GTI-Technical Note-1	Ambient Noise Tomography (ANT) Advanced Sub-Surface Imaging Technology for Mineral Exploration

SUMMARY

Golden Taurus Ingeniería (GTI), in collaboration with the **Institute of Mine Seismology (IMS),** offers to the mining and mineral exploration sector sub-surface imaging solutions using the advanced technology known as **Ambient Noise Tomography (ANT)**

Ambient Noise Tomography (ANT) is a technology for mineral exploration, imaging geological structure and to locate mineralised zones essential for present and future industrial demands.

Discovering hidden deposits of a wide range of minerals is vital to meet present and future global demand. While traditional methods have contributed to our current understanding, advanced techniques are now available to obtain subsurface information at greater depth and even under cover, but with minimal environmental impact.

ANT, a seismic technique that generates a 3D velocity model of the subsurface by analysing naturally occurring ambient seismic noise, offers depth measurement capabilities without the need for active energy sources. This technology has proven to be a powerful tool for investigating the subsurface at greater depths, allowing the identification of mineral deposits, hydrocarbons, geothermal resources, geological faults and crucial geotechnical information. ANT therefore provides a less disruptive method for subsurface characterisation.

ANT can image a wide range of depths, from shallow to very deep, depending on the frequency ranges sampled and always contingent on the frequencies available in the ambient wave-field. This provides a comprehensive 3D volumetric understanding of the subsurface.

Furthermore, ANT holds significant potential for groundwater investigations. The same value proposition that holds for mineral resource development, also applies to groundwater resource development. By mapping subsurface structures and identifying potential groundwater resources through the analysis of natural seismic noise, ANT can generate 3D models of S-wave velocity. These models can reveal hydrogeological structure and groundwater flow pathways. In both contexts ANT exploration can limit the cost of subsequent drilling campaigns, by identifying high priority zones at an early stage.

This note provides a technical and economical overview of ambient noise tomography (ANT) for subsurface prospecting, highlighting its advantages over traditional methods.

Advantages of Ambient Noise Tomography for Subsurface Prospecting

1. Introduction

Subsurface prospecting is crucial for various applications, including geotechnical engineering, resource exploration, and seismic hazard assessment. Traditional methods often involve active seismic sources, which can be costly, environmentally impactful, and logistically challenging. Ambient noise tomography (ANT) has emerged as a promising alternative, leveraging naturally occurring seismic waves to image subsurface structures.

2. Technical Principles of Ambient Noise Tomography

ANT utilizes ambient seismic noise, which is generated by a multitude of natural and anthropogenic sources (e.g. ocean waves, wind, human activity). Unlike active seismic methods that rely on controlled energy sources, ANT processes the continuous, passive recordings from an array of seismometers.

The fundamental principle behind ANT is the concept of "noise correlation interferometry." By cross-correlating long records of ambient noise between pairs of seismic stations, it is possible to retrieve an estimate of the Green's function - the impulse response between the two stations. This retrieved Green's function approximates the seismogram that would be recorded if one station were an active source and the other a receiver.

The steps involved in ANT typically include:

- **Data acquisition:** Deployment of a network of sensors to continuously record ambient seismic noise over an extended period (typically 2-4 weeks, but depending on ambient noise levels and noise floor of deployed seismometers).
- **Preprocessing:** Removal of instrument responses, identification and removal of earthquake signals, amplitude normalization of other high amplitude transients, and spectral whitening to balance the energy across different frequencies.
- **Cross-correlation and stacking:** Computation of cross-correlation functions between all possible pairs of stations of simultaneous recordings over a characteristic period, followed by stacking of all cross-correlations over the entire recording period. This process reinforces the coherent surface wave arrivals, primarily Rayleigh and Love waves (Love waves can be detected where three-component data is available) and cancels out incoherent noise.
- **Dispersion curve extraction:** Analysis of the cross-correlation functions to extract dispersion curves, which show how the phase velocity of surface waves varies with frequency. Higher frequencies are sensitive to shallower structures, while lower frequencies probe deeper.
- **Inversion:** Inversion of the obtained dispersion curves to construct 2D or 3D shear-wave velocity (V_S) models of the subsurface. Shear wave velocity is a critical parameter for characterizing material properties and is directly related to stiffness and density.

3. Advantages of Ambient Noise Tomography vs. Other Prospecting Technologies

3.1. Comparison with Active Seismic Methods (e.g. Reflection/Refraction Seismics)

Feature	Ambient Noise Tomography (ANT)	Active Seismic Methods
Energy Source	Passive: Utilizes naturally occurring ambient seismic noise.	Active: Requires controlled energy sources (e.g. vibrators, explosives, hammer blows).
Logistics/Cost	Generally lower logistical demands, easier deployment in difficult terrain. Reduced equipment and operational costs.	Higher logistical demands, requires specialized equipment, more expensive.
Environmental Impact	Minimal to none, as no artificial sources are used.	Can have environmental impacts (noise, ground disturbance) depending on source type.
Safety	Inherently safer due to passive nature.	Potential safety concerns associated with active sources.
Depth Penetration	Can achieve significant depth penetration (kilometers) depending on array aperture and recording duration.	Varies; typically good for shallower targets (reflection/refraction), but deep penetration requires very large sources.
Resolution	Resolution is dependent on station spacing and frequency content of noise. Generally good for imaging lateral variations.	High resolution possible, especially for reflection seismics, but can be limited by source-receiver geometry.
Noise Levels	Less susceptible to localized cultural noise as it relies on coherent signals over long periods.	Can be significantly affected by ambient noise levels, requiring careful survey design.
Applicability	Well-suited for urban environments, environmentally sensitive areas, and remote and densely vegetated regions.	Challenging in urban areas due to cultural noise; limited in environmentally sensitive areas.
Data Acquisition Time	Requires longer recording times (days to months).	Relatively short acquisition times for individual shots.

3.2. Comparison with Gravity and Magnetic Methods

Gravity and magnetic methods measure variations in the Earth's gravitational and magnetic fields, respectively. While useful for mapping large-scale density and susceptibility contrasts, they provide limited direct information on elastic properties and structural details compared to seismic methods. ANT, by providing shear-wave velocity models, offers a more direct and detailed characterization of mechanical ground properties, which is crucial for engineering and geotechnical applications. Depth sensitivity of seismic dispersion allows for more constrained inversion resulting in models of 3D structure.

3.3. Comparison with Electrical Resistivity Tomography (ERT)

ERT measures subsurface electrical resistivity, which is sensitive to lithology, water content, and porosity. While valuable for hydrological and environmental studies, ERT provides different physical parameters than ANT. ANT's strength lies in directly imaging elastic properties, which are more directly related to the mechanical behavior of the subsoil (e.g. liquefaction potential, bearing capacity). Combining ANT with ERT can provide a more comprehensive understanding of the subsurface. However, due to constraints with regards to instrumentation, ERT is typically confined to the very near-surface whereas ANT routinely extends imaging to seismic wavelengths of several kilometers.

4. Economical Advantages of Ambient Noise Tomography

The economic benefits of ANT stem primarily from its passive nature and reduced logistical requirements:

- **Reduced Equipment Costs:** Eliminates the need for expensive and specialized active seismic sources (e.g. large vibrators, explosive charges, specialized source vehicles). The primary equipment cost is for a network of seismometers, which can often be rented or repurposed from existing seismic networks.
- **Lower Operational Costs:**
  - **Personnel:** Requires fewer specialized personnel for source operation and safety compared to active methods.
  - **Permitting:** Simplified permitting processes, as there are no active sources generating noise or ground disturbance. This can significantly reduce administrative overhead and accelerate project timelines.
  - **Logistics:** Easier deployment in challenging or remote terrain, reducing transportation costs and time. No need for extensive land clearing or road building for source deployment.
  - **Environmental Mitigation:** Avoids the costs associated with environmental impact assessments and mitigation measures often required for active seismic surveys.
- **Increased Accessibility:** The ability to operate in urban environments, environmentally sensitive areas, and areas with restricted access opens up new possibilities for cost-effective surveying where traditional methods would be impractical or prohibitively expensive.

While the data acquisition time for ANT can be longer, the overall cost savings in terms of equipment, logistics, personnel, and permitting often make it a more economically attractive option for a wide range of subsoil prospecting applications.

5. Limitations and Future Directions

Despite its numerous advantages, ANT also has some limitations:

- **Resolution:** The resolution of ANT is generally lower than high-resolution active reflection seismic surveys, particularly for very fine features or sharp boundaries. This is because it primarily relies on surface waves, which have longer wavelengths.
- **Data Processing Complexity:** The processing of ambient noise data requires specialized software and expertise in signal processing and inversion.
- **Recording Duration:** Achieving sufficient signal-to-noise ratio for reliable Green's function retrieval often requires longer recording durations, which can delay the availability of results.

- **Dependence on Noise Source Distribution:** The quality of the retrieved Green's functions depends on the azimuthal distribution of ambient noise sources. Anisotropic noise illumination can introduce biases.

Future advancements in ANT include:

- **Improved Inversion Algorithms:** Development of more robust and efficient inversion algorithms for complex 3D structures and anisotropy.
- **Integration with Other Geophysical Methods:** Synergistic use of ANT with other geophysical techniques (e.g. active seismic, gravity, ERT) to overcome individual limitations and provide a more comprehensive subsurface image.
- **Utilization of Body Waves:** While ANT primarily uses surface waves, research is ongoing to extract body wave information from noise correlations, which could improve resolution, constrain model inversion and allow for greater depth penetration.
- **Enhanced Role for 3-Component Data:** HVSR, Love waves and Rayleigh wave ellipticity add constraints to inversion results.

6. Conclusion

Ambient noise tomography offers compelling technical and economic advantages for subsurface prospecting. Its passive nature eliminates the need for expensive and environmentally impactful active sources, leading to reduced logistical demands, lower operational costs, and increased accessibility in challenging environments. While resolution and processing complexity present ongoing challenges, the continuous advancements in algorithms and data processing techniques are rapidly expanding its capabilities. As a result, ANT is becoming an increasingly favoured and cost-effective tool for a wide range of geotechnical, environmental, and resource exploration applications, complementing and, in many cases, surpassing the capabilities of traditional prospecting technologies. Its inherent safety and minimal environmental footprint further solidify its position as a sustainable and efficient geophysical method for understanding the Earth's subsurface.

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