



Global Geophysical Services

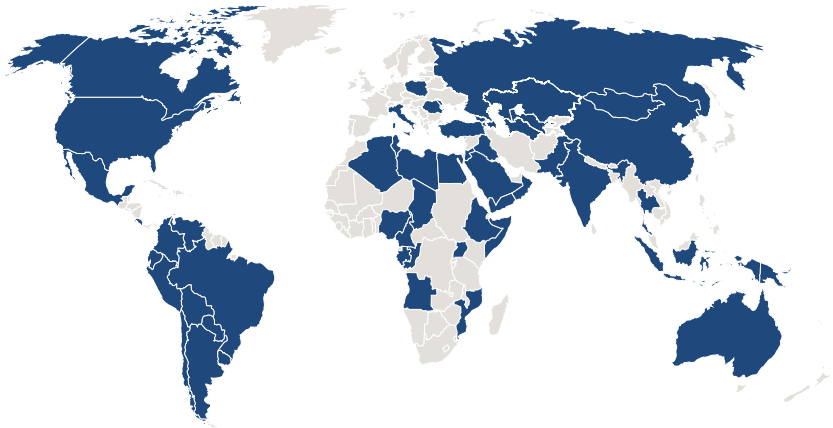
Ambient Noise Tomography

September 2024

WHO WE ARE

ABOUT US

- Worldwide operations in challenging environments
- Blue areas represent operating experience of Global personnel



- Expert provider of Reservoir Grade™ geoscience solutions to the global energy and sustainable development industries
- Pure-play nodal seismic acquisition provider partnered with industry-leading technology providers



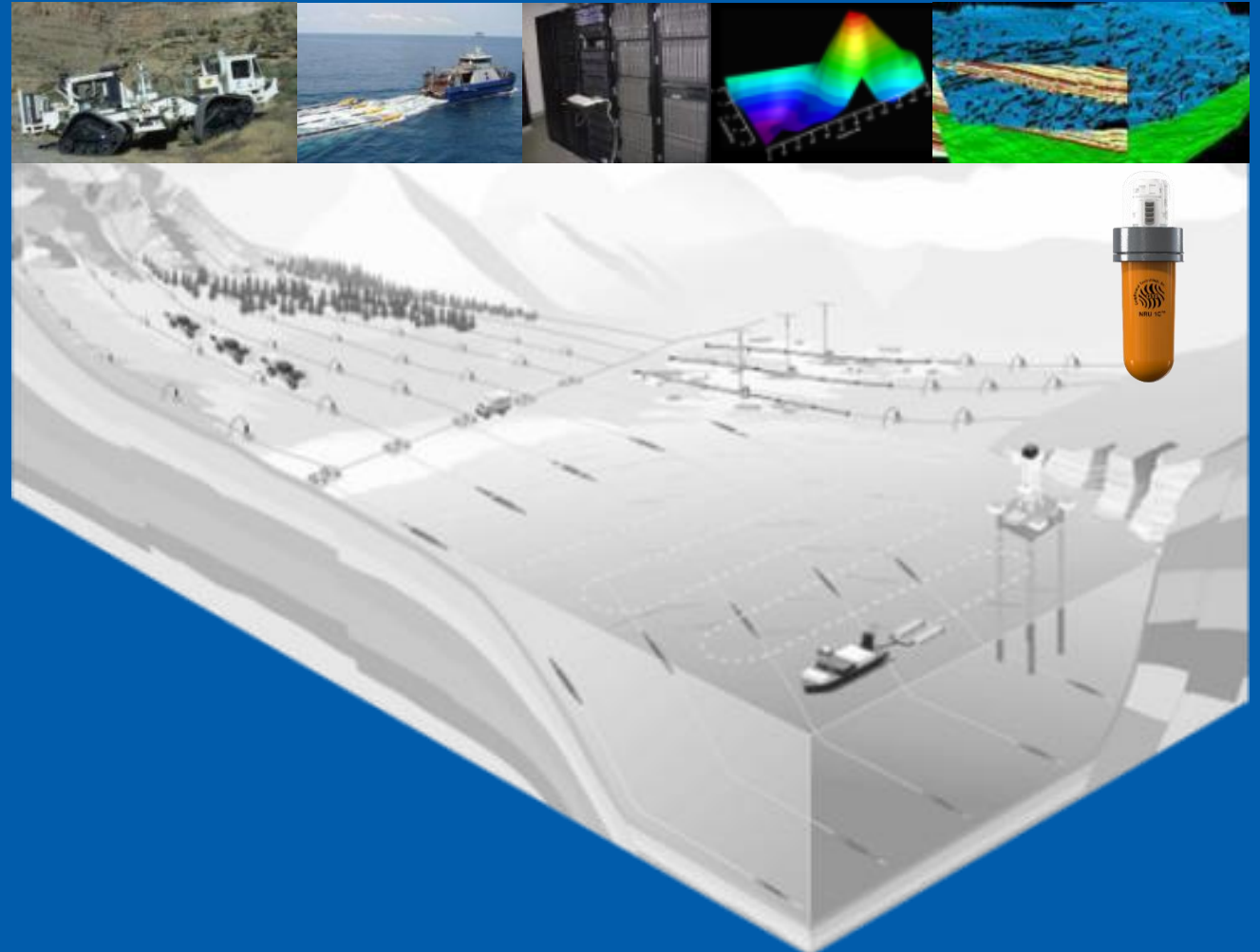
We provide seismic data solutions which create earth models of increased confidence

WHAT WE DO

SERVICES

- Integrated seismic data services
- Land acquisition
- Shallow marine acquisition
- Nodal acquisition systems
- Ambient Noise Tomography
- Data processing, analysis, and interpretation

- Focused on the application of geoscience for subsurface characterization, resource optimization, and risk reduction



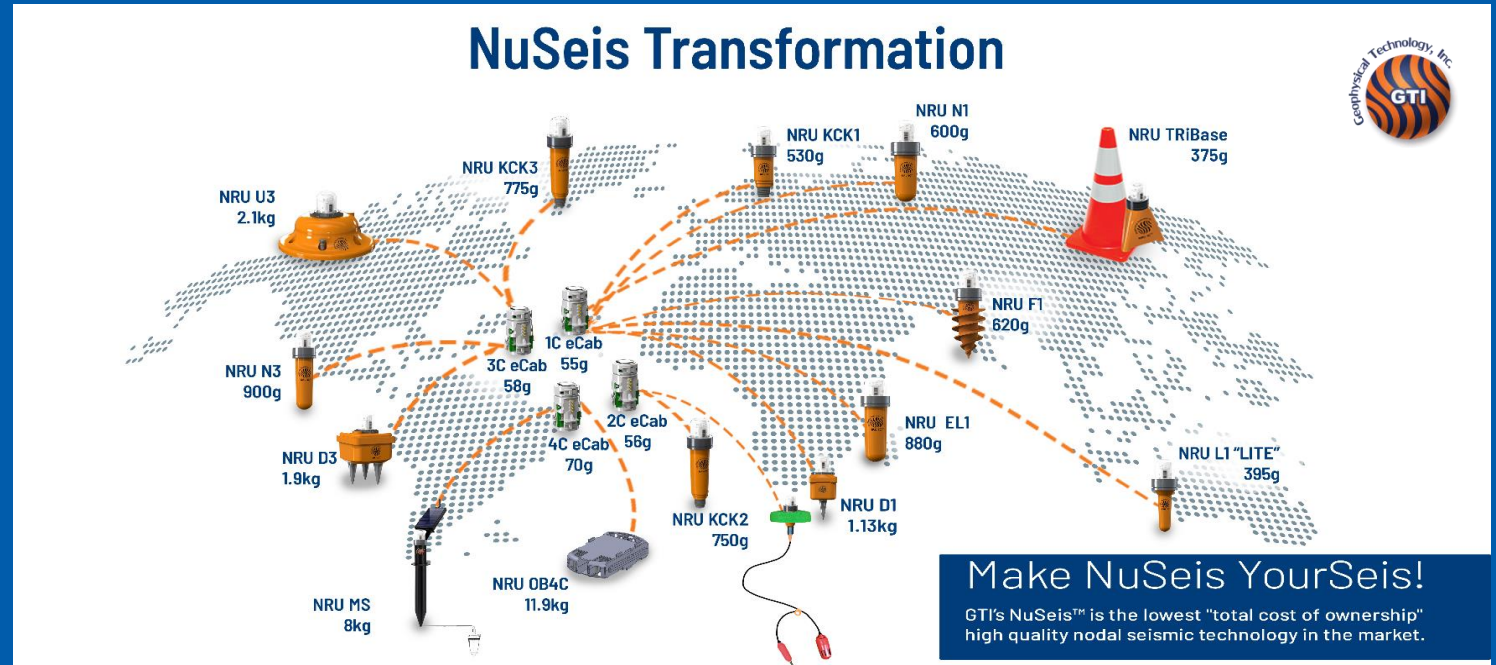
HOW WE DO IT

TECHNOLOGY

- Unlimited access to industry leading NuSeis nodal technology
- Excellent land, transition zone and shallow marine experience and capabilities
- Diversified ecofriendly seismic offering including a large controlled-source seismology profile
- Tracked 80K Vibroseis technology
- Unbeatable scale and technology

Industry Leading NuSeis Technology

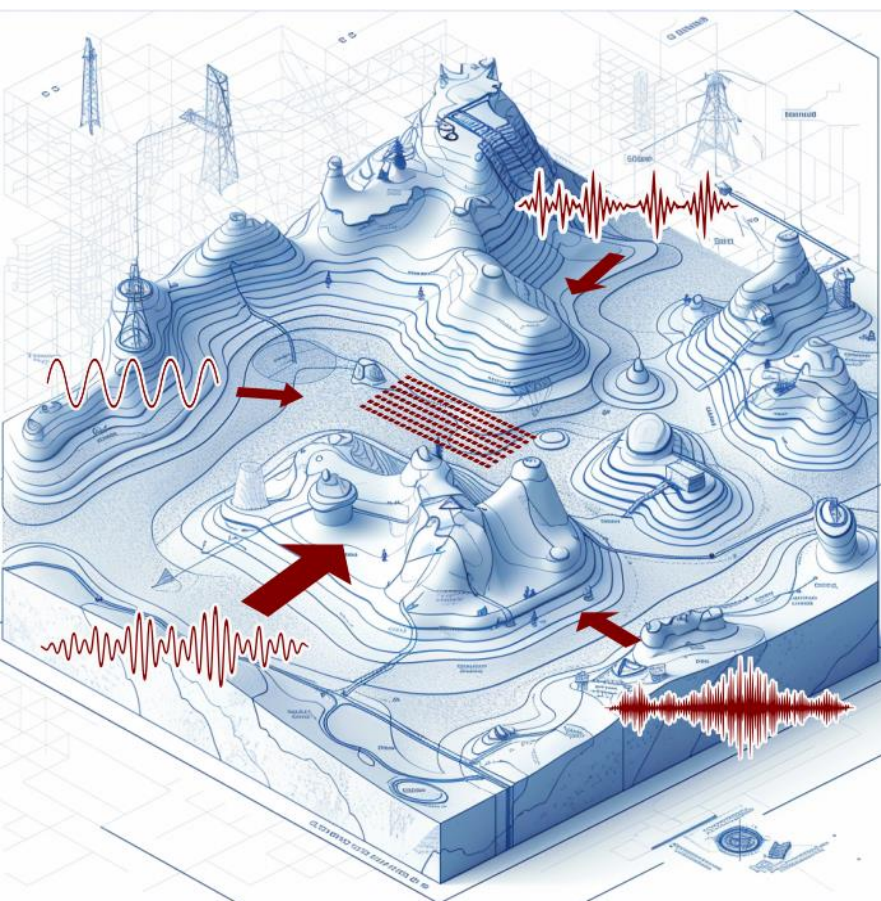
- Form factor options for all environments
- Fast data download & recharge
- EarthGrip coupling providing high data quality
- 10-year long life asset
- GPS / DGPS – no survey required
- NuSeis automation and robotics for node deployment & retrieval



ANT OVERVIEW

AMBIENT NOISE TOMOGRAPHY

- Cost-effective passive seismic
- Wireless node arrays
- High resolution subsurface imagery



NATURAL SOURCES (AMBIENT)

- Ambient seismic background energy creates a constant and random mix of waves moving through the subsurface

RAYLEIGH WAVES (NOISE)

- Rayleigh waves are surface seismic waves from significant energy sources including earthquakes, tides, trains, and industrial equipment
- ANT measures the velocity and wavelength of Rayleigh waves
- Naturally occurring Rayleigh waves are low amplitude and sporadic
- Requires days to weeks to measure velocities accurately, longer times provide higher accuracy

VELOCITY MODEL (TOMOGRAPHY)

- ANT relies on the cross-correlation technique, which measures the similarity between the signals recorded at different locations
- Cross-correlated data from multiple station pairs is processed into imagery of subsurface velocity variations and used to interpret geological features

NODES

WIRELESS PASSIVE SEISMIC ACQUISITION

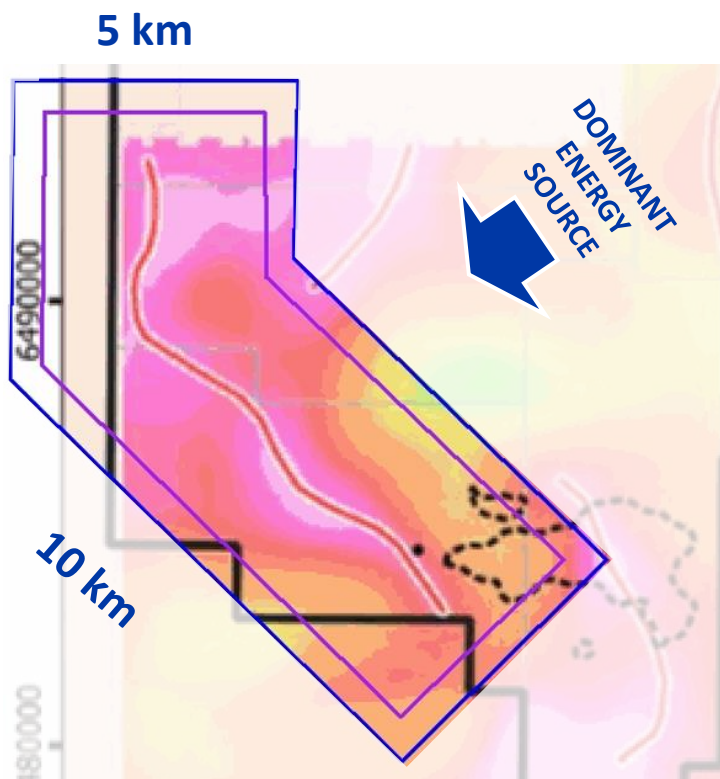
- NuSeis™ NRU N1
- Autonomous, continuous, self-contained nodal seismic recording unit
- 1 channel, 24-bit digitization
- Integrated, high sensitivity global navigation satellite system (GNSS)
- Electromagnetic wireless data download
- Robust two-part, water-tight polymer assembly
- Operation autonomy of 22.5 days sampling every 4ms 24 hours per day collecting approximately (160MB / day)
- Unbeatable quality, scale, sensor configurations and programmability



SURVEY DESIGN

NODE COVERAGE COMPARISON

- Azimuth of dominant surface wave energy is NE, so a corridor within ± 20 degrees from this azimuth is used



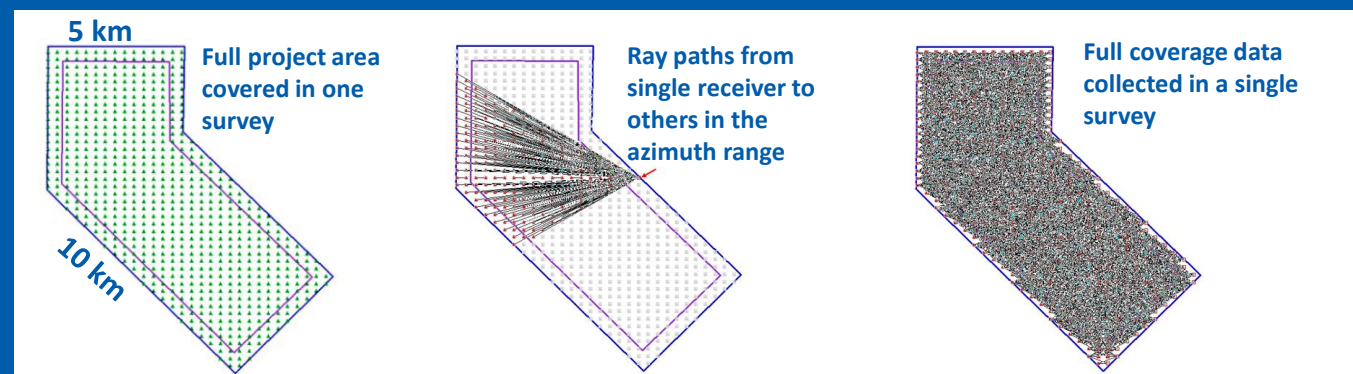
GLOBAL CAN DEPLOY THOUSANDS OF NODES AT ONCE

- More nodes, shorter collection time, simpler processing

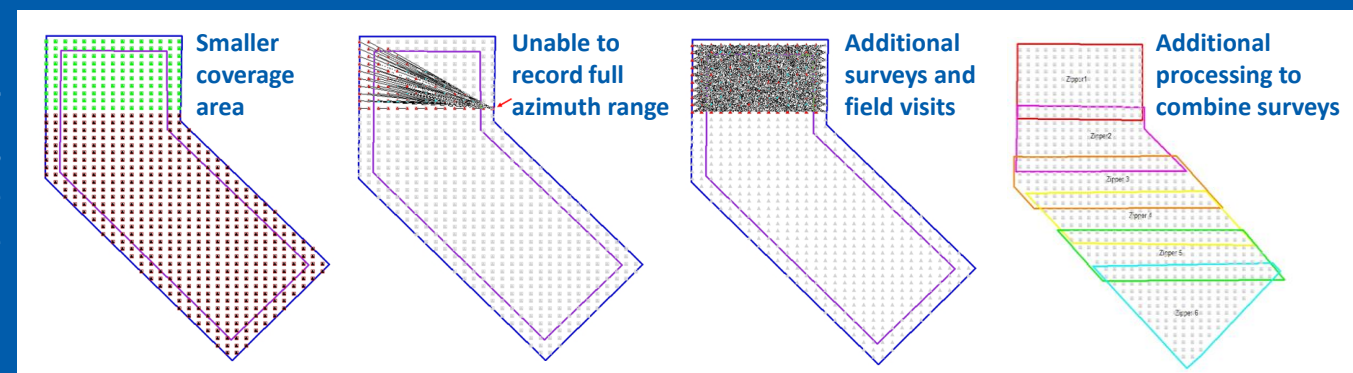
SMALLER COVERAGE REQUIRES MULTIPLE SURVEYS

- Inefficient logistics, additional collection time, loss of data
- Specialized processing to stitch together

GLOBAL
Higher node count for full target coverage



OTHERS
Fewer nodes requires multiple surveys for same area



PROCESSING

FROM RAYLEIGH WAVE TO 3D IMAGE

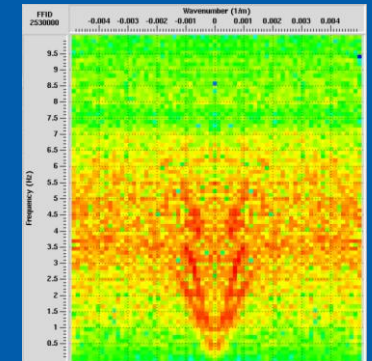
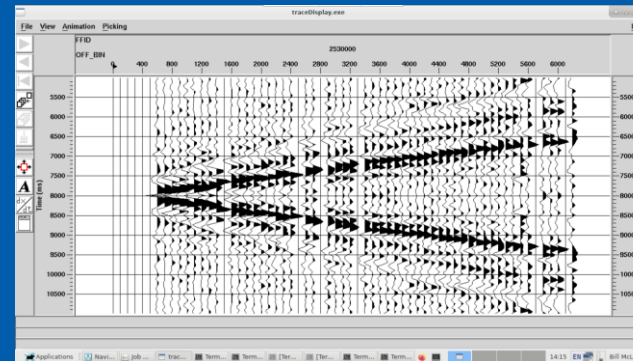
- GGS PROCESSING CAPABILITIES
- Global Patented azimuthal anisotropy algorithms
- 45 Teraflops (45 trillion floating-point operations per second) of latest high performance computing (HPC) capacity

PROCESSING

- Each receiver pair provides an average Rayleigh wave velocity between the two node locations
- An ANT survey typically has thousands of receiver pairs and many thousands of intersecting ray paths
- Cross-correlation used to measure the similarity between the ambient wave field at pairs of receivers of stations
- Tomography processes the point-to-point receiver measurements to create a 2D velocity for each location
- Stacking data with longer collection time improves the signal to noise ratio on cross-correlations

THRESHOLDING DATA FOR FINAL CROSS-CORRELATION

- Eliminate noise, Pick the quietist spread, align with dominant energy source

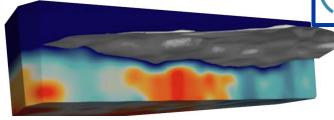


ANT IN MINING PROJECTS AROUND THE GLOBE

ANT USED IN MANY REGIONS AND COMMODITIES

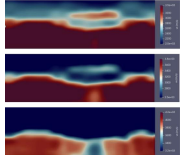
Uranium

Imaging Large Anomalies
Pasfield Lake Project
Terra Uranium



T92

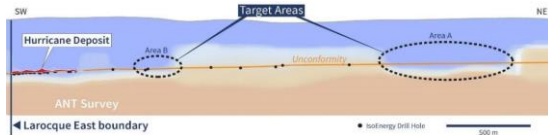
- ANT imaged unconformity basement contact in high detail
- Good resolution down to 1625m
- Identified anomalous structures showing uranium potential



Uranium

Identifying Alteration
Larocque East Project
ISOEnergy

- ANT survey used to highlight alteration halos and plan drill targets

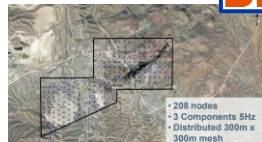


IsoEnergy

Copper

ANT in a Multi-Physics Approach
Laramie province, Ocelot
BHP

- Provide sharp resolution of quaternary cover/bedrock interface
- Useful in discriminating the pre-Cambrian from other parts of the basement

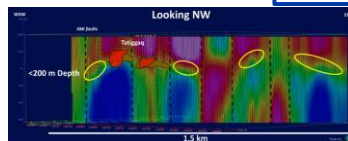


BHP

Uranium

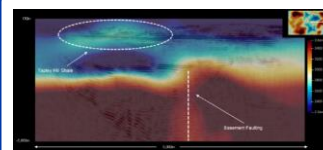
Establishing Drill Targets
Aberdeen Uranium Project
Forum Energy Metals

- Successfully established new drill targets over a one plus kilometer east-northeast extension along the Tatiggaq fault zone



FORUM
ENERGY METALS CORP.

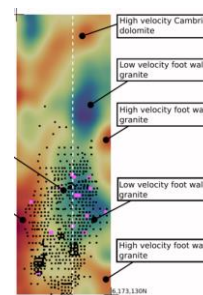
CCDA
MINERALS



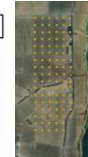
Copper
Multiple ANT Surveys
Emmie Bluff & IOCG
Coda Minerals

- Mapped features from 350m to 1.5km
- Validated previous geophysical datasets

REX
MINERALS

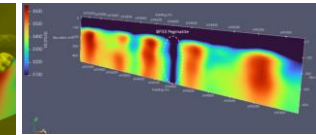
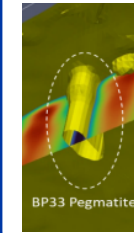


IOCG
Real-Time ANT
Hillside Deposit,
Rex Minerals



- Accurately captured structural framework to 1km depth
- Confirmed future exploration areas

CORE
LITHIUM

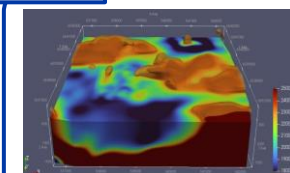


Lithium

ANT Blind Test
Lithium Exploration,
Core Lithium

- Successfully imaged distinct low velocity anomaly correlating with drilling interpretation

Inflection
Resources



Copper-Gold
Imaging Porphyry Basement Sequence
Duck Creek Project
Inflection Resources

- 30 sq km ANT survey imaged previously unknown features of interest in the prospective basement sequence

LITHIUM

BLIND TEST OF ANT ON PEGMATITES

PROJECT

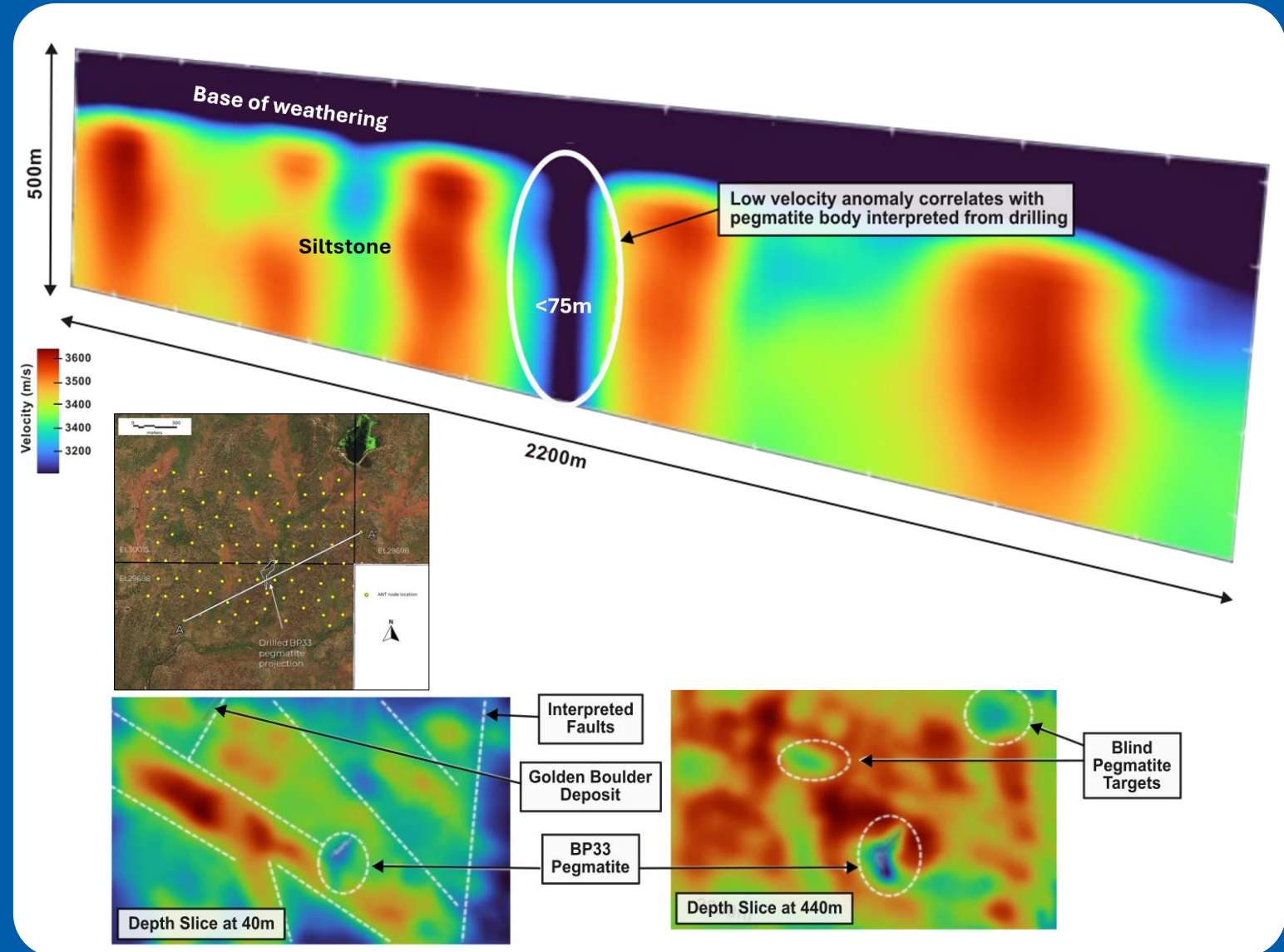
- BP33 Pegmatite
- Location: Australia, Northern Territory
- Company: Core Lithium

SURVEY DESIGN

- Spacing: 200 m
- Nodes: 100
- Depth: 500 m

TARGET

- Direct detection of pegmatites in the Bynoe pegmatite field
- Results were successful with the BP33 body imaged as a distinct low
- Only 5% drill core measured velocity contrast between the slower pegmatite and the surrounding faster host rock



COPPER-GOLD

IMAGING PORPHYRY BASEMENT SEQUENCE

PROJECT

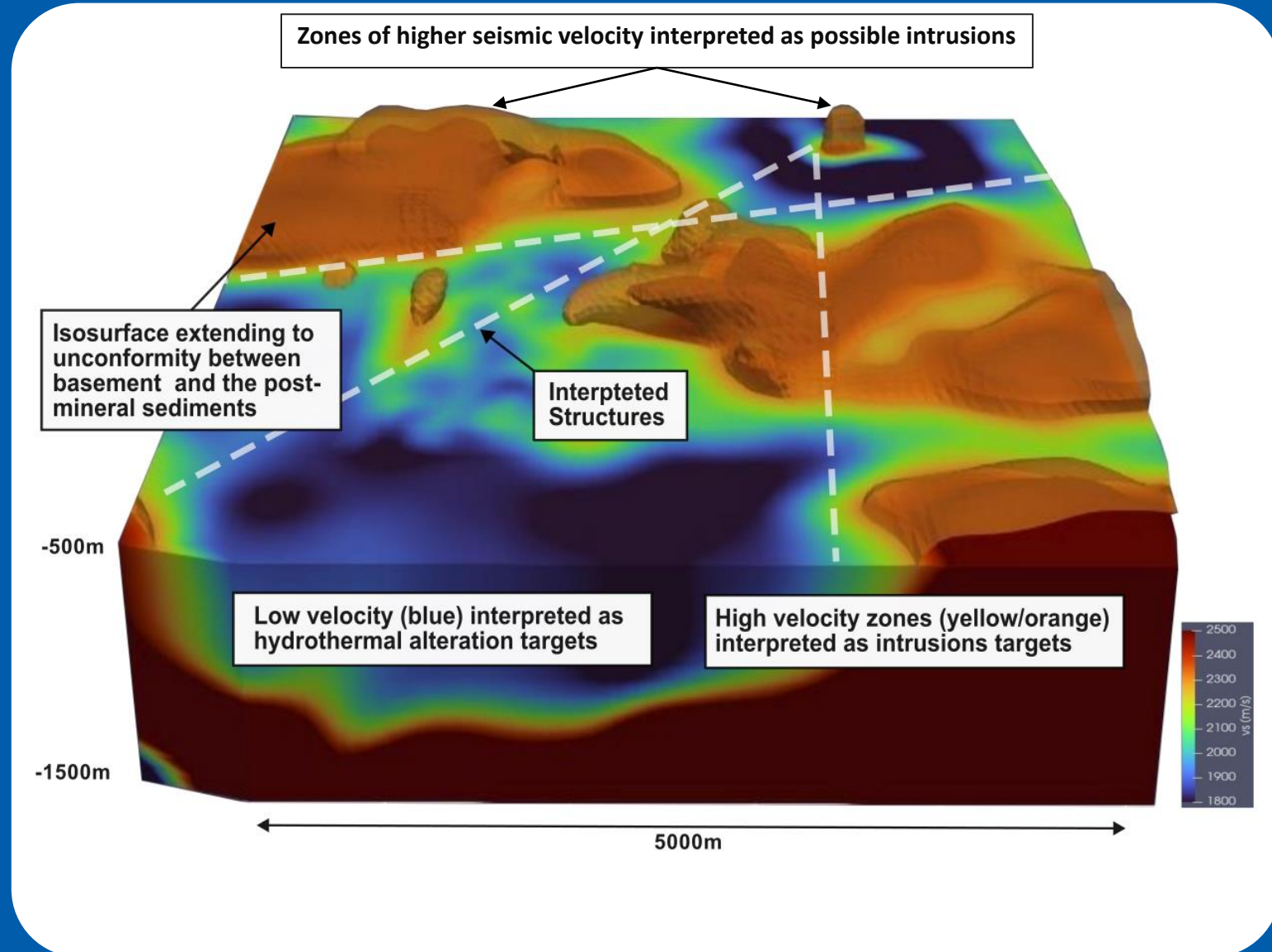
- Duck Creek
- Location: Australia
- Company: Inflection Resources

SURVEY DESIGN

- Area: 30 km²

TARGET

- Map the paleosurface and basement rocks
- Identify areas of potential alteration or intrusions in the basement sequence for further drill testing



PROJECT

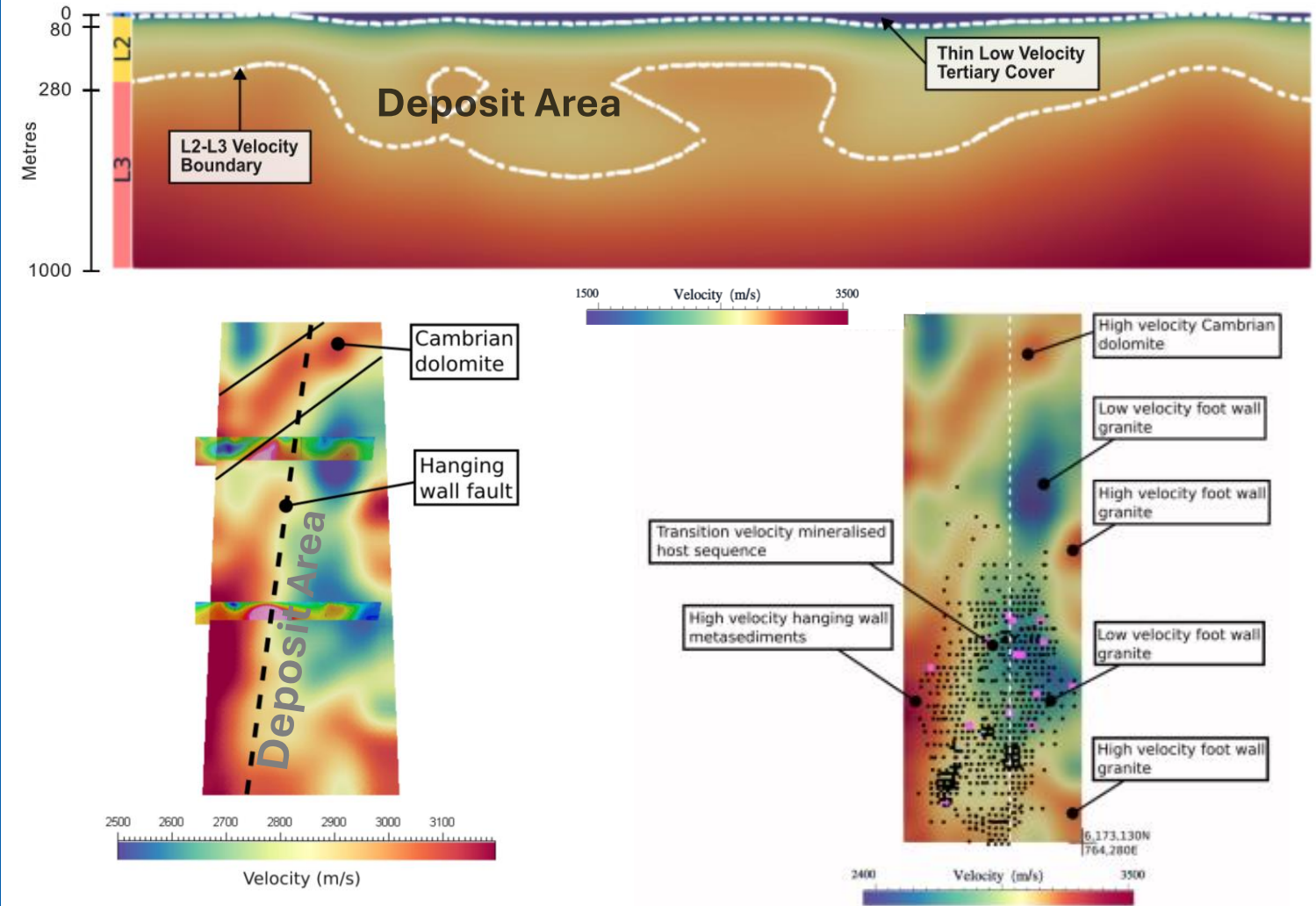
- Hillside IOCG Deposit
- Location: Australia, South Australia
- Company: Rex Minerals

SURVEY DESIGN

- Survey Area: 5.5 km²
- Nodes: 100
- Initial Spacing: 260 m
- Recording Time: 14 Days

TARGET

- Depth of cover
- ANT images the western fault boundary of the PPSC where the highest concentrations of Cu can be found
- Structures linked to mineralization



MULTIPLE PHASE ANT SURVEY

PROJECT

- Project: Emmie IOCG & Emmie Bluff
- Location: Australia, South Australia
- Company: Coda Minerals

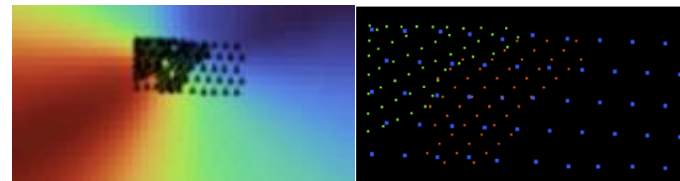
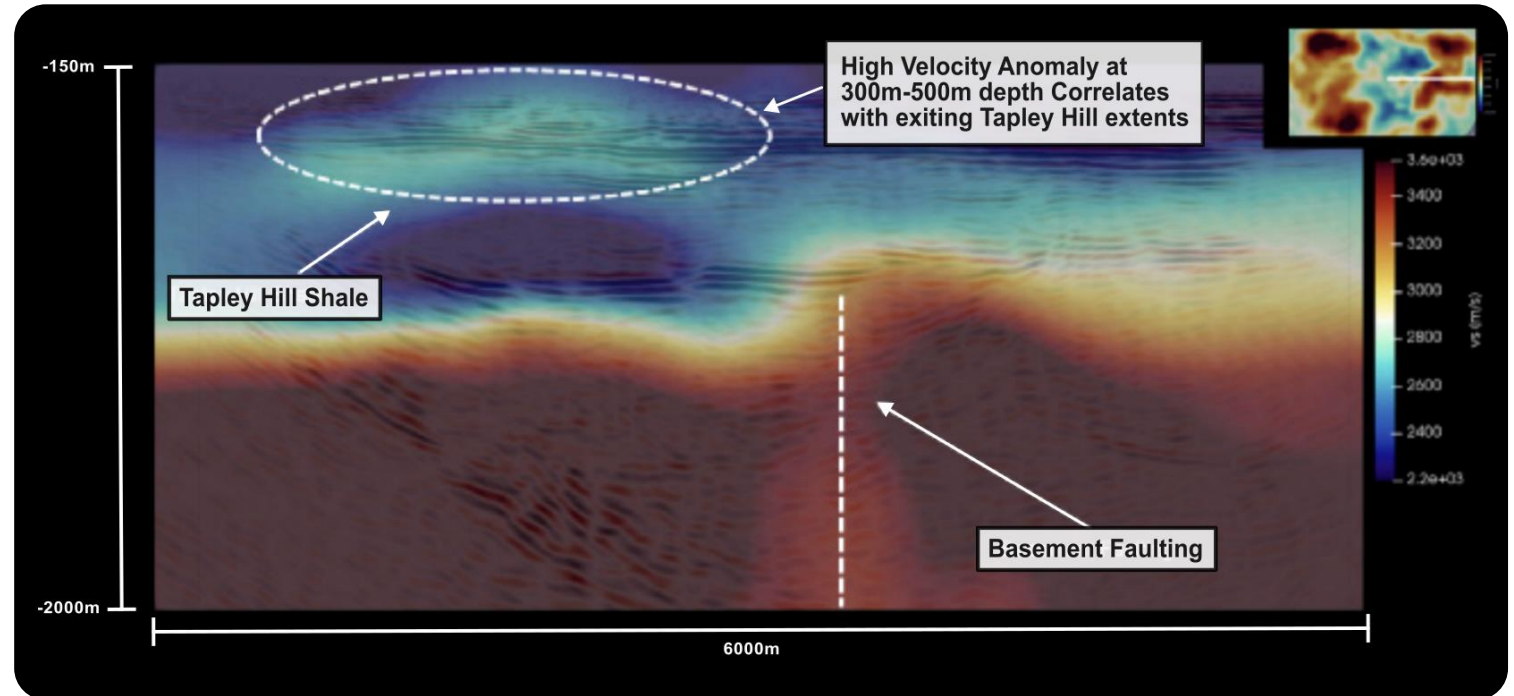
SURVEY DESIGN

- Survey Area: 40 km²
- Nodes: 50
- Initial Spacing: 500 m
- Infill Spacing: 200 m

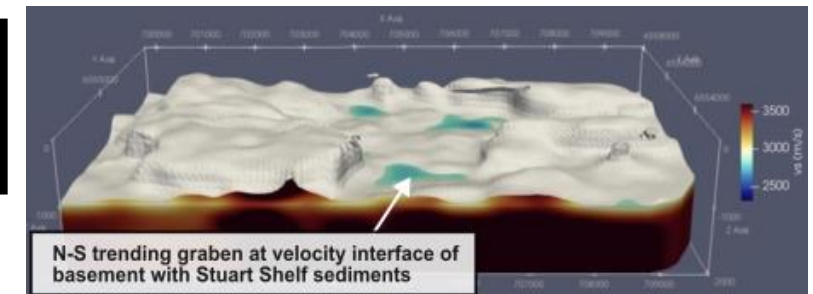
TARGET

- IOCG Basement Structural Controls to understand mineralization in drilling
- Map the depth of the Stuart Shelf sedimentary cover over the basement

ANT Velocity section with 2D seismic



Infill surveys aligned nodes with dominant noise direction



COPPER

INTEGRATED PHYSICS APPROACH

PROJECT

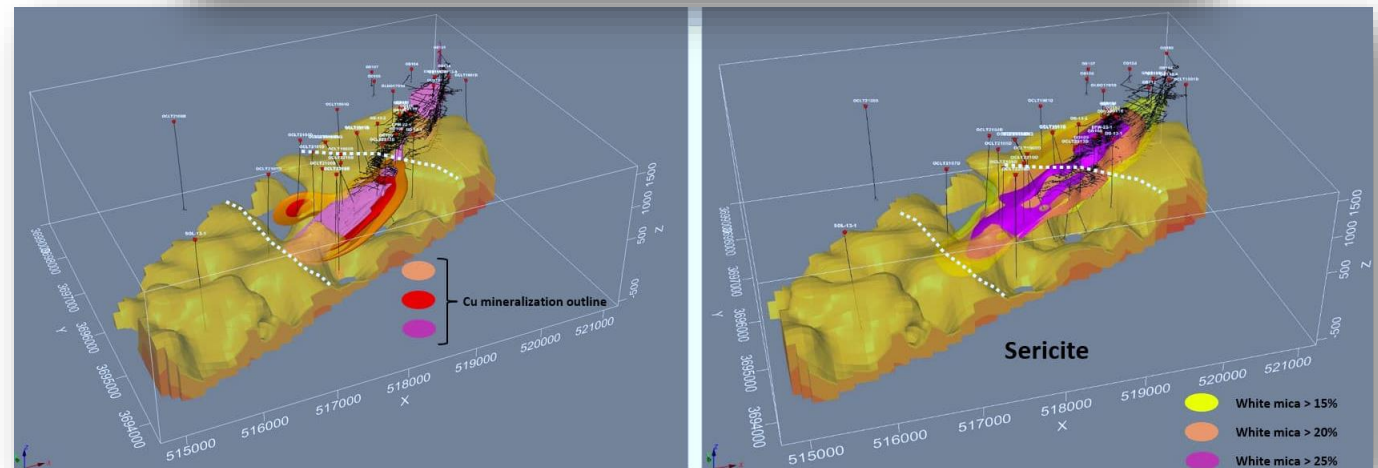
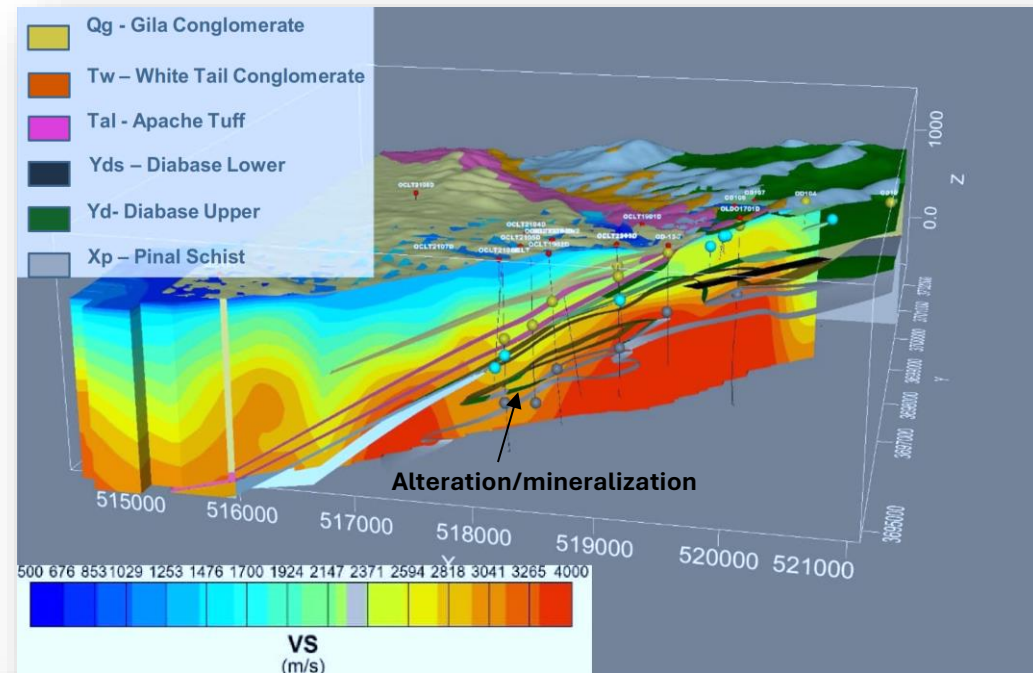
- Ocelot
- Location: USA, Arizona
- Company: BHP

SURVEY DESIGN

- Nodes: 208
- Spacing: 300 m

TARGET

- Identify depression of low velocity interpreted as the combined results of alteration/mineralization, intense structural damage zone and porosity
- Image the quaternary cover/bedrock interface
- Image damage zone associated with higher grade alteration/mineralization



COPPER - REE

COPPER HOSTING TROUGHS

PROJECT

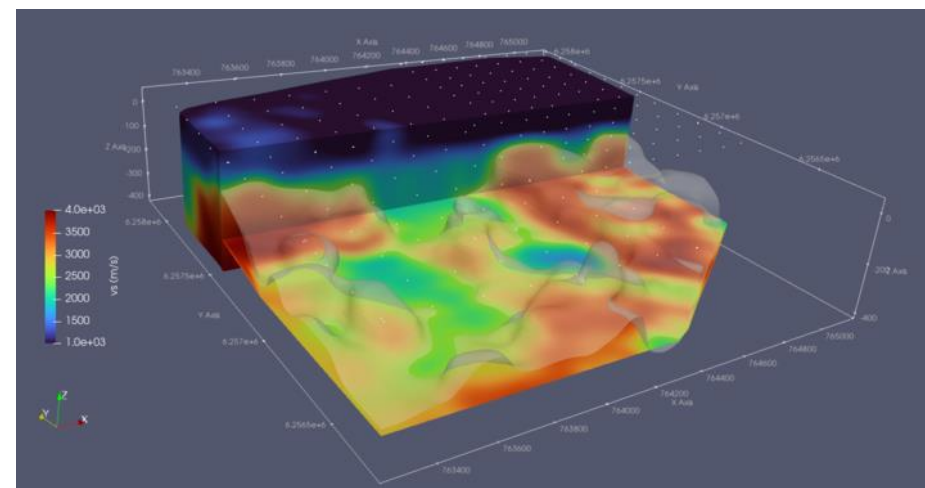
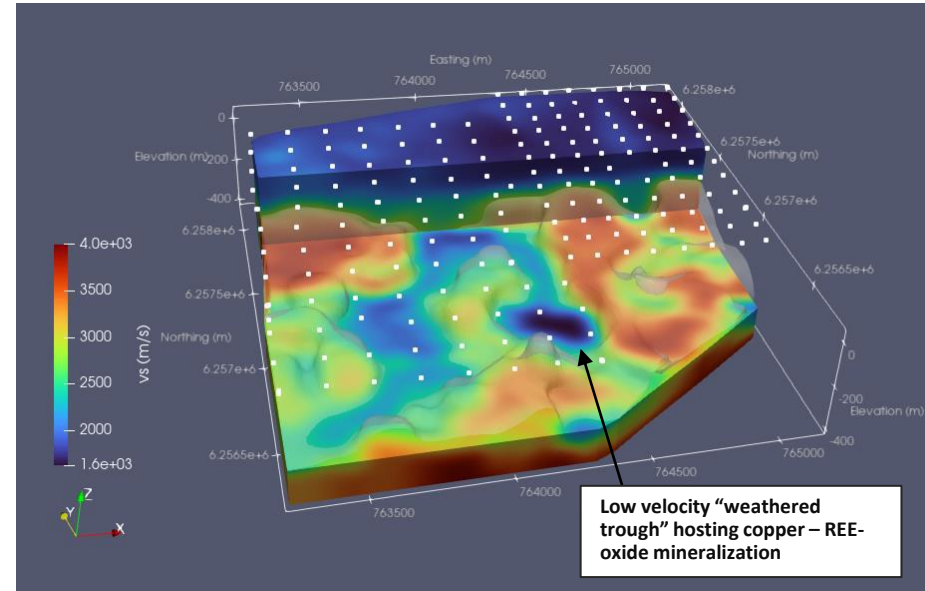
- Alford East Copper-REE Project
- Location: Australia, South Australia
- Company: Thor Energy PLC

SURVEY DESIGN

- Nodes: 96
- Spacing: 115 - 150 m

TARGET

- Preliminary ANT models clearly delineate low-velocity, weathered 'troughs' that host the oxide copper-gold-REE mineralization within the Alford Copper Belt
- Mineralization is associated with rocks that are significantly less dense with lower seismic velocity than the surrounding fresh units



URANIUM

IMAGING LARGE ANOMALIES

PROJECT

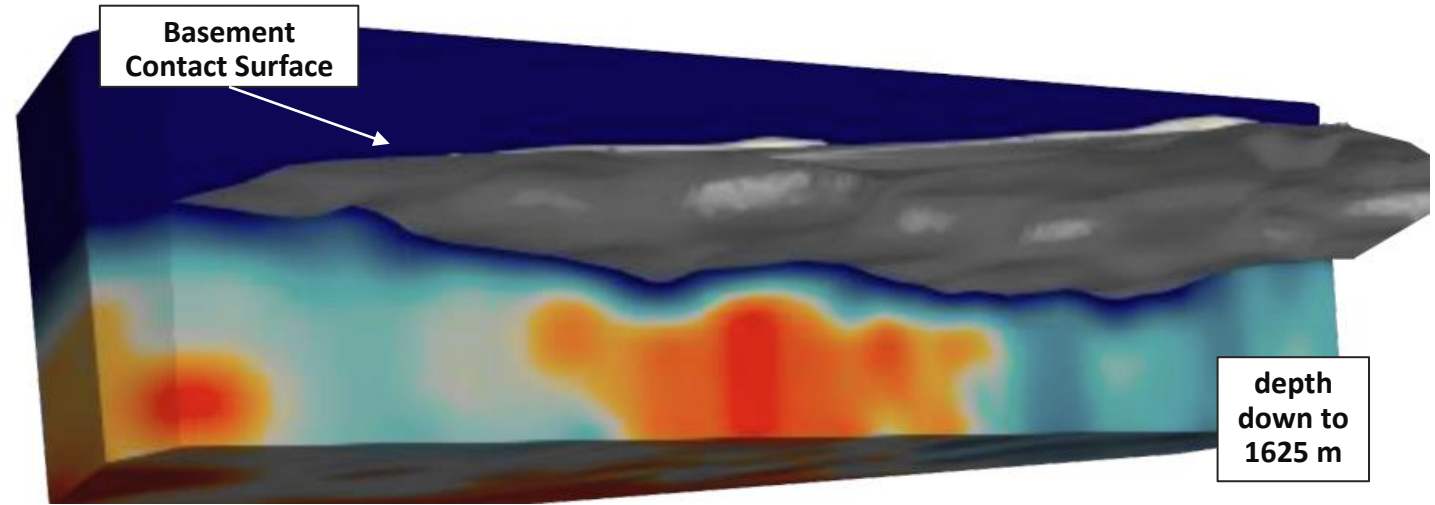
- Pasfield Lake
- Location: Canada, Saskatchewan
- Company: Terra Uranium

SURVEY DESIGN

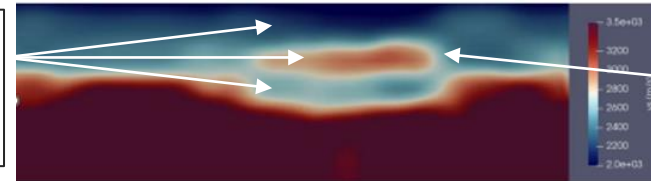
- Nodes: 60
- Area: 16 km²
- Spacing: 600 m
- Depth: 1625 m

TARGET

- Image the unconformity basement contact in high detail at 800-1000m
- Identified anomalous structures showing uranium potential

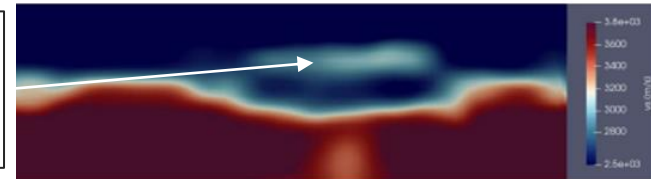


Multi-Layer Cover shows 3 layers with higher velocity region through middle

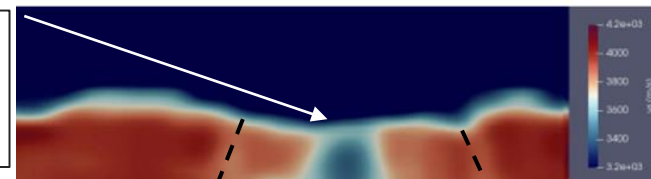


Possible alteration in the sandstone

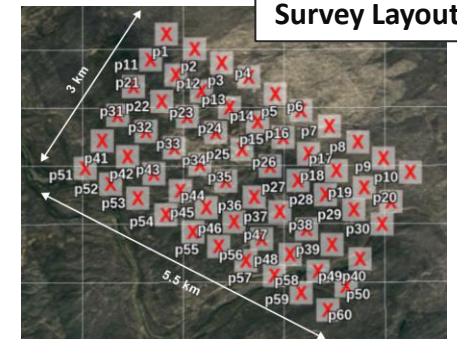
Undulations in cover layers identified possible basement faulting into sandstone



Distinct low velocity fault structure correlates with EM surveys anomaly



Survey Layout



URANIUM

IDENTIFYING ALTERATION

PROJECT

- Larocque East, Hawk
- Location: Canada, Saskatchewan
- Company: IsoEnergy

SURVEY DESIGN

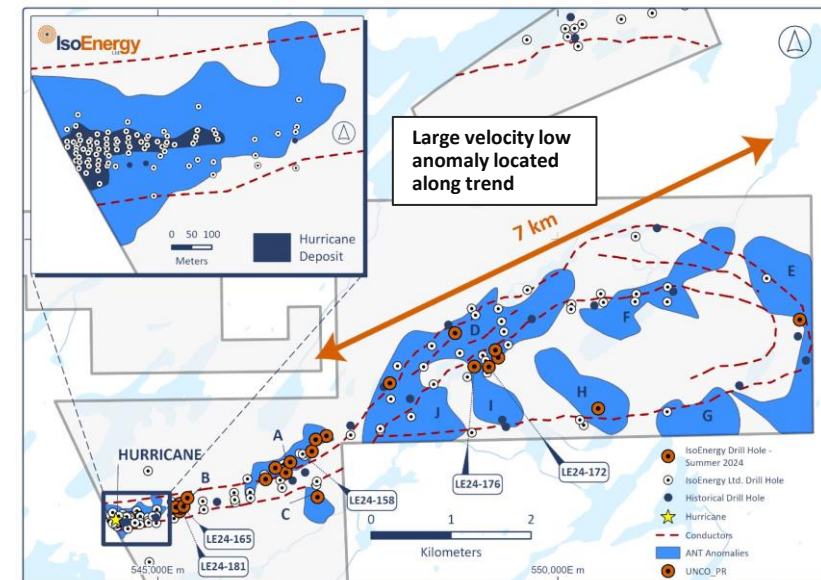
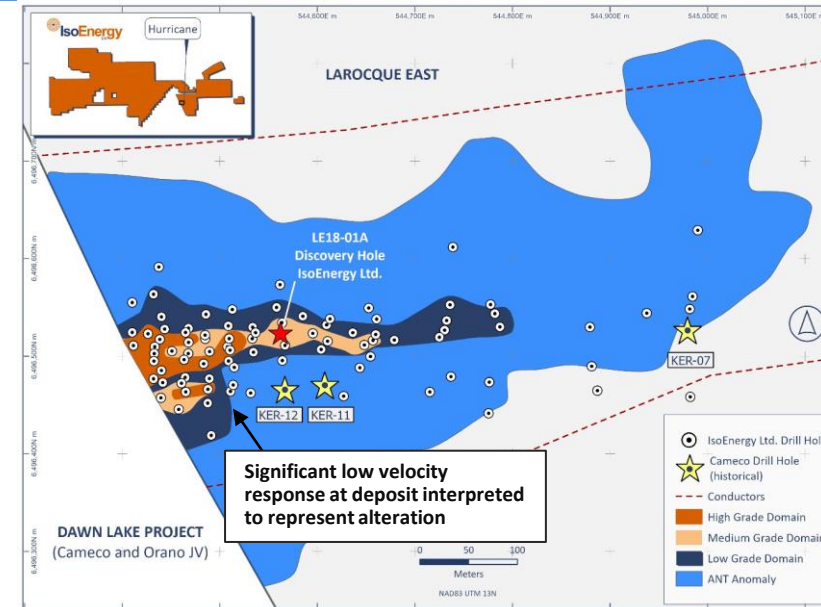
- Area: 27.3 km²

TARGET

- ANT survey used to highlight alteration halos and plan drill targets



Altered sandstone 12 to 20 metres above the unconformity in Target Area B (LE24-181, 271.8- 276.7m). The core is strongly bleached with intervals of desilicification and strong clay alteration



URANIUM

ESTABLISHING DRILL TARGETS

PROJECT

- Aberdeen Uranium
- Location: Nunavut, Canada
- Company: Forum Energy Metals

SURVEY DESIGN (Tatiggaq / Ned / Bjorn)

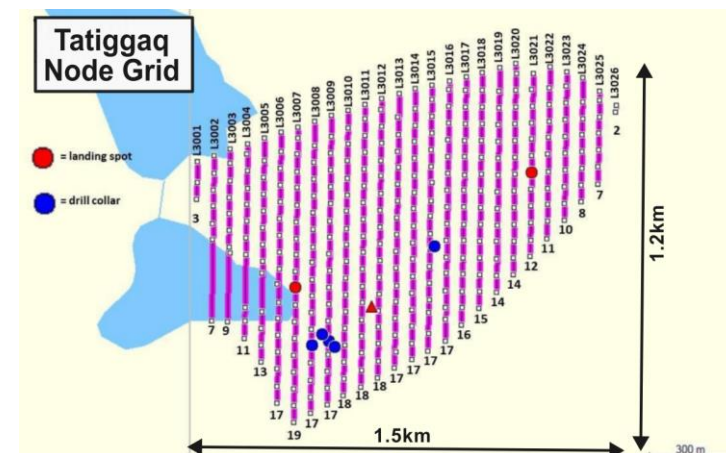
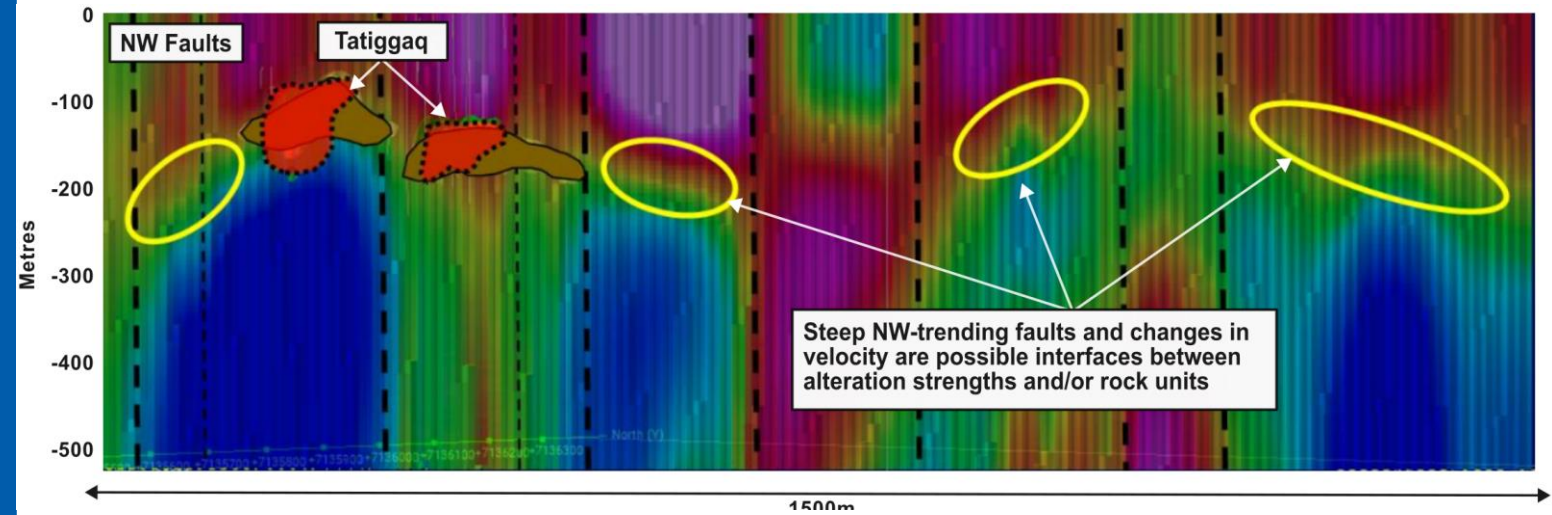
- Nodes: 344 / 77 / 54
- Spacing: 60m / 150m / 150m
- Recording Time: 24-26 days

TARGET

- Tatiggaq fault zone metasedimentary bodies hosting mineralization
- Steep-dipping ore controlling structures

RESULT

- Successfully established new drill targets over a one plus kilometer east-northeast extension along the Tatiggaq fault zone



THANK YOU

CONTACT

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What are Rayleigh waves?

- Rayleigh waves are one type of surface seismic wave that are polarized vertically, in other words, their particle motion is in a vertical plane. Natural sources of Rayleigh waves include earthquakes, tides, and surf that can impart a significant amount of energy into the near surface. Cultural sources of Rayleigh wave include trains, highways, wind turbines, and other industrial equipment.

How can Rayleigh waves be recorded?

- Because Rayleigh waves are polarized vertically, we can measure their velocity and wavelength using only a single component vertical geophone and a single channel nodal recording unit. While using a 3-component geophone and 3-channel nodal recording unit can allow us to record the full particle motion, this is not a requirement for measuring Rayleigh wave velocity.

How do we measure Rayleigh wave velocities using passive seismic recordings?

- Passive seismic refers to deploying recording equipment and sensors to record the ambient wave field. This is opposed to active seismic where a seismic source is used to produce a seismic signal at a known time and specific location. With passive seismic we use a technique called cross-correlation to measure the similarity between the ambient wave field at pairs of receivers or stations. By measuring the relative time difference between similar wave forms at two receivers we can compute average velocity. Because naturally occurring Rayleigh waves are usually low amplitude and may be episodic, we do need to analyze many hours of data to measure velocities accurately.

RECORDING TIME AND NODE ARRAY

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What time duration do we need to record for?

- Stacking data over longer duration improves the signal to noise ratio on cross-correlations, so the longer time we record for the more accurate the velocity measurement becomes. In practice we usually record passive data for periods ranging from five days to a few weeks. Wind noise, which is random and broadband, can obscure Rayleigh waves and can be a factor in deciding on total field recording time.

What kind of recording array do you need?

- In order to accurately measure a time difference between receiver pairs we usually need those receiver pairs to be hundreds of meters to a few kilometers apart. A typical ANT recording array contains between 60 and 1000 recording stations depending on the size of the area of investigation. Because the receivers are placed relatively far apart from each other, nodal recording units which record the seismic data locally on memory chips, are far more cost effective than cabled or satellite telemetry recording systems. Nodal recording units weigh less than 1 kg and 100 units or more can be deployed by a team of two people in a single day, depending on terrain type and mode of transport. Typical field transportation includes helicopters, UTV's, off-road vehicles, and walking.

Geophone Response

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Geophone Concepts

- Geophones are defined by the natural resonance frequency of the spring holding up with moving coil. The geophone response is electrically “damped” to flatten the response, so you don’t actually see a big peak at the resonance frequency in the following plots. 3 hz high sensitivity element the response at 1 hz is 10 V/m/s which is 12.5% of published sensitivity (-18 db).
- The response curves of the geophone are always flat (i.e. constant) going toward higher frequencies from the resonance frequency. The response curve of the geophones always “roll-off” (ie have a lower response) going toward lower frequencies from resonance frequency.
- The response (also called sensitivity) of the geophone comes from wire windings wrapped around a magnet. The more windings in the coil going around the magnet the higher the voltage. High sensitivity geophones just have more windings than conventional sensitivity geophones.

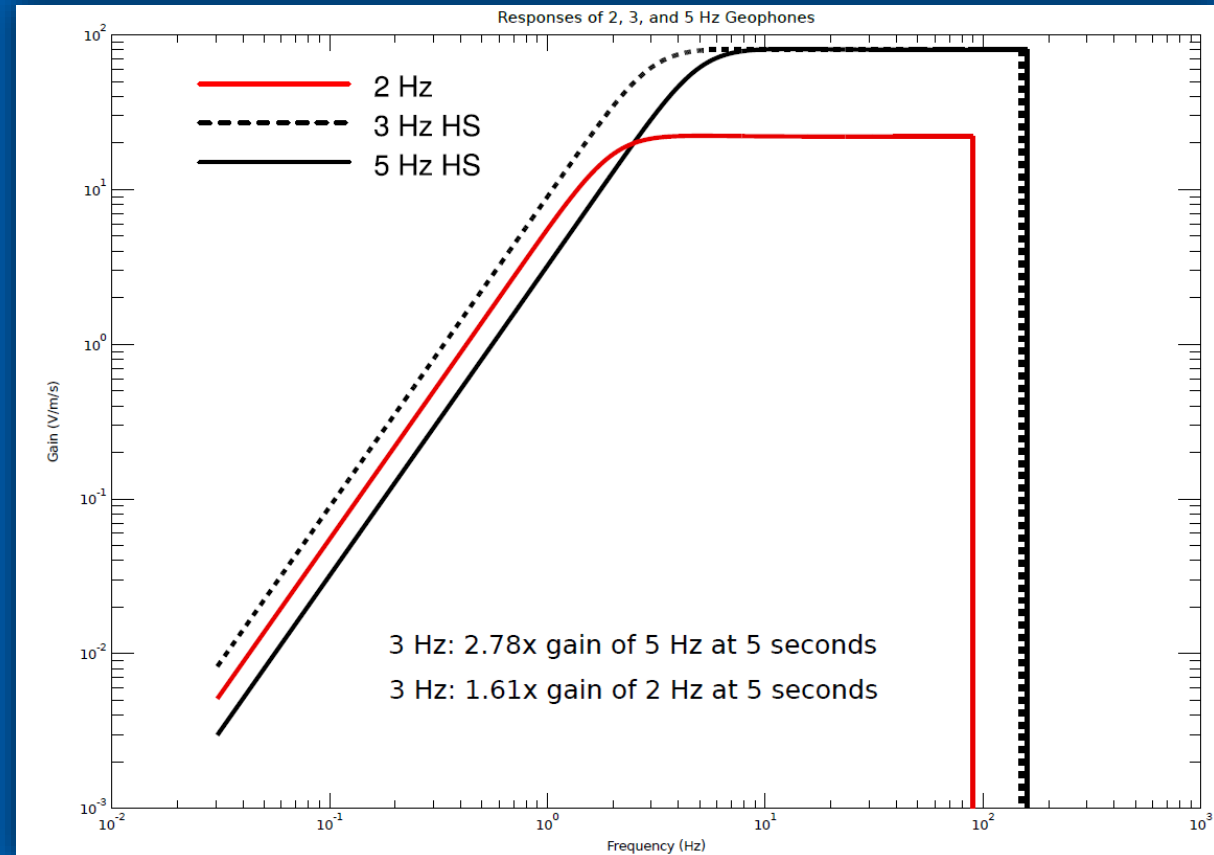
Low Frequency Geophones

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System Response Comparison

- 5 Hz high sensitivity element the response at 1 Hz is 3.5 V/m/s which is 4.4% of published sensitivity (-27 db).
- 3 Hz high sensitivity element the response at 1 Hz is 10 V/m/s which is 12.5% of published sensitivity (-18 db).
- 2 Hz “standard” sensitivity element the response at 1 Hz is 6 V/m/s which is 27.2% of published sensitivity (-11 db).



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What is Tomography?

- The initial measurement of Rayleigh wave velocity is made between pairs of receivers, so this provides an average velocity between those specific two points on the ground. In an ANT survey we will typically have thousands of receiver pairs, so this means we have many thousands of velocity measurements for many thousands of intersecting ray paths. Tomography refers to the process of taking those point-to-point receiver measurements and computing a 2D velocity for each grid location covering the area of investigation. The higher the ray path density, the more accurate the tomography becomes, due to the power of statistics.

What is a Dispersion Curve?

- Rayleigh waves are usually “dispersive” which means that different frequencies travel at different velocities. Low frequency Rayleigh waves have much longer wavelengths than high frequency wavelengths. For example, 1 hz Rayleigh waves typically have wavelengths well over 1 km whereas 10 hz and higher will have wavelengths of a few hundred meters or less. Because the low frequency waves are traveling deeper in the earth, they generally have faster velocities. In contrast, the high frequency waves which are traveling shallower in the earth, are more affected by the near surface, and tend to have slower velocities. A “dispersion curve” shows the specific relationship between frequency and velocity for a particular location. To compute dispersion curves we need to run tomography at several different frequencies.

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How do we compute shear wave velocity using an ANT survey?

- For mineral exploration we are interested in measuring rock properties like shear or compressional velocity. Fortunately, Rayleigh wave velocity is on the order of 92% of shear wave velocity so that is a simple and well understood relationship. What is more complicated is that we need to compute shear velocity for a full 3D volume and not a 2D slice. This is where the dispersion curves come into play. Because different frequencies map to different depths we can use a computational process called “inversion” to essentially map the 2D Rayleigh wave dispersion curve data to a shear wave velocity in a 3D volume.

How deep can an ANT survey image?

- How deep an ANT survey can image is dependent on the frequency of the Rayleigh waves recorded. A typical ANT survey for mineral explorations relies on frequencies between 0.5 hz and 15 hz and can image as shallow as 50 m to well over 1000 m in depth, which is adequate for most mining applications. For deeper imaging, such as required for crustal studies, we use recording units designed to record frequencies down to 0.1 hz or lower. The size of the recording array needs to be adjusted relative to the depth of imaging. Surveys designed for deep targets will have the receivers being relatively more spread out and surveys designed for shallow targets will have the receivers relatively closer together.

DATA SOURCES AND VOLUME

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How much data does a survey produce?

- 3.2 GB per station over 20 days (160MB / day), if there were only 100 stations the total survey would be about 320 GB.

How does ANT respond to natural vs cultural energy sources?

- Sources of Rayleigh waves for ANT signal would be a repetitive or continuous source. When we stack several days of data together the signal to noise ratio improves. That is generally the case for bodies of water and certain anthropomorphic sources like trains, busy highways, and railroads.
- One can measure Rayleigh wave velocity from individual earthquakes or nuclear explosions which is how the methodology was developed in the first place. That is a different work flow as one is locating a specific source (also landslides, avalanches, and volcanic explosions) at a specific time and measuring the Rayleigh wave velocities for a very short period of time (a few minutes or less).
- Having man-made sources like drills (or mining) may work as a source in some cases but it might be the “ideal” scenario where the drill is “just the right distance” away. If the drill is too close there are likely going to be a lot of P-waves and S-waves with high amplitude that will make it harder to isolate the Rayleigh waves. If the drill is too far away we might not even detect the Rayleigh waves.

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Why only use 1-component (1C) geophones?

- Rayleigh waves are generated by constructive interference of P-waves (compressional waves) and vertically polarised S-waves (shear waves) at the Earth's surface. Love waves are purely composed of horizontally polarised S-waves and have no vertical motion.
- For earthquake studies, geophysicists use 3 component (3C) geophones, or more likely an array of 3C and 1C sensors, to record ground motion in three orthogonal directions: vertical, north-south, and east-west. This information allows the polarisation of the waves to be determined, making it easier to identify S-waves in seismograms and can also give the direction of the incoming P-waves to understand the source direction.
- The 1C geophones record data that fits Ambient noise studies, relying on very low amplitude signals.

Does ANT work under lakes or the ocean?

- Yes, ANT can work under lakes and the ocean provided that the sensor is positioned on the water bottom. Rayleigh waves are a type of acoustic wave that travel along the surface of solids and, like shear waves, don't exist in a liquid.
- From an academic point of view, the surface wave traveling along a solid-liquid interface is considered a Scholte wave rather than a Rayleigh wave. However, on a practical basis, Rayleigh and Scholte wave velocities are within a few percent when the wavelength of the surface waves is substantially greater than the water depth. So, for most mining applications the difference between these two surface wave types will have little to no impact on the ANT workflow.

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How is passive seismic data recorded in lakes or the ocean?

- Seismic nodes designed for recording in deep water are typically referred to as Ocean Bottom Nodes or OBN's. Because OBN units cannot obtain GPS time underwater they must use an internal clock that can maintain sub-millisecond timing for at least a month. The external housing for OBN units must also be rated for much higher pressures so as to avoid water intrusion in the electronics compartment. For relatively shallow water, ie less than 50 m in depth, the OBN units can easily be dropped from a boat with a tether connected to an anchor and buoy system designed for later retrieval.
- For very shallow water, typically less than 7 m in depth, land recording nodes can actually be used for 'marine' applications. In the shallow water environment, a sensor is deployed on the bottom of the lake or transition zone and transmits the analog seismic signal to a recording node positioned above the water surface by a conducting wire pair. The land recording node can float on the surface of the water with a floating "collar" or be attached to a PVC pipe or wooden pole, so that a GPS timing signal can be received. For arctic or winter conditions, the nodes can be placed on surface ice with the sensor deployed on the bottom through a drilled hole in the ice.