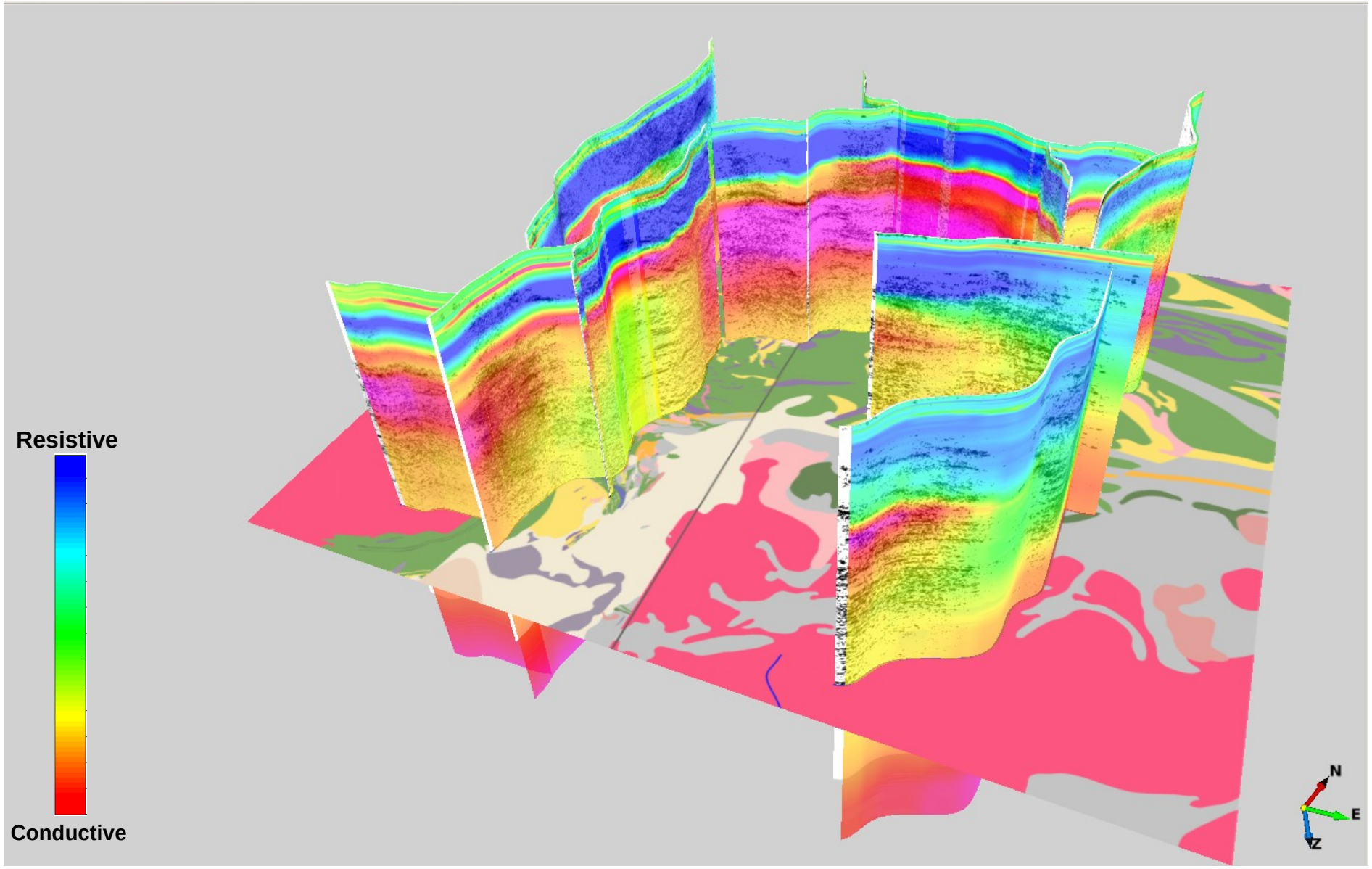
METAL EARTH

Lithoprobe AG- (14, 16a, 18, 21, 23, 24) and KSZ-12



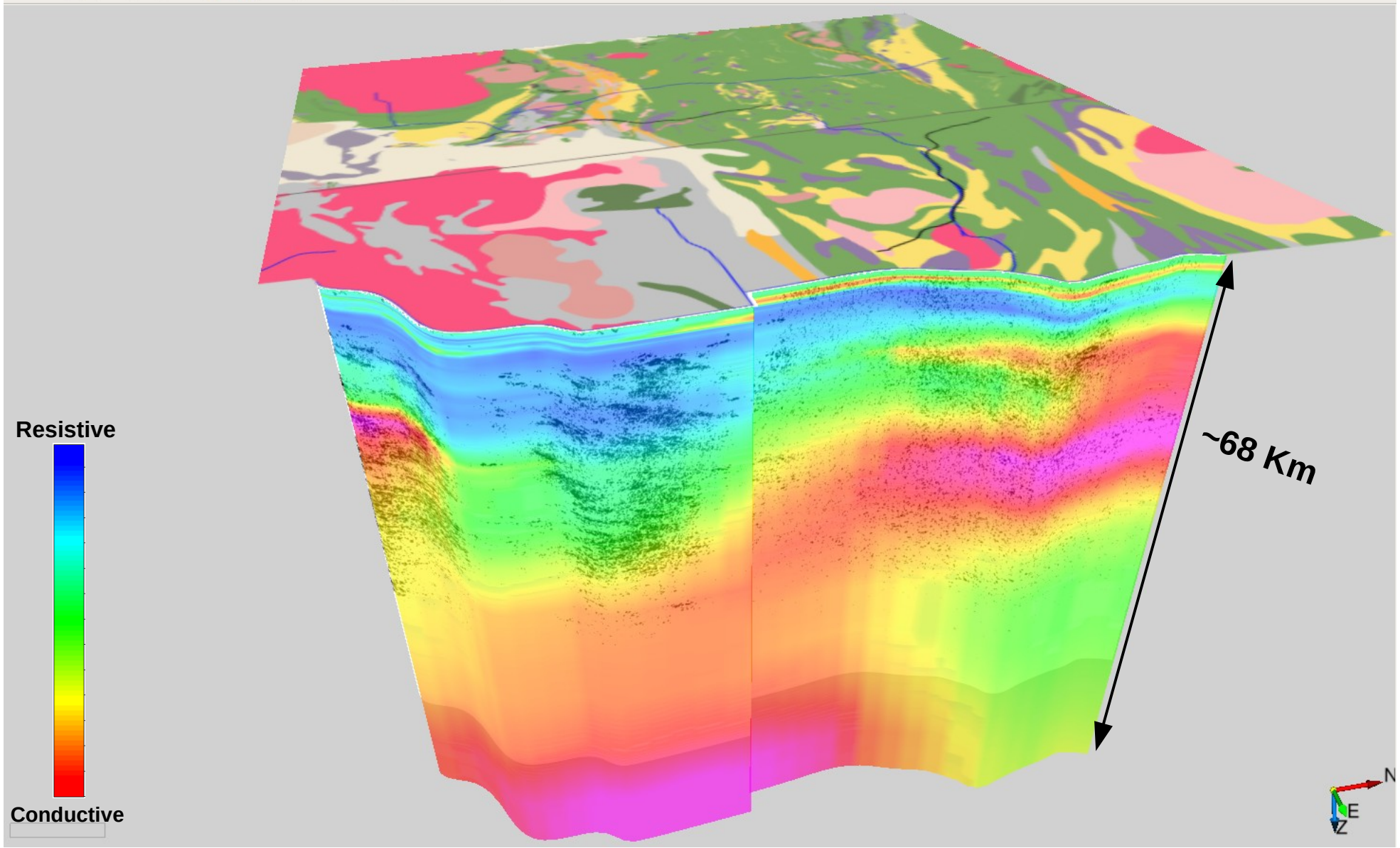
METAL EARTH

Projected Electrical Resistivity along Seismic Transects



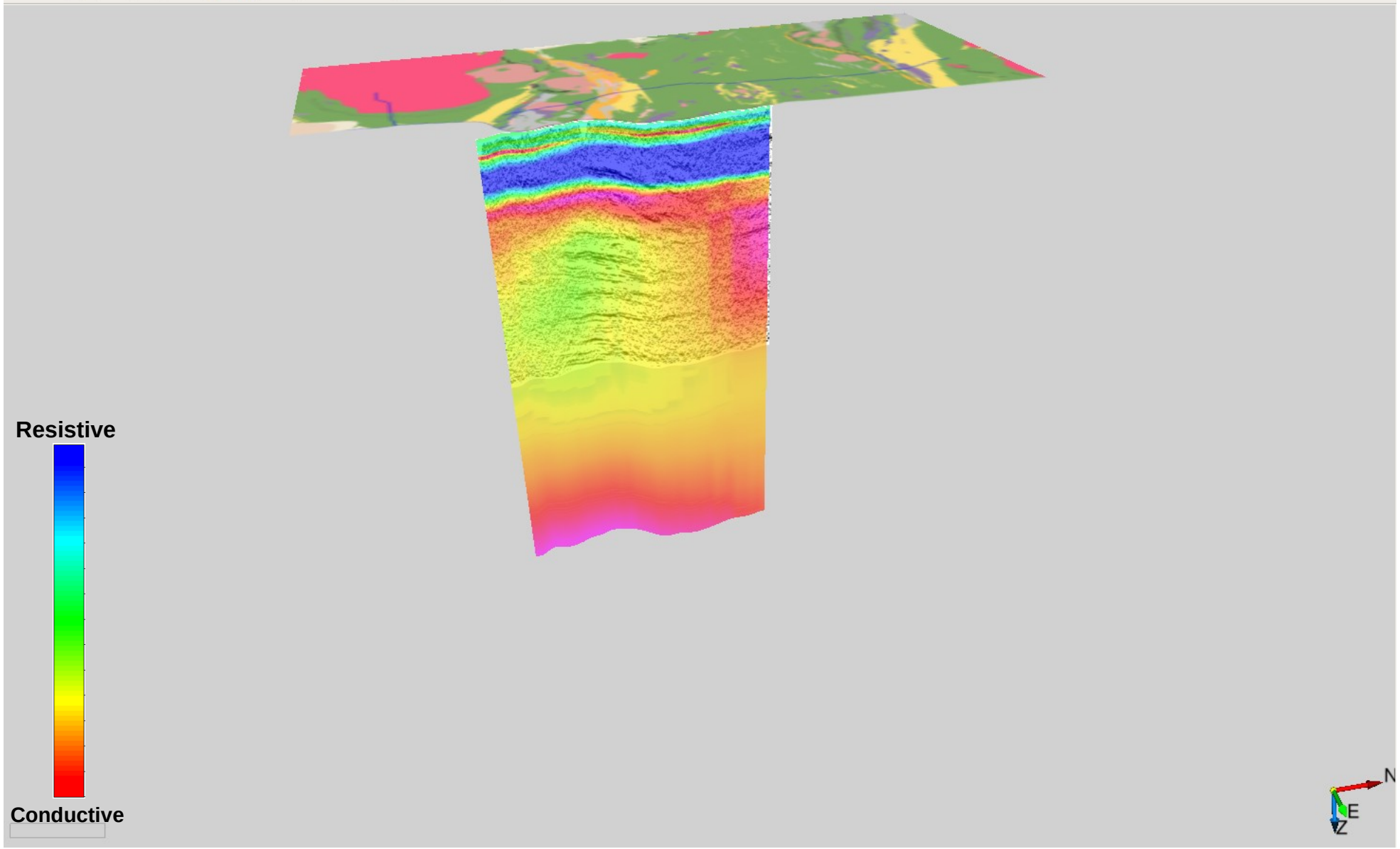
METAL EARTH

Projected Electrical Resistivity along AG-14 and AG-16a



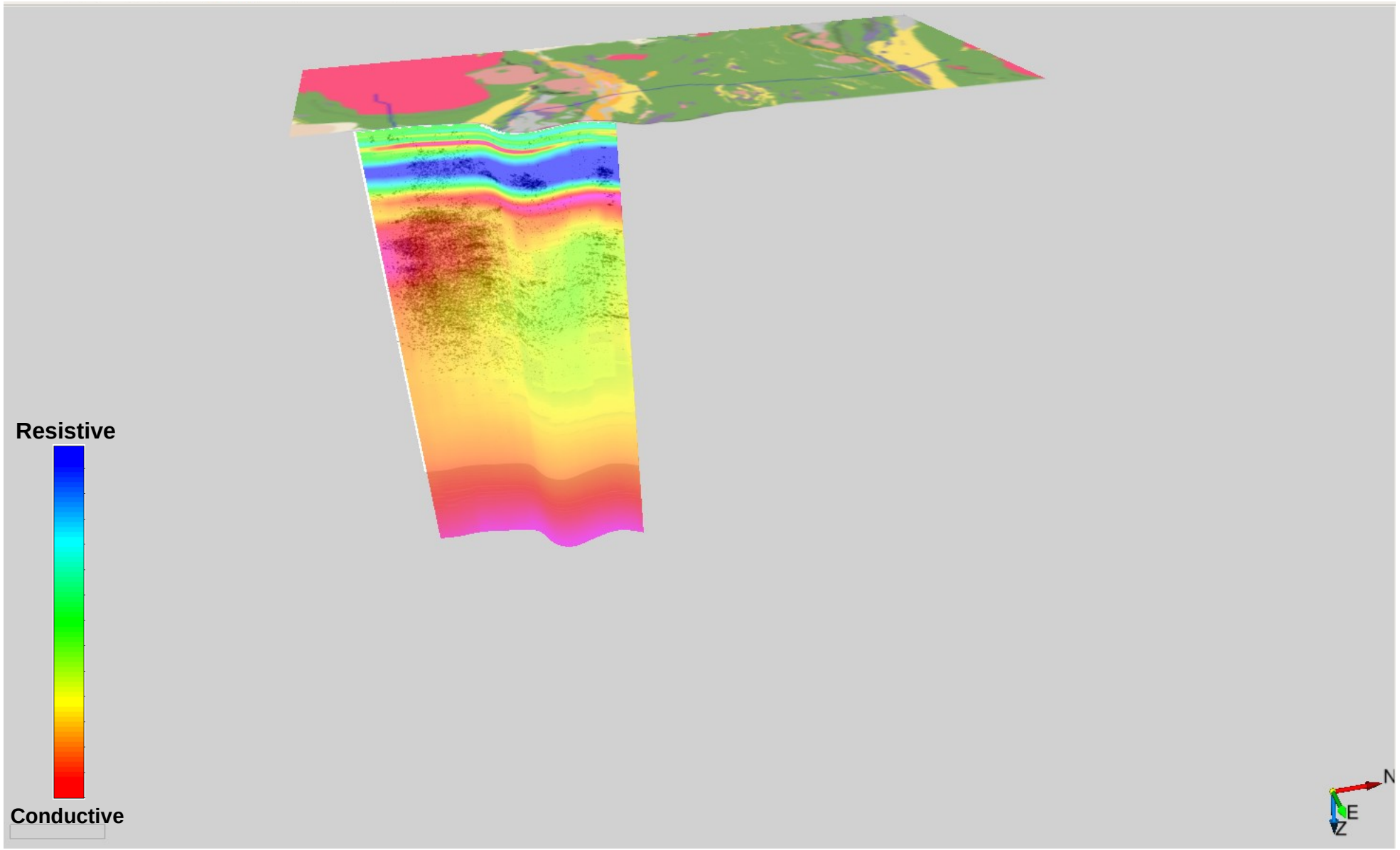
METAL EARTH

Projected Electrical Resistivity along ME-LarderLake



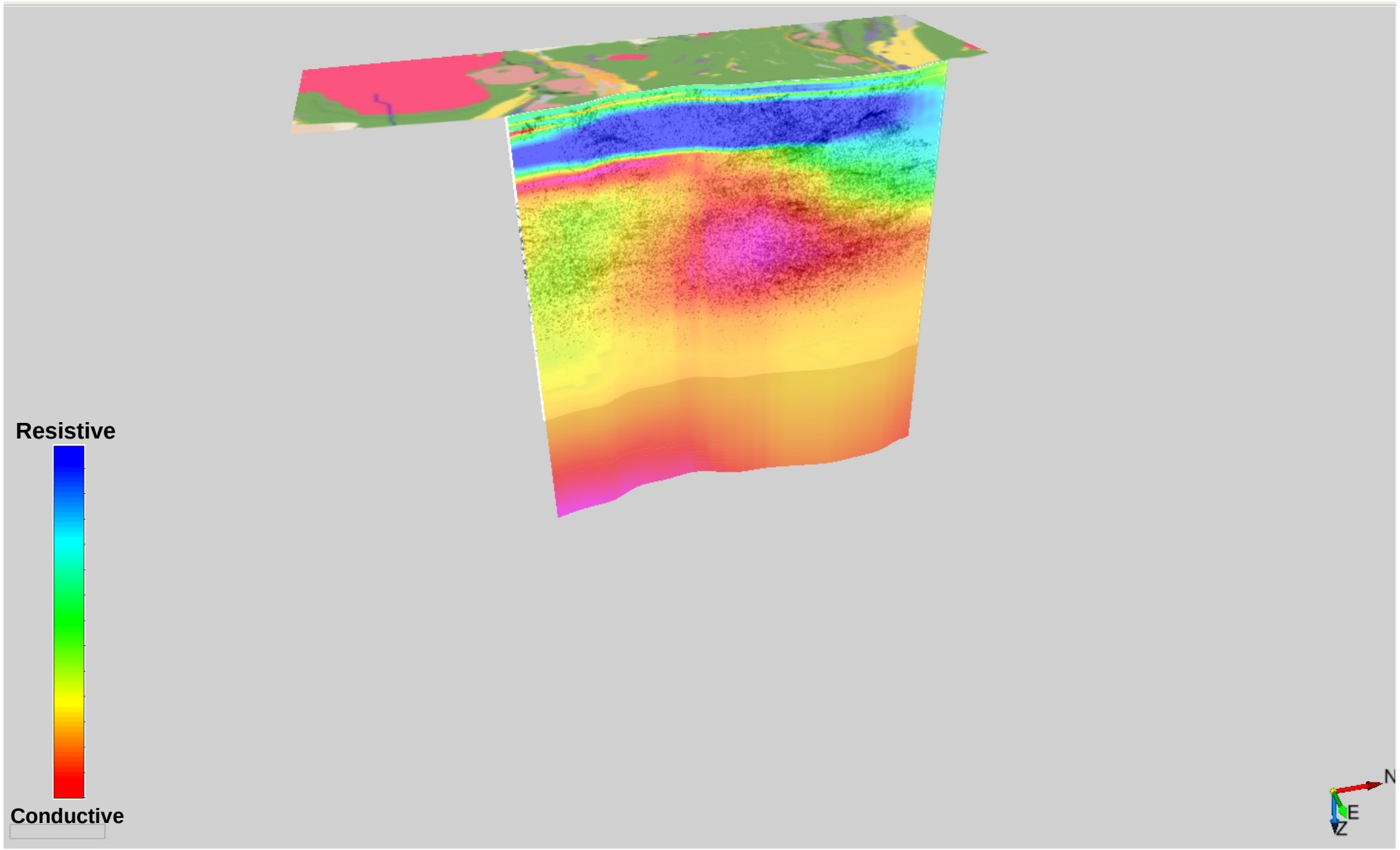
METAL EARTH

Projected Electrical Resistivity along AG-23



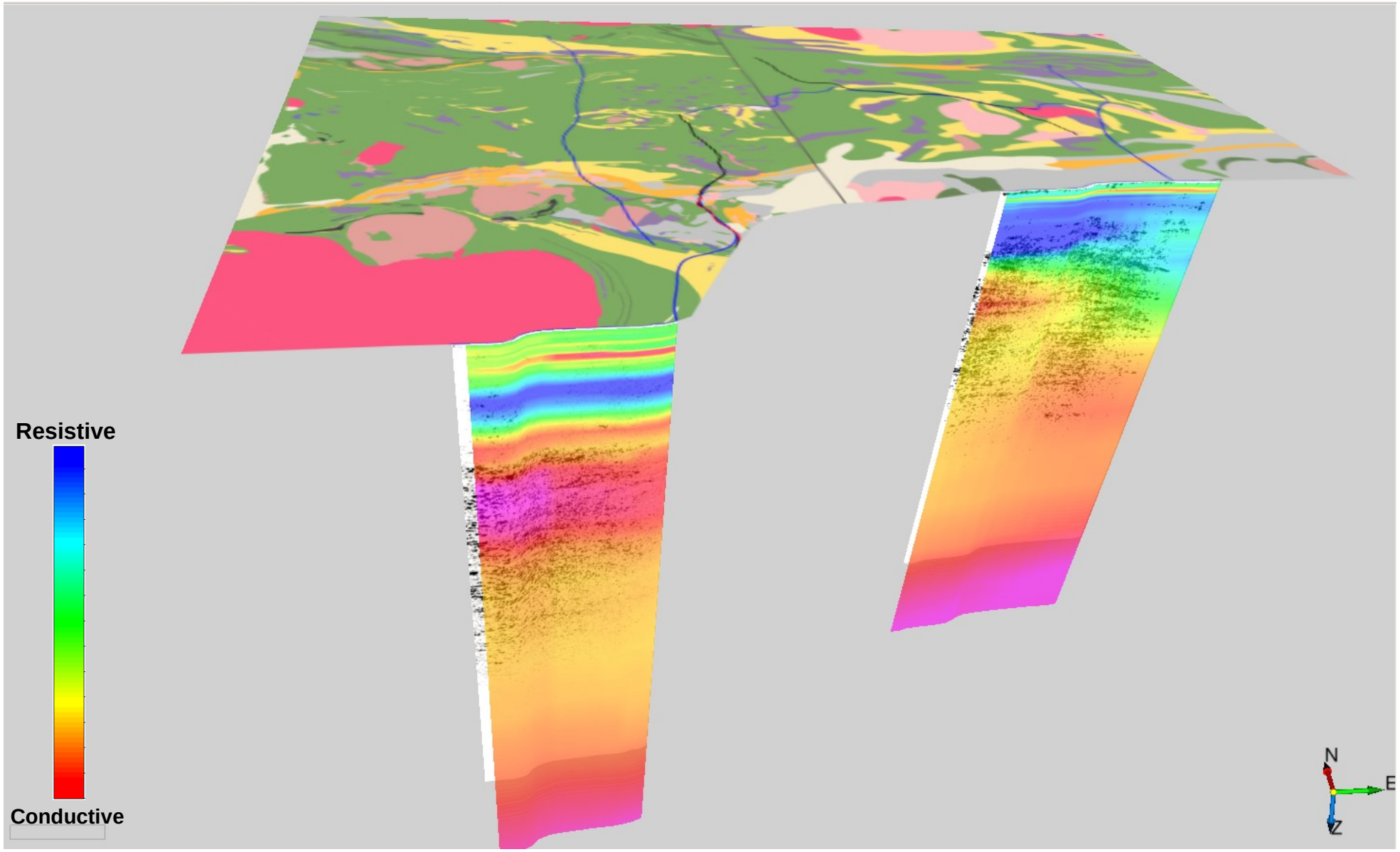
METAL EARTH

Projected Electrical Resistivity along KSZ-12



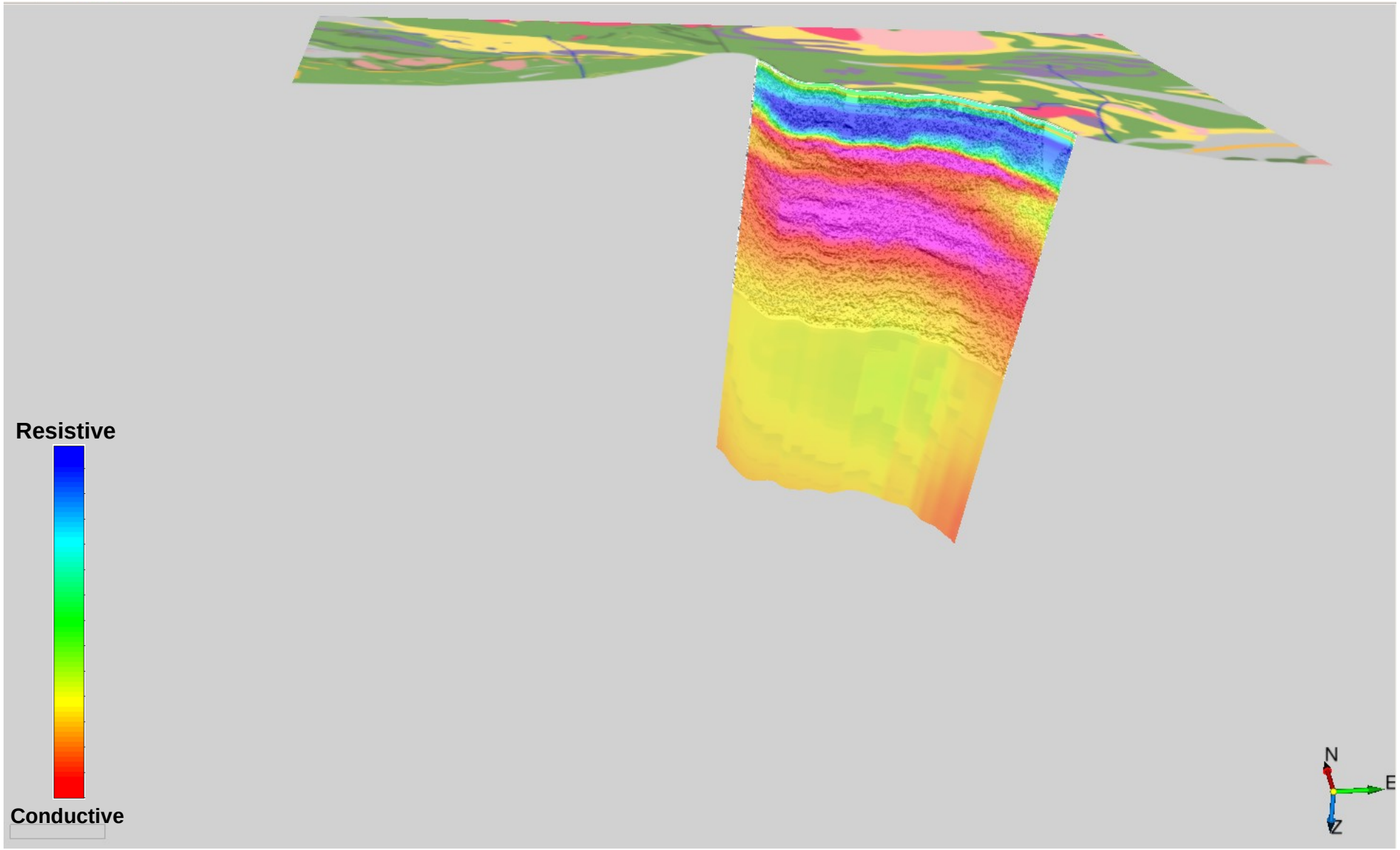
METAL EARTH

Projected Electrical Resistivity along AG-24 and AG-18



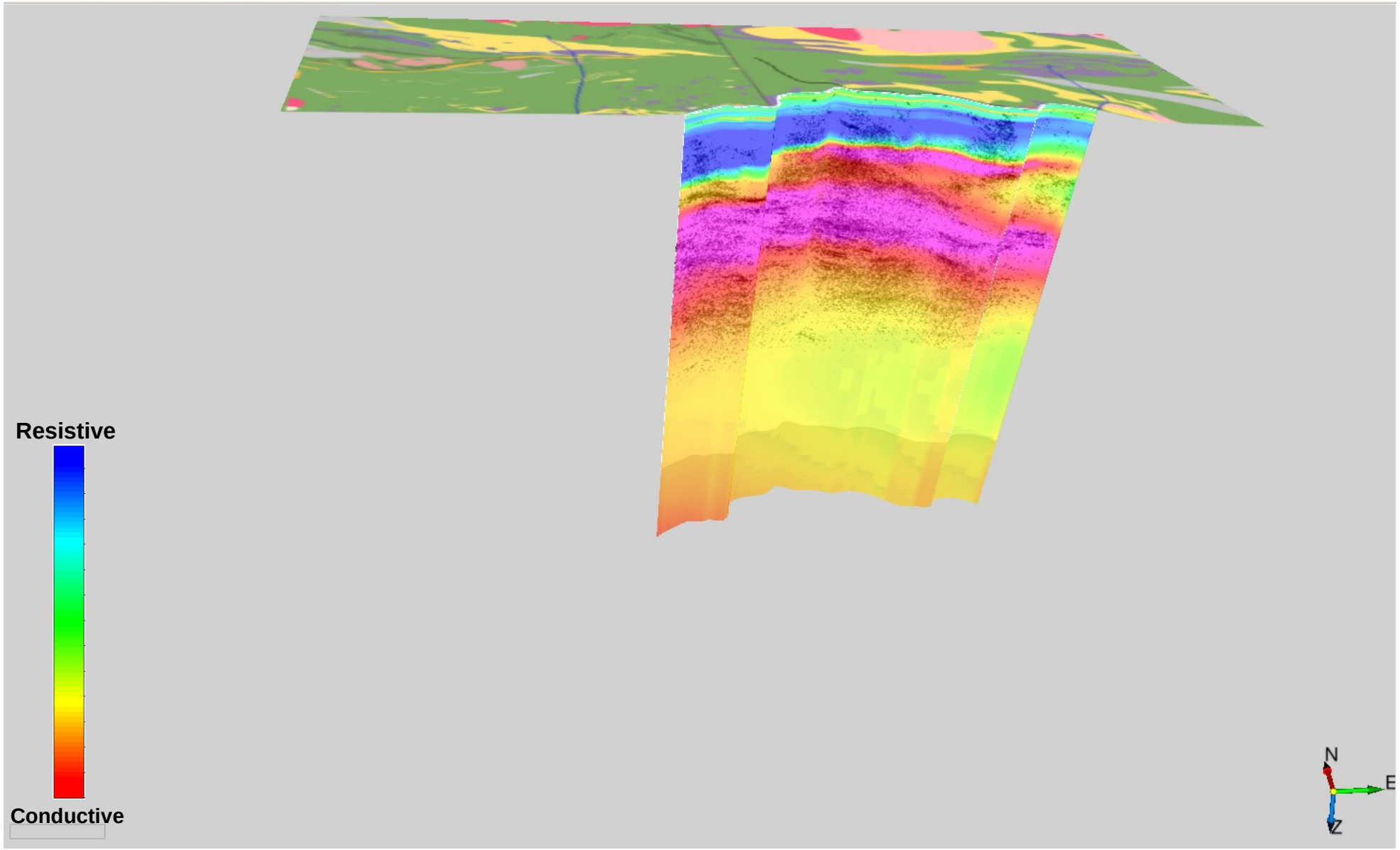
METAL EARTH

Projected Electrical Resistivity along ME-Rouyn



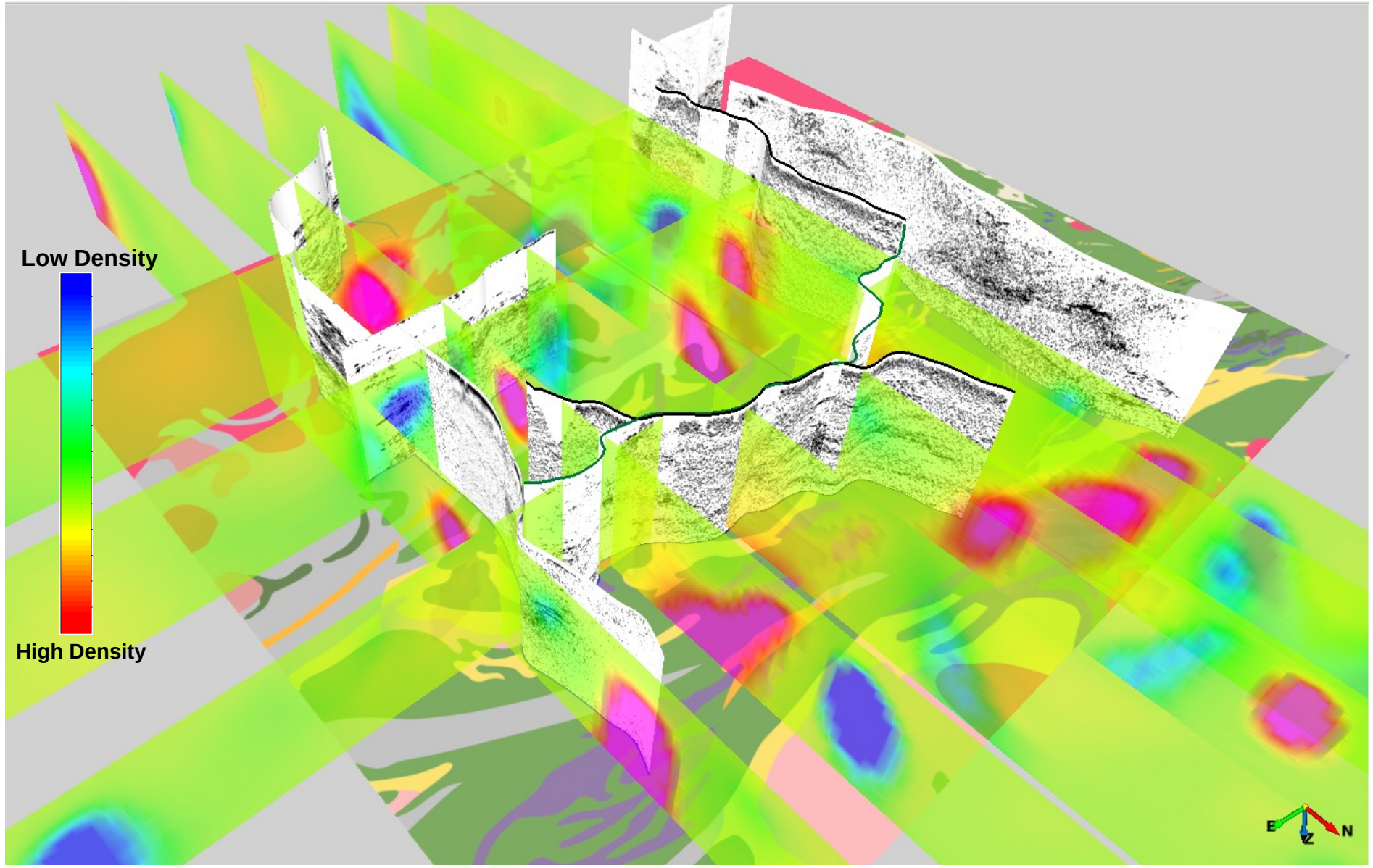
METAL EARTH

Projected Electrical Resistivity along AG-21



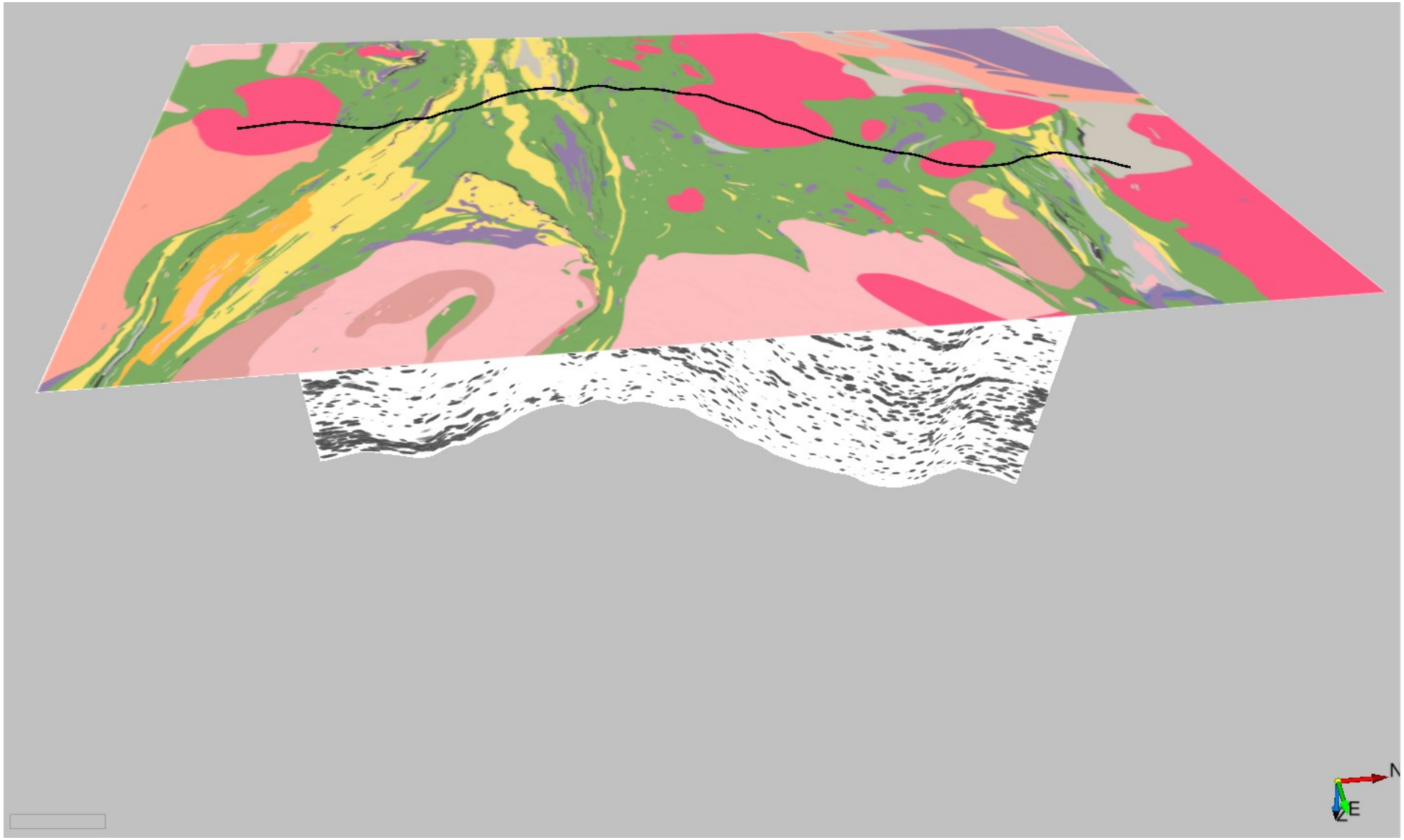
METAL EARTH

3D Density Variation Model from Gravity Data Inversion



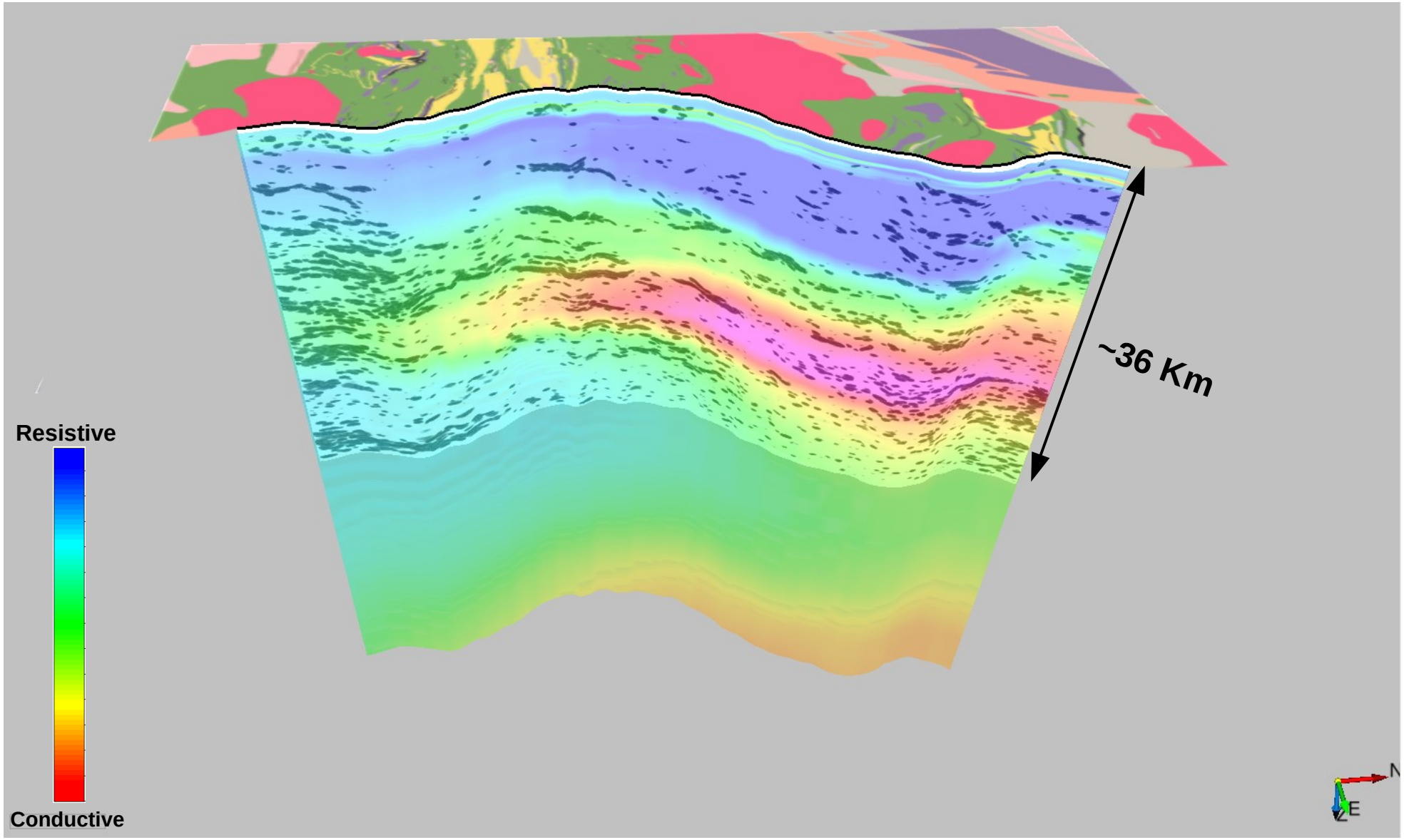
METAL EARTH

Metal Earth Swayze Transect



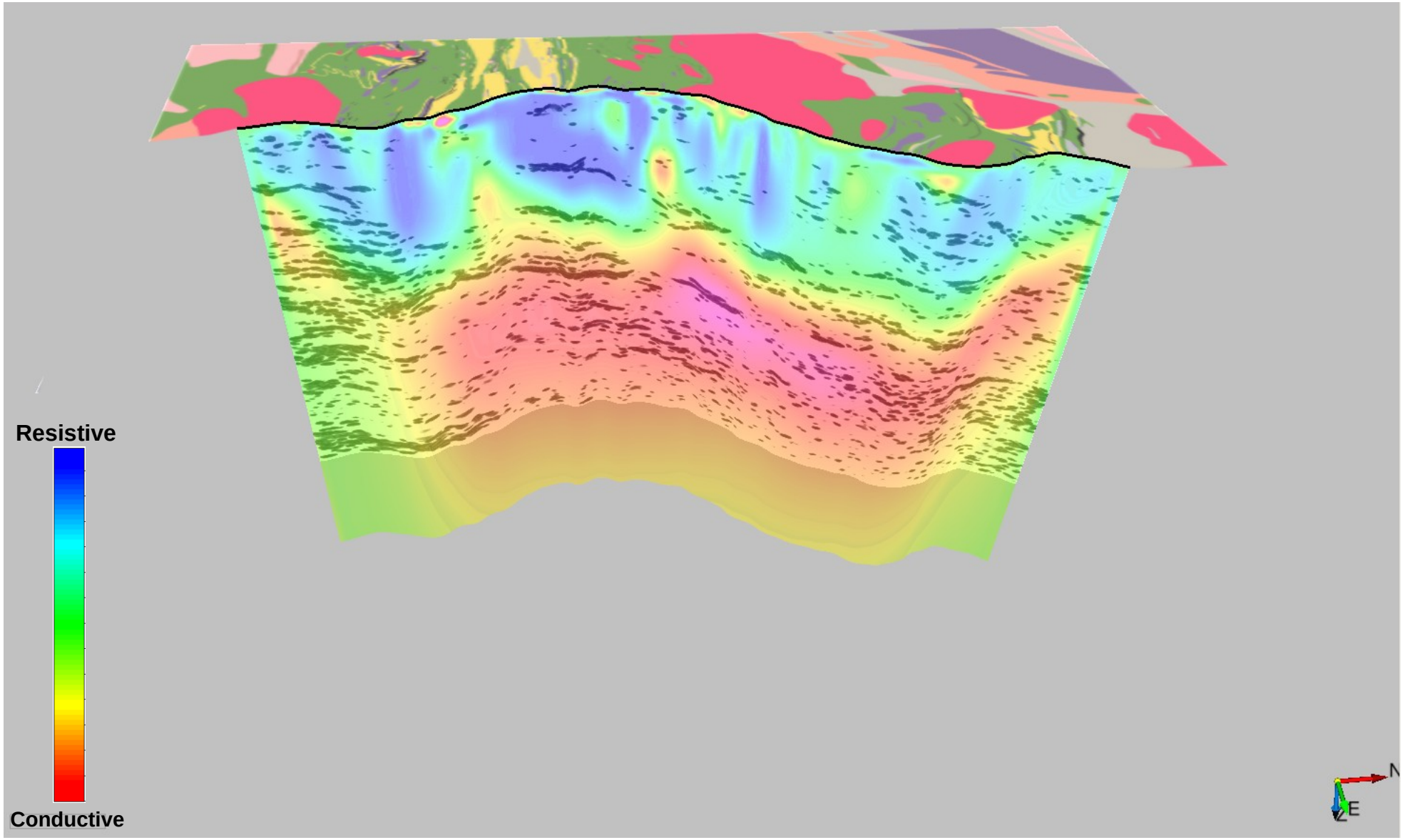
METAL EARTH

Projected Electrical Resistivity from Lithoprobe MT data 3D inversion



METAL EARTH

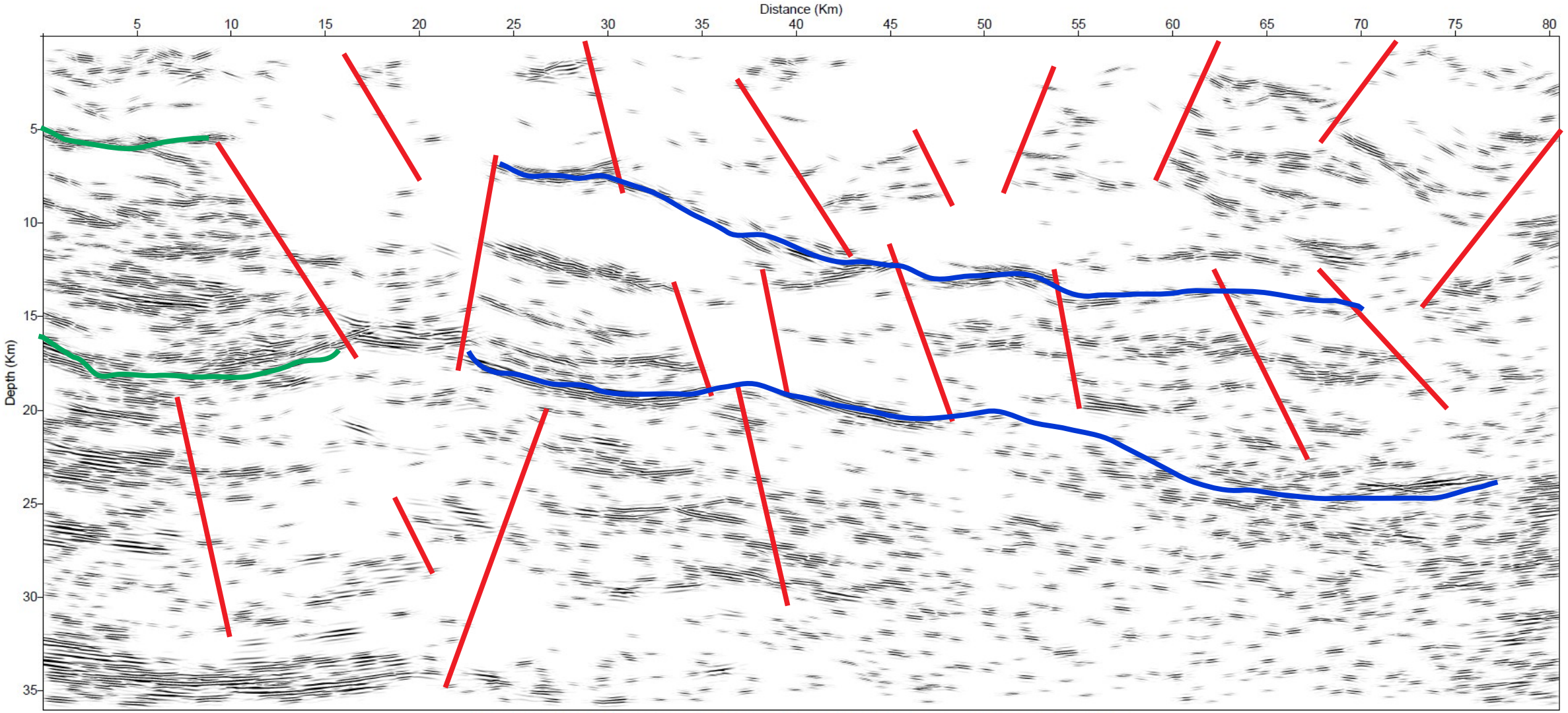
Projected Electrical Resistivity from new Metral Earth MT inversion



Eric Roots and Graham Hills have 3D inverted Metal Earth MT data by combining them with Lithoprobe MT data.

METAL EARTH

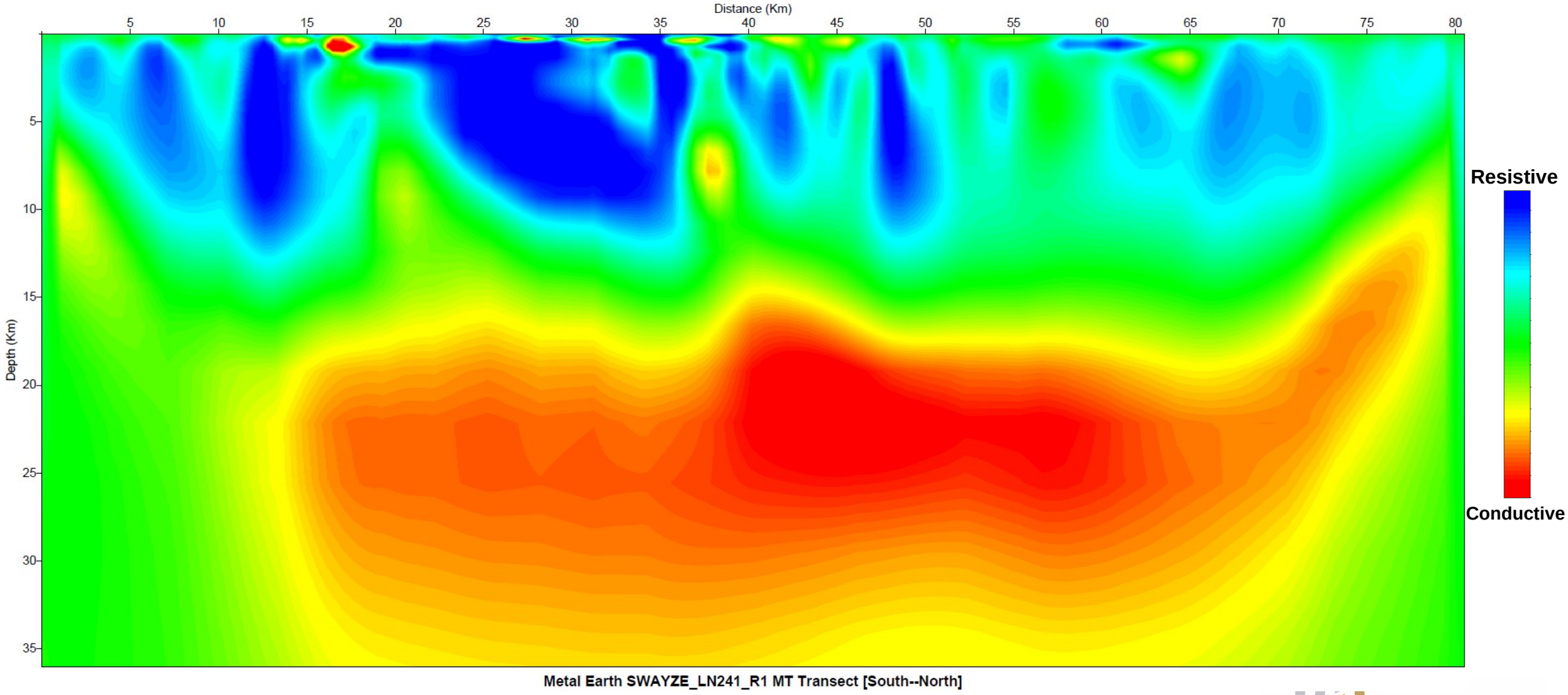
Dip Coherency Filtered Seismic Section –- Swayze Transect



Metal Earth SWAYZE_LN241_R1 Seismic Transect Curvelet Reconstruction [South--North]

METAL EARTH

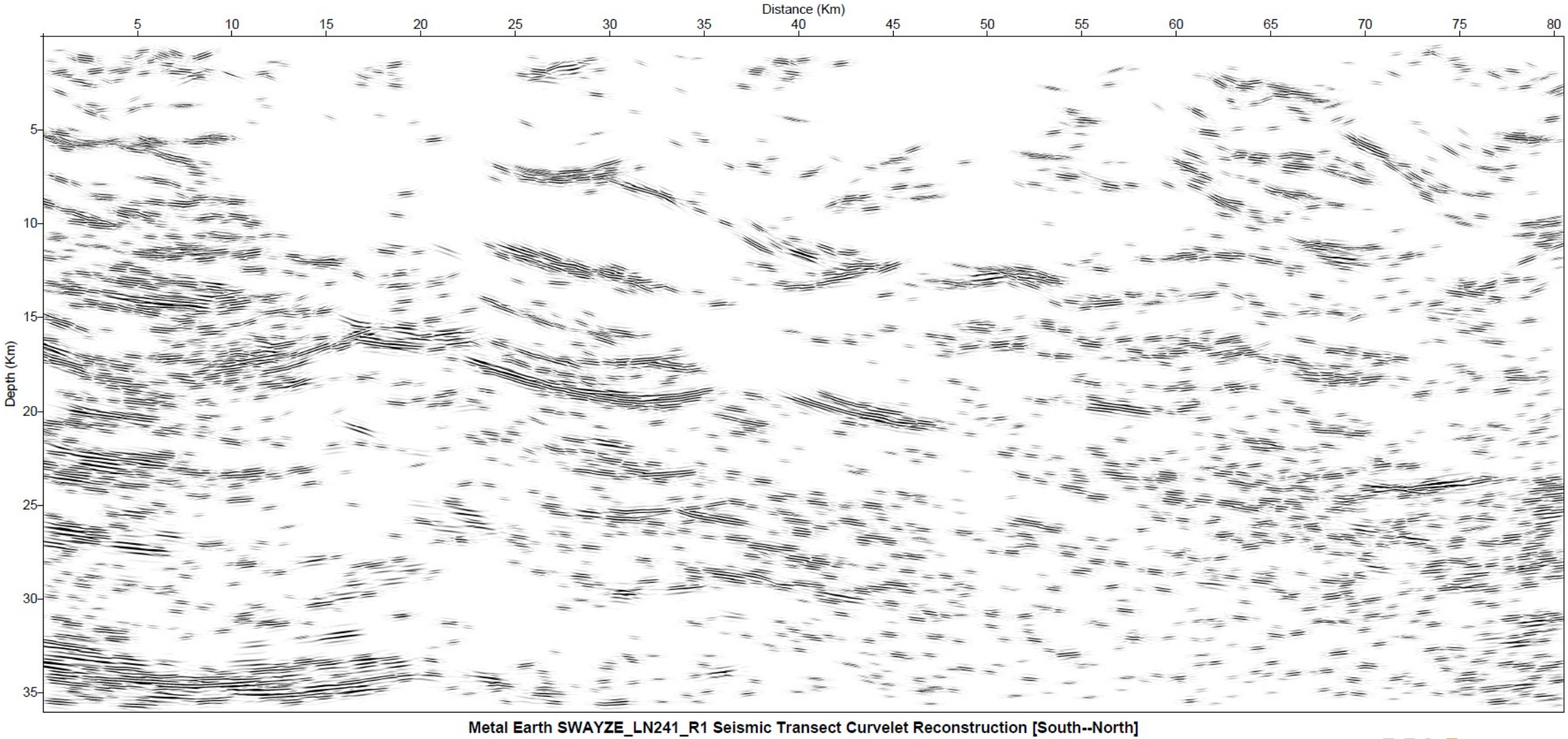
MagnetoTelluric (MT) section – Swayze Transect



Eric Roots provided the XYZ file of MT section. Mostafa Naghizadeh converted it into the SEGY format.

METAL EARTH

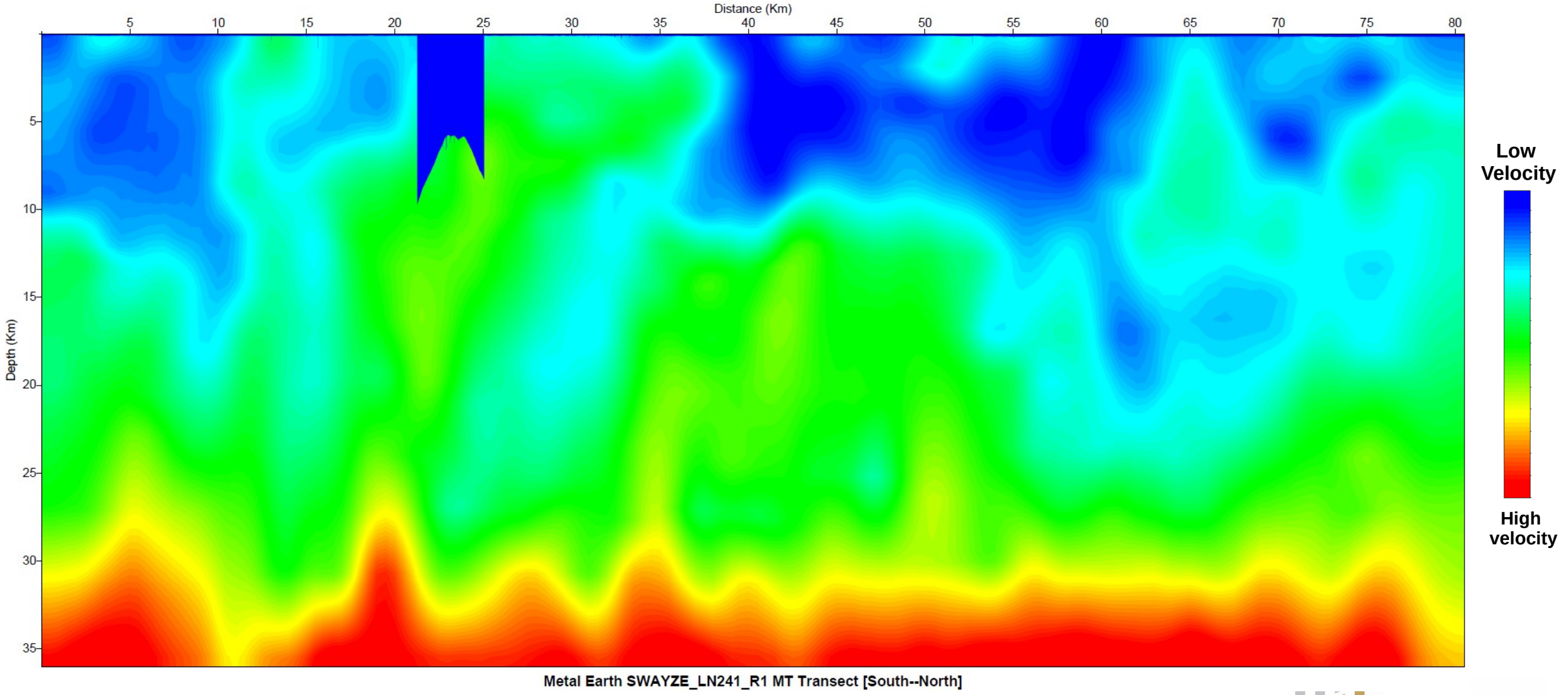
Dip Coherency Filtered Seismic Section –- Swayze Transect



Metal Earth SWAYZE_LN241_R1 Seismic Transect Curvelet Reconstruction [South--North]

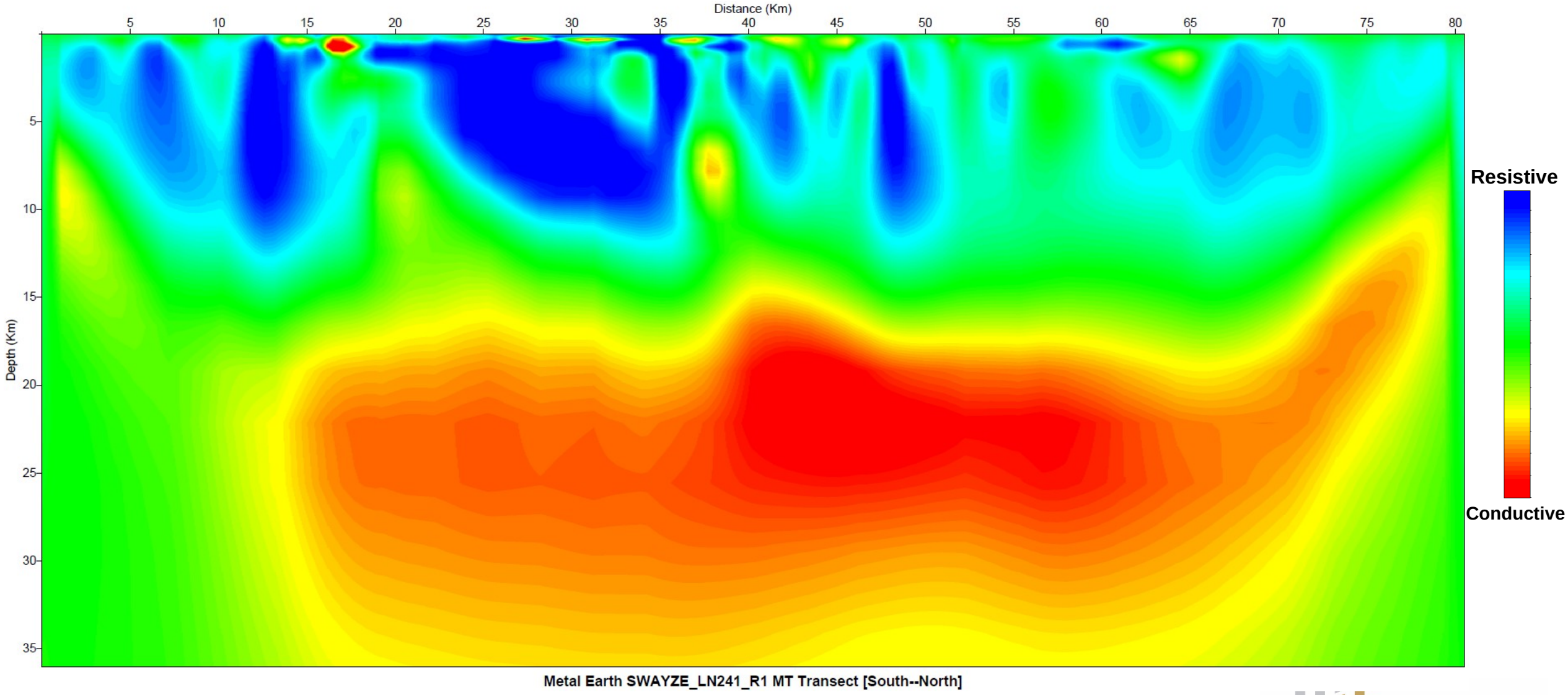
METAL EARTH

Stacking Seismic Velocity -- Swayze Transect



METAL EARTH

MagnetoTelluric (MT) section – Swayze Transect



Eric Roots provided the XYZ file of MT section. Mostafa Naghizadeh converted it into the SEGY format.

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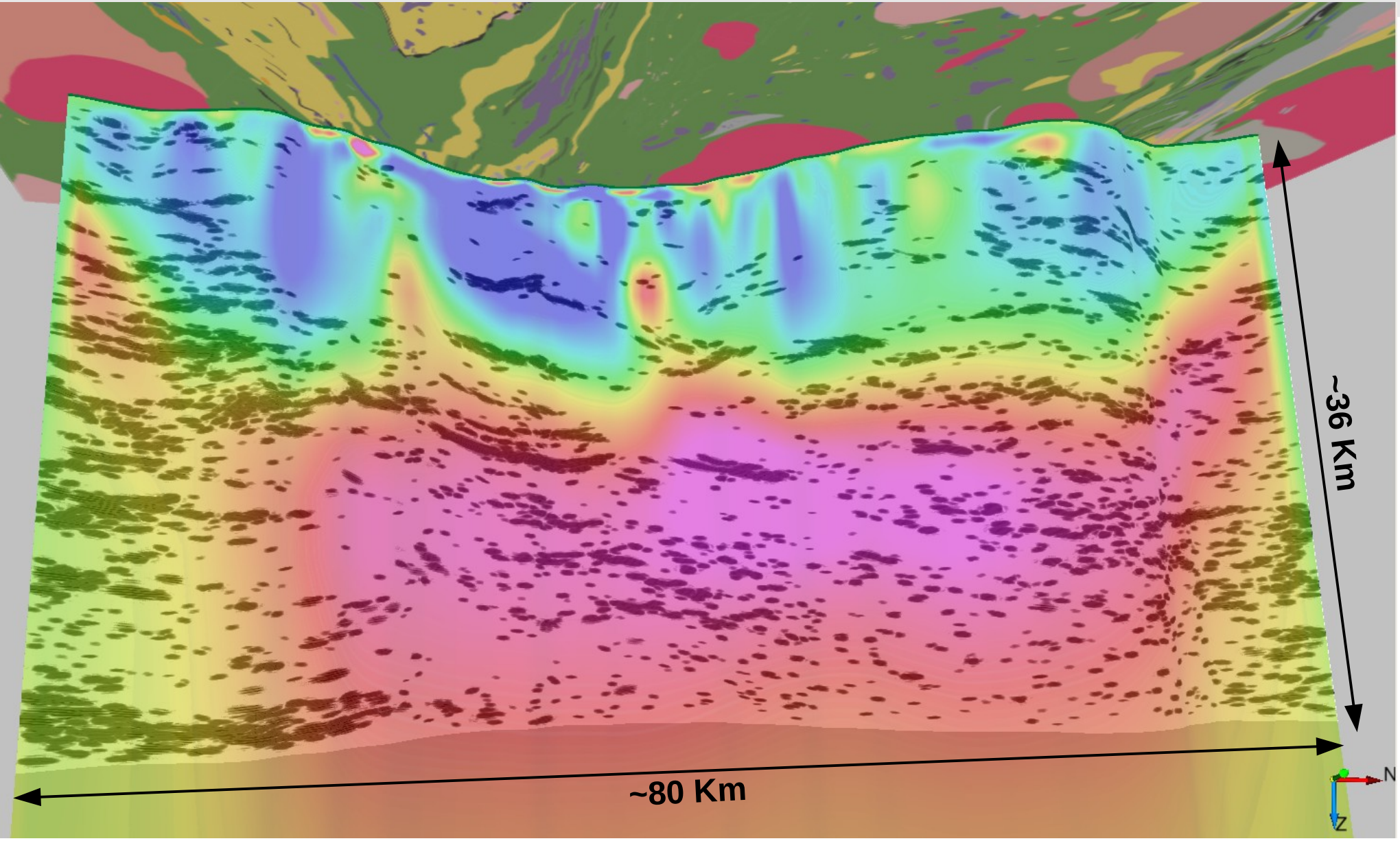
Seismic and MT sections -- Swayze Transect



Resistive

Conductive

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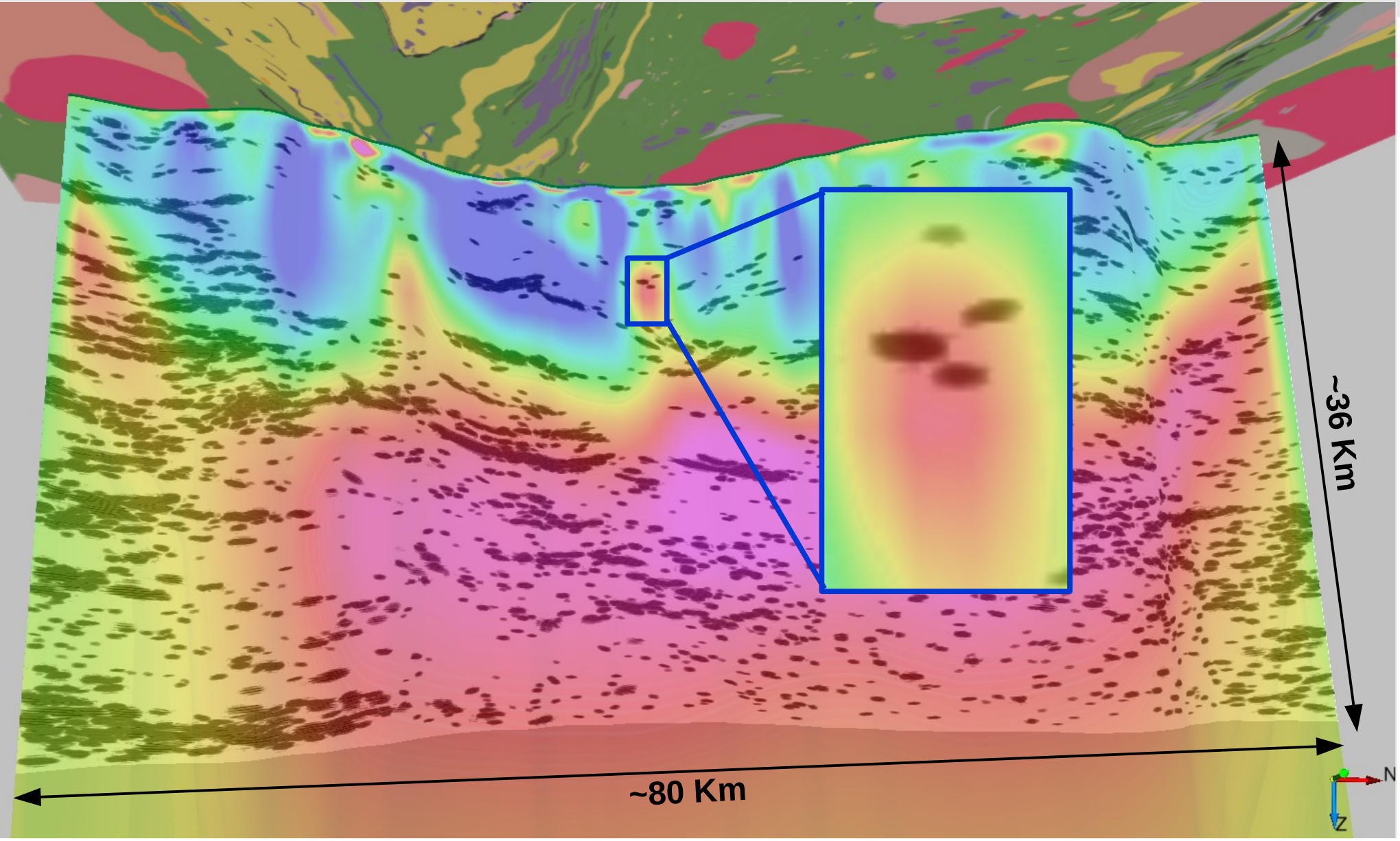
The Blinking Ghost of Swayze



Resistive

Conductive

METAL EARTH

Conclusions

- Metal Earth has acquired **16 R1 (regional)** and **13 R2 (high-resolution)** seismic surveys.
- More than **60 Lithopobe seismic transects** were downloaded and their coordinates were remapped and cleaned up, making them suitable to be viewed in **3D geological visualization** software.
- Slices of **3D MT resistivity model** were projected on Metal Earth and Lithoprobe seismic section in order to reduce the uncertainties about the nature of seismic reflections.
- The **Metal Earth MT** data provides **higher resolution resistivity** images for **shallow depths** compared to the 3D model from coarsely sampled Lithoprobe MT stations.
- There was a **good correlation** between Metal Earth **seismic reflections and MT resistivity** model in Swayze area, highlighting **potential pathways** that could be suitable for future mineral prospecting projects.
- The process of inverting **Gravity and Magnetic** surveys and projecting them on seismic sections is underway to further improve the interpretation of geophysical models.
-

METAL EARTH

Current and Future Metal Earth Seismic Research

- **Multi-Focusing imaging** of complex geological structures (**Hossein Jodeiri, Ph.D.**)
- **Cross-dip analysis** and processing of the crooked seismic lines (**Christopher Mancuso, M.Sc.**)
- **Interpretation, seismic modeling**, tectonics, and structural geology integration of Larder Lake and Rouyn Transects (**Robert Rapolai, M.Sc.; Elton Mpongo, M.Sc.**)
- **Full-Waveform Inversion** of hard rock seismic data with co-supervision of Dr. Gerhard Pratt at Western University (**Brian Villamizar, Ph.D.**)
- Processing and Interpretation of **High Resolution R2** seismic surveys (**Saeid Cheraghi, RA**)
- Processing and Interpretation of **Passive Seismic** surveys (Prospective **Ph.D.**)
- **Integration and joint inversion** of various geophysical surveys
- ...

METAL EARTH

Acknowledgments

- SAExploration Ltd., Seismic Data Acquisition
- Absolute Imaging Inc., Seismic Data Processing
- Metal Earth and MERC Staff (Administration, Faculty, PDFs, Students, …)
- Harquail School of Earth Sciences
- Eric Roots
- Desmond Rainsford (OGS)
- OpendTect, QGIS, Seismic Unix, Octave, Curve-Labs software developers.

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Zipped SEGY files of Lithoprobe Transects: http://ftp.geogratis.gc.ca/pub/nrcan_rncan/vector/lithoprobe/zipped_segys/; Released to public under Open Government Licence – Canada : https://open.canada.ca/en/open-government-licence-canada

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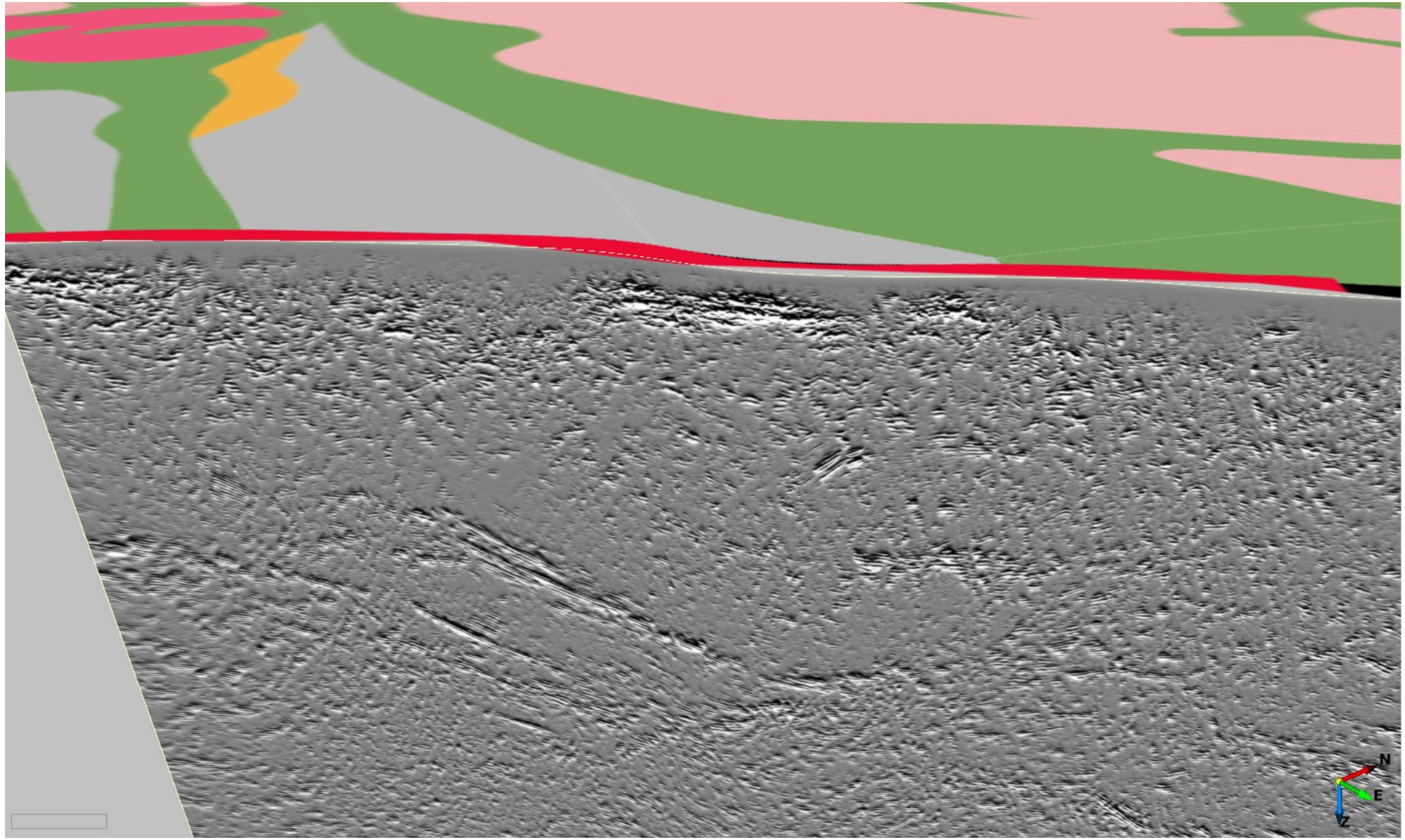
HARQUAIL SCHOOL OF EARTH SCIENCES / ÉCOLE DES SCIENCES DE LA TERRE

MERC
Mineral Exploration Research Centre

Southern part of Metal Earth Chibougamau R1 Transect



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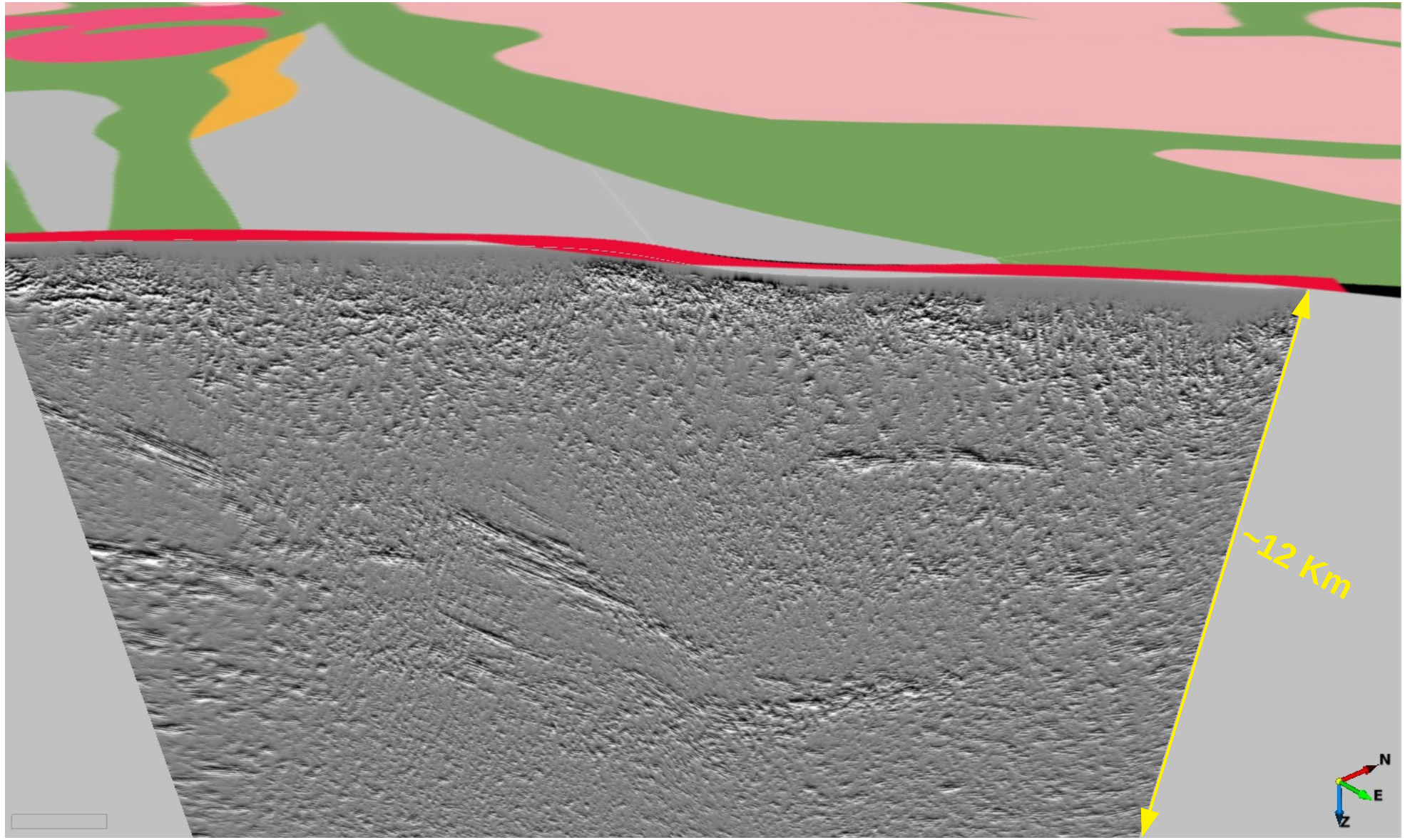
Metal Earth Chibougamau R22 Transect



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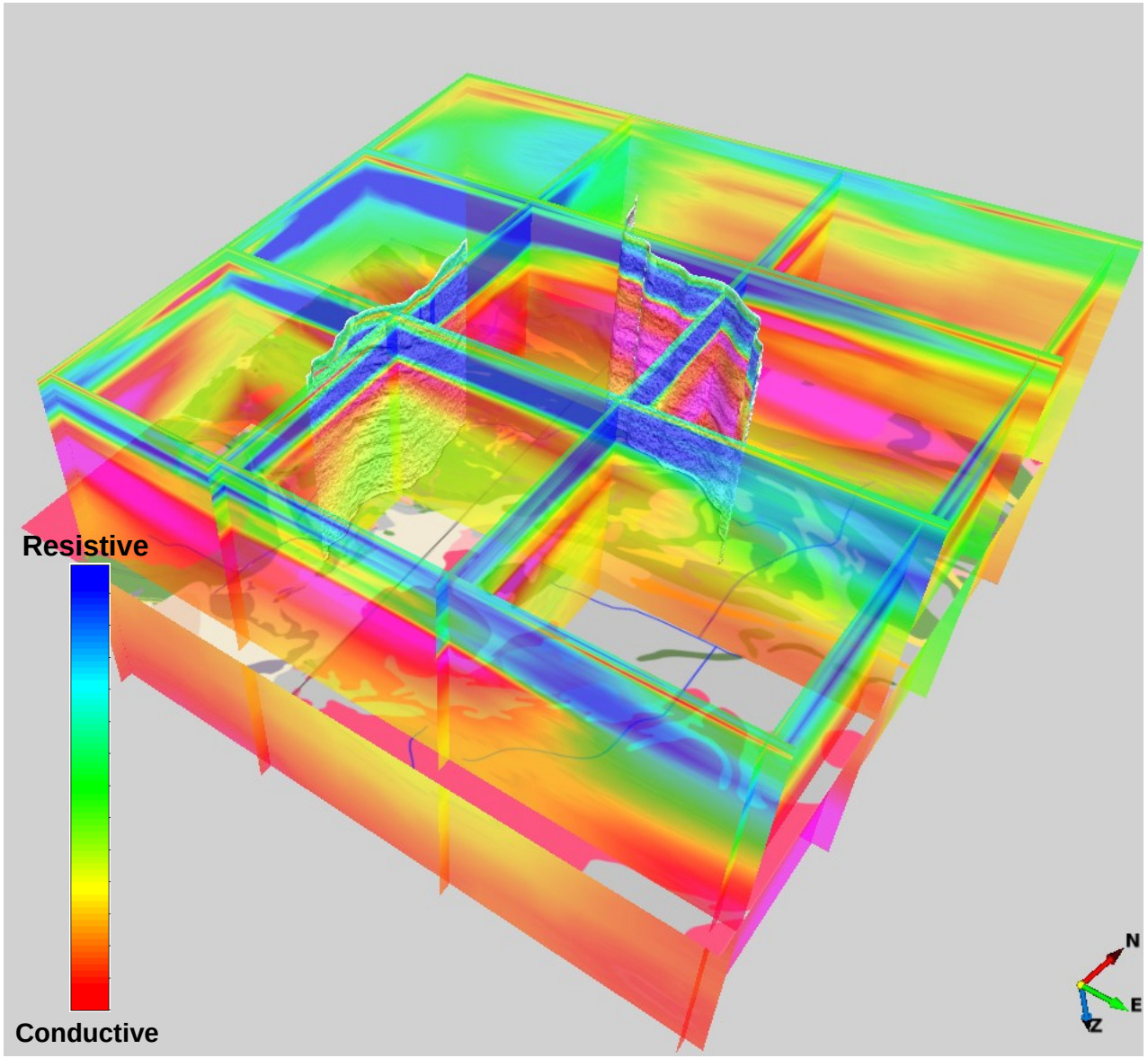

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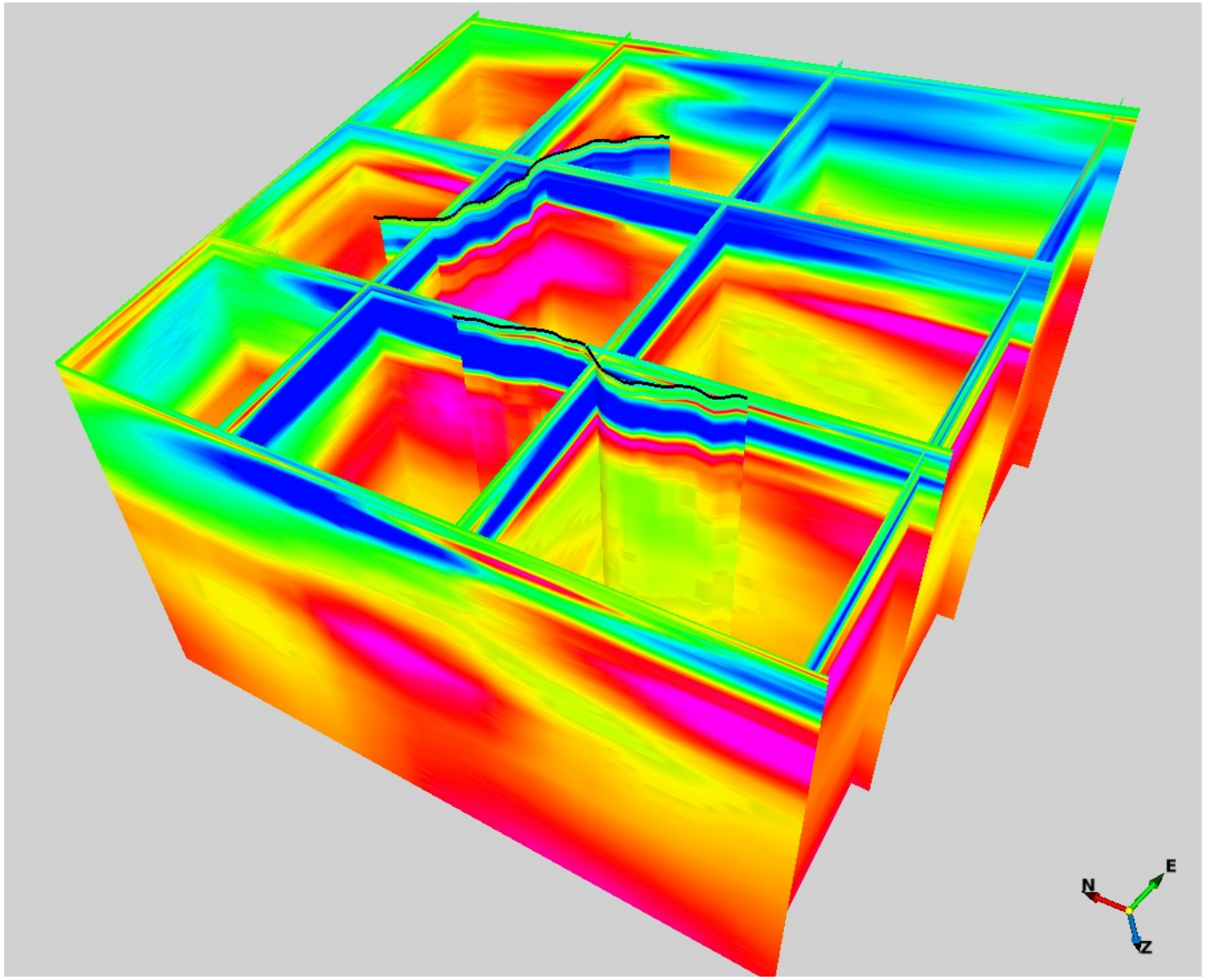

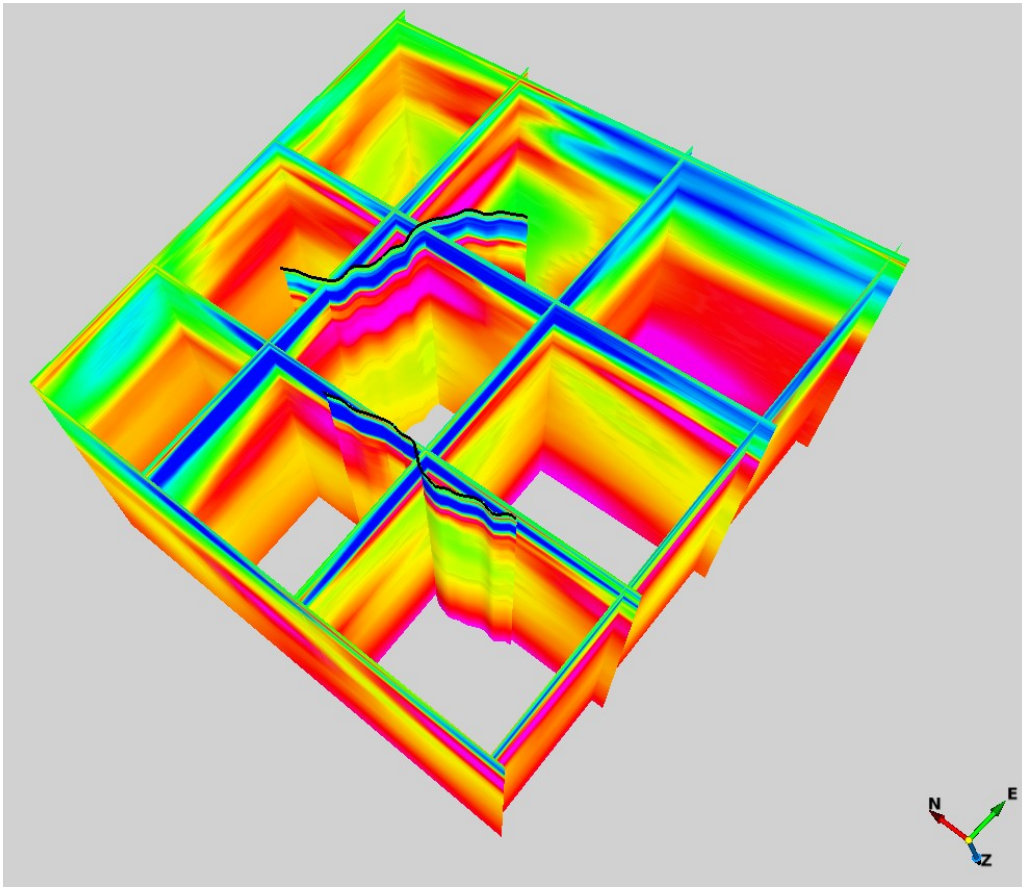

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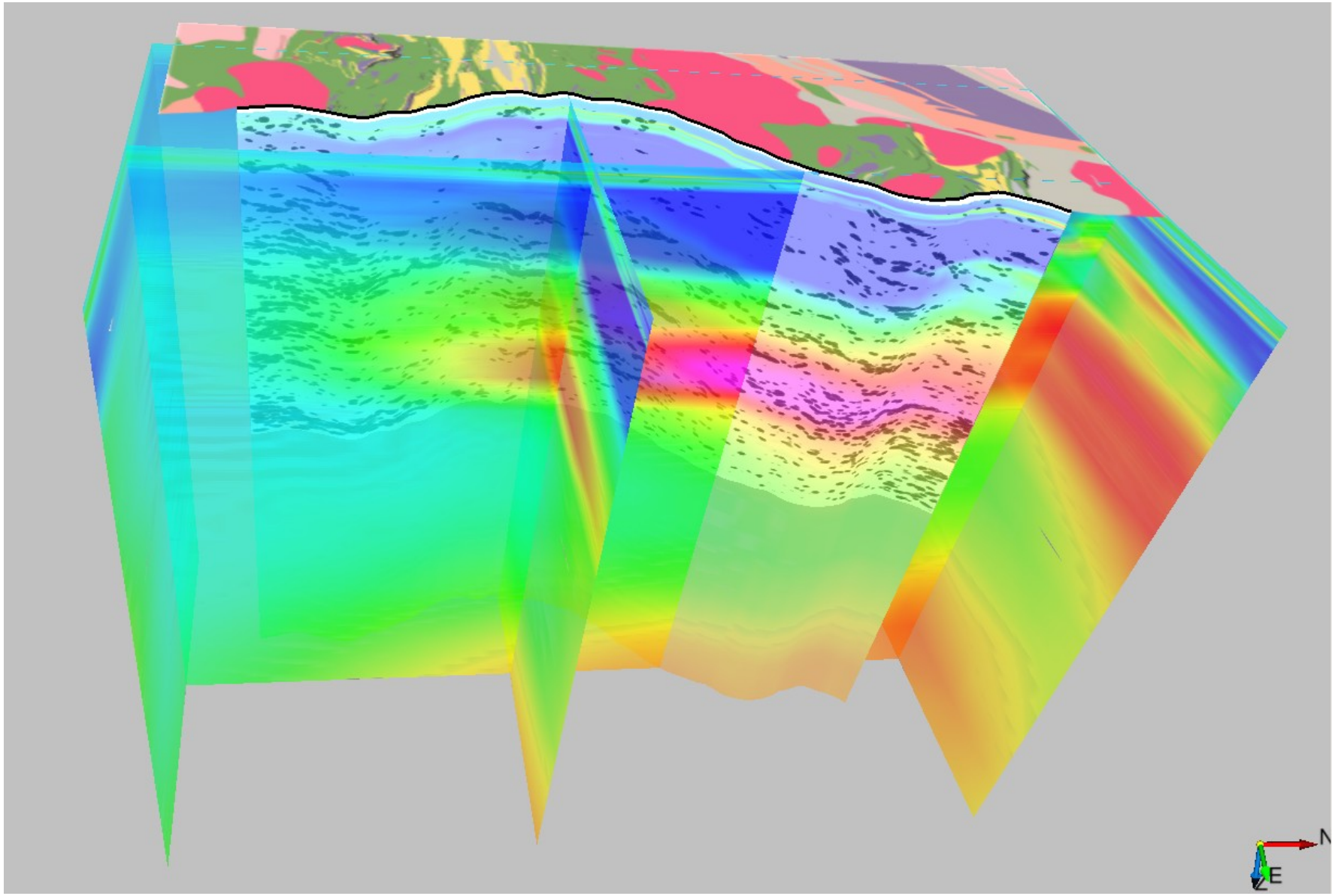

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