Case Study

Ambient Noise Tomography for Copper-Gold Porphyry Exploration:

Reko Diq, Balochistan, Pakistan

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SUMMARY

This case study explores Fleet Space Technologies' use of Ambient Noise Tomography (ANT) at the Reko Diq Project in Balochistan, Pakistan, home to one of the world's largest undeveloped copper-gold porphyry deposits. Commissioned by Reko Diq Mining Company (RDMC), a joint venture involving Barrick Gold Corporation, the ANT survey targeted Cu-Au porphyry mineral exploration.

Key words: Ambient Noise Tomography, Passive Seismic, Copper-Gold Porphyry.

INTRODUCTION

This case study examines the application of Ambient Noise Tomography (ANT) by Fleet Space Technologies (Fleet) for Reko Diq Mining Company (RDMC) at the Reko Diq Project in Balochistan, Pakistan (Figure 1). The Reko Diq Project represents one of the world's largest undeveloped copper-gold porphyry deposits, situated in the western Chagai District. RDMC, a joint venture involving Barrick Gold Corporation, the Balochistan province, and Pakistani state-owned enterprises, engaged Fleet to conduct an ANT survey focused on copper-gold (Cu-Au) porphyry exploration.

The Reko Diq Project has indicated and measured resources of 3,653 Mt @ 0.42% Cu; 0.25 g/t Au within the Western Porphyry Complex (WPC) and 277 Mt @ 0.45% Cu within the Tanjeel deposit (Barrick, 2024). The project anticipates commencing production in 2028 through an open-pit mining operation. The ANT survey was designed to map major geological structures linked to mineralisation, with a focus on the D1 (NW-trending) and D2 (NNE-trending) structural trends, and to identify potential 'hypogene feeder' zones associated with hydrothermal alteration and copper-gold porphyry mineralisation within the Reko Diq porphyry complex (Figure 2).

RDMC deployed a total of one hundred Geodes® across the project area, arranged as sequential 100-node grids. This deployment strategy was designed to achieve the desired coverage and resolution across the targeted zones. These nodes facilitated continuous data acquisition and monitoring managed through the ExoSphere Cloud interface. The collected seismic data was processed using Fleet's proprietary automated system to generate detailed 3D shear velocity models of the subsurface. This case study details the methodology, findings, and geological interpretations derived from these models.

Figure 1: Location of the Reko Diq Project, Balochistan Province, Pakistan.

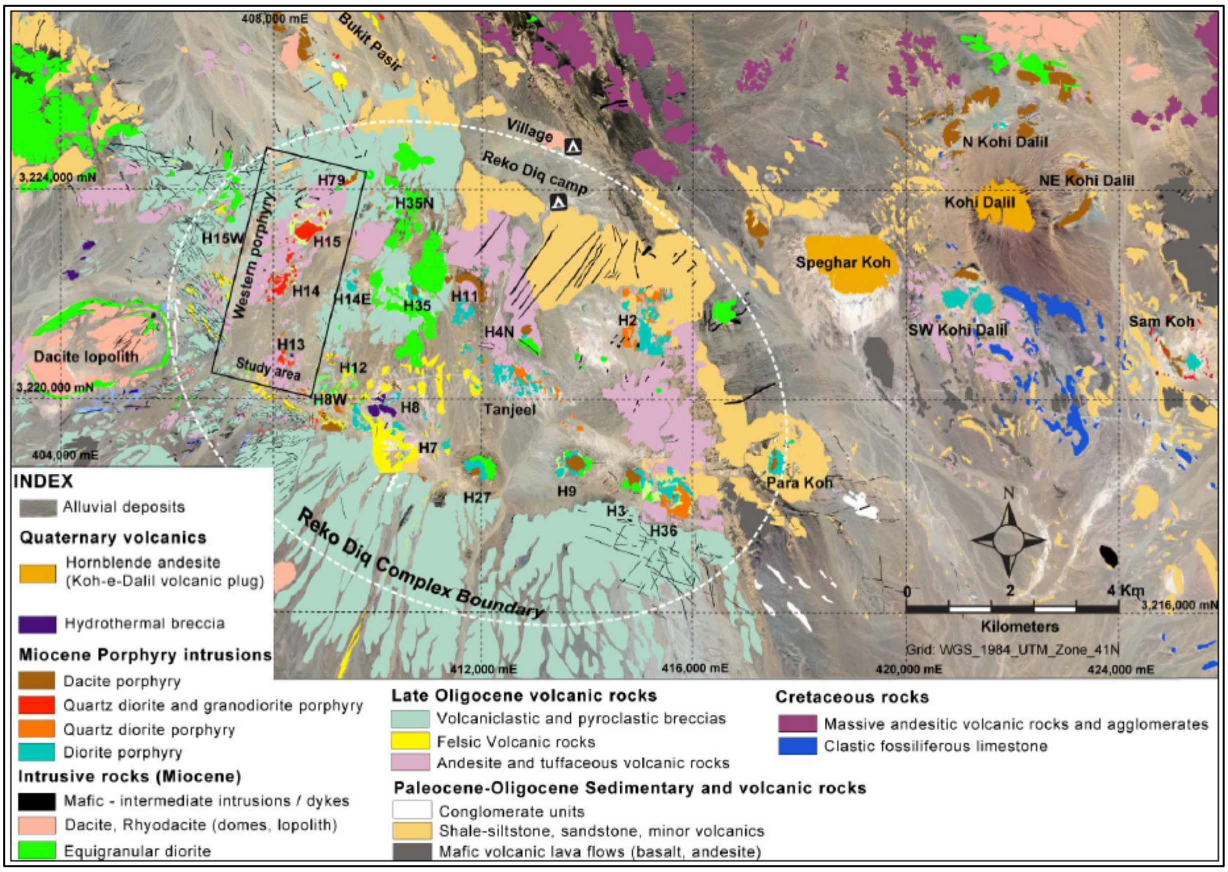

Figure 2 - Satellite imagery and outcrop geology map of the Reko Diq porphyry complex and surrounding porphyry centres within the district. The WPC study area observed by Razique, 2013, is characterised by a cluster of middle to late Miocene porphyry intrusions.

METHODOLOGY - ANT SURVEY DESIGN AND EXECUTION

The project employed a comprehensive ANT survey strategy using strategically positioned Geode arrays tailored to different exploration scales. The deployment comprised two regional 9x11 Geode arrays with an approximate spacing of one kilometre, designed to cover the broader Western and Eastern Regional zones of the Reko Diq Project. To achieve higher resolution imaging over specific target areas, the Western Porphyry and Tanjeel Infill surveys using 10x10 Geode arrays with 500-metre spacing over the WPC and the Tanjeel target area. The H14-H15 Infill survey, consisting of a 10x10 array with an approximate 250-metre spacing, specifically targeted the H14 and H15 porphyries. In total, RDMC completed five distinct survey arrays (Figure 3).

Ambient seismic noise data recorded by the Geodes was continuously transmitted via satellite to the ExoSphere Cloud for processing. The data processing workflow involved dividing the continuous seismic records into 5 to 10-minute segments, applying spectral whitening to enhance the signal, and computing cross-correlations for each pair of Geode stations and extracting surface wave travel-times via dispersion analysis. The resulting travel-times were then used to model the Earth's 3D shear velocity structure beneath the survey areas using a probabilistic tomographic modelling workflow. Signal-to-noise ratios and frequency content varied across the different surveys, with surface waves recovered from regional surveys exhibiting lower ratios and frequencies compared to the higher density infill surveys. Beamforming analysis was conducted to assess the directionality of the ambient seismic noise sources. Details of the ANT methods can be found in Olivier et al. (2022) and Jones et al. (2024).

Three primary velocity models were generated from the processed data:

1. **Reko Diq Velocity Model:** This model combined data from the Western and Eastern Regional surveys and was generated on a 100-metre grid.
2. **WPC Velocity Model:** This model integrated data from the Western Porphyry Infill and H14-H15 Infill surveys, resulting in a higher resolution 50-metre grid.
3. **Tanjeel Velocity Model:** This model was derived from the Tanjeel Infill survey data and produced on a 50-metre grid.

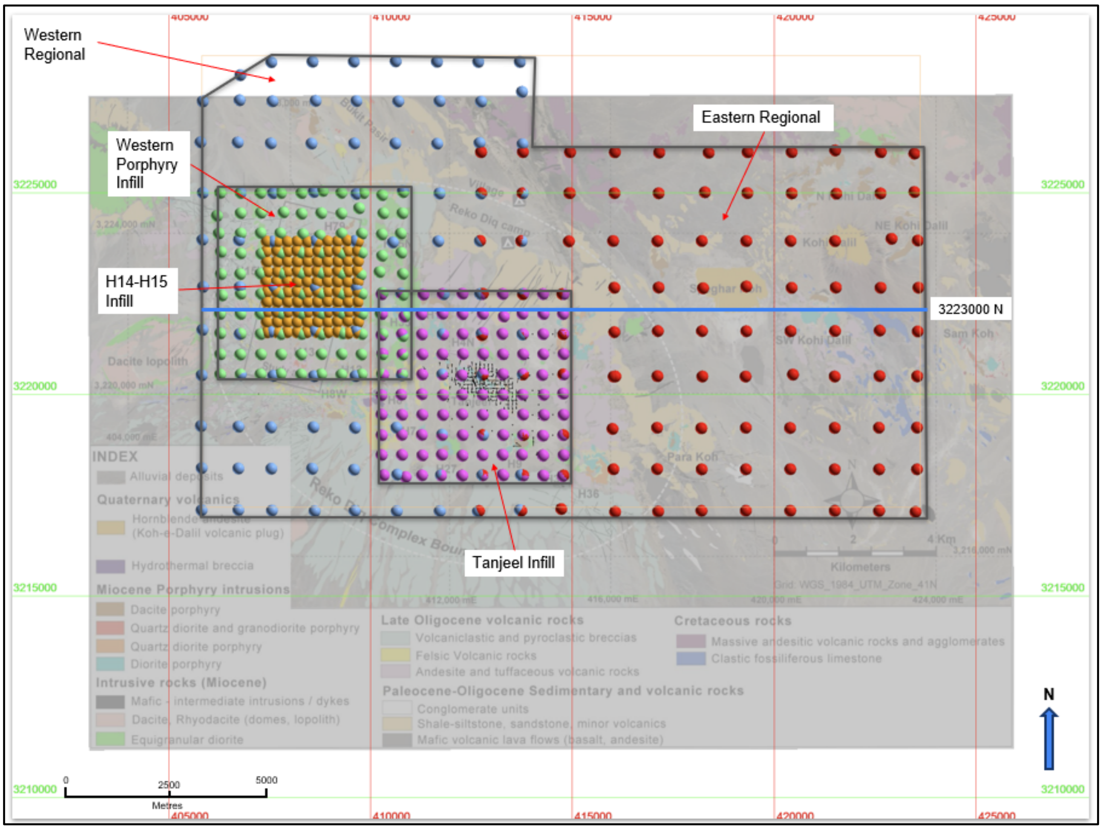

Figure 3 - Layout of the five ANT survey arrays within the Reko Diq porphyry complex overlaying satellite image and outcrop geology map (after Razique, 2013). Cross section line 3223000 N shown for reference to location of Figures 4 & 5.

RESULTS - VELOCITY MODELS & GEOLOGICAL INTERPRETATION

The 3D shear wave velocity models provided detailed insights into the subsurface structure of the Reko Diq porphyry complex. Each model revealed distinct features relevant to the project's exploration objectives.

The Reko Diq Velocity Model revealed a contrast in subsurface elevation between the western and eastern parts of the survey area. Areas corresponding to known porphyry targets were associated with high-velocity zones (≥ 3300 m/s) thought to be hypogene feeders. The model also showed complex velocity contours beneath the shallow H4 (Tanjeel) supergene target and deeper high-velocity contours (≥ 3500 m/s) at the base of the model. These features may correlate with an interpreted underlying batholith, and the potential extent and intensity of alteration haloes associated with the porphyry intrusions (Figure 4). Additionally, a set of linear features (lineaments) were discernible in the plan view of the velocity model that are parallel to regional-scale D1 and D2 structures.

The high-resolution WPC Velocity Model identified central zones of very-high velocity (≥3300 m/s) bounded by high velocity (2900–3200 m/s) margins thought to be alteration haloes associated with the H15, H14, and H13 porphyry targets within the WPC (Figure 5). Intermediate velocity zones (≤2800 m/s) are interpreted to be less altered volcano-sedimentary basement rocks that border the WPC. Interpretation of the model allowed for the delineation of the D1 and D2 structures within the WPC and offered valuable insights into the extent and intensity of alteration associated with the targeted porphyry systems.

The Tanjeel Velocity Model revealed a complex subsurface velocity structure beneath the shallow Tanjeel target (Figure 6). High velocity zones near the H4, H8, H9, and H35 porphyry targets, with intermediate velocity margins surrounding these areas. Lineaments were clearly visible in plan views. Geological interpretation of the model enabled the mapping of the D1 and D2 structural trends and identified velocity anomalies potentially associated with alteration zones linked to the porphyry targets - H35, H8, H4, and H9 - as well as beneath the Tanjeel supergene blanket (Figure 7).

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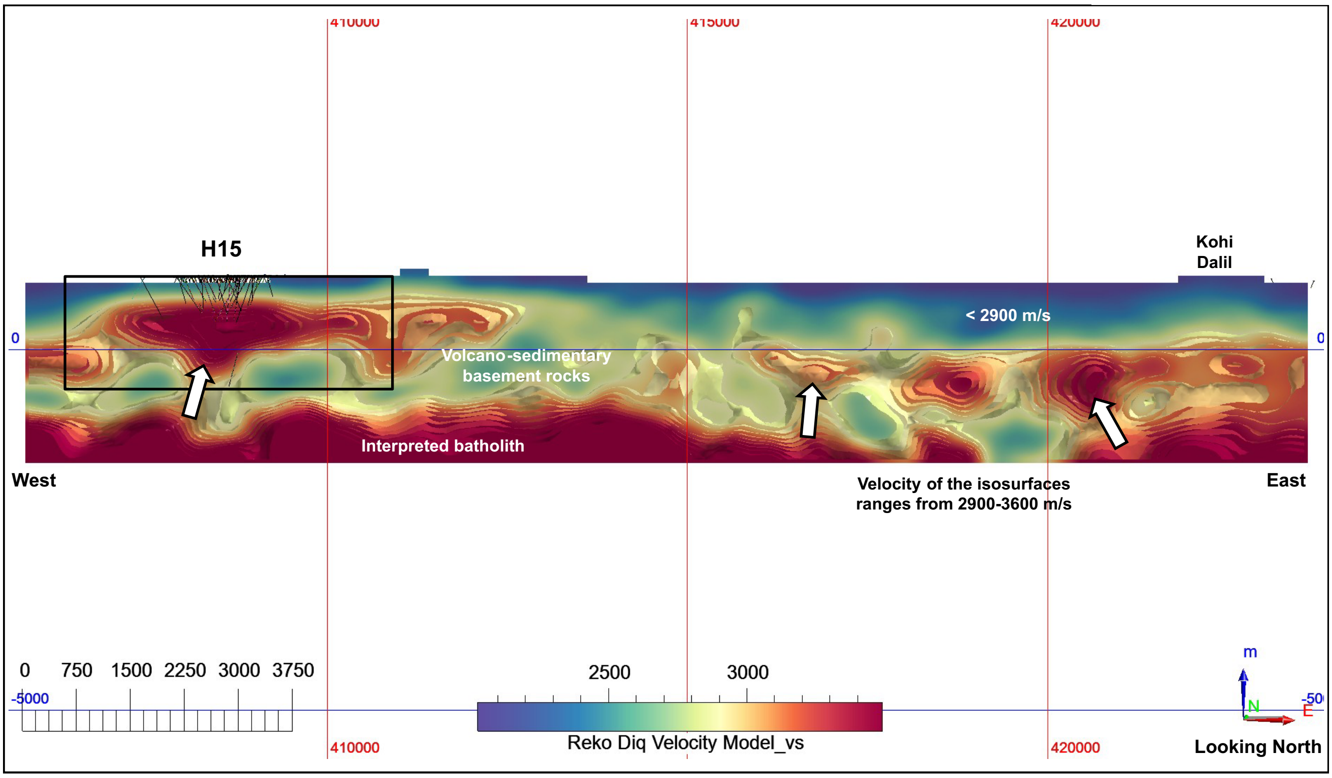

Figure 4 - Cross section (3223000 N) view of the Reko Diq Velocity Model; looking N. The subsurface is deeper on the eastern side of the model. Drill hole traces shown for the H15 porphyry target that is within the WPC. Insert shows the position of Figure 5.

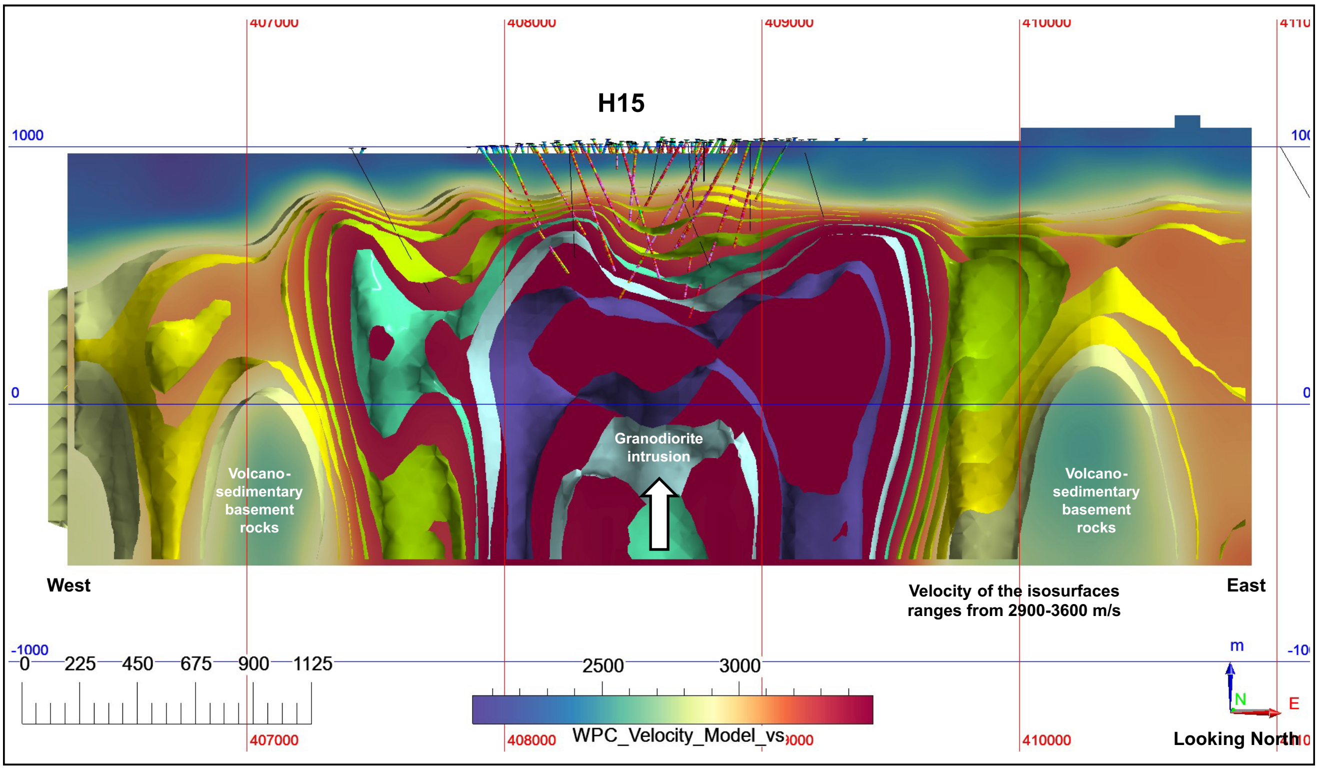

Figure 5 - Cross section (3223000 N) view of the WPC Velocity Model; looking N. The high-resolution WPC Velocity Model for H15 shows a central zone of very-high velocity (≥3300 m/s), surrounded by high velocity margins (2900–3200 m/s), with intermediate velocity zones (≤ 2900 m/s) forming the outer boundary. Drill hole traces show copper mineralisation (red and magenta indicate high grades).

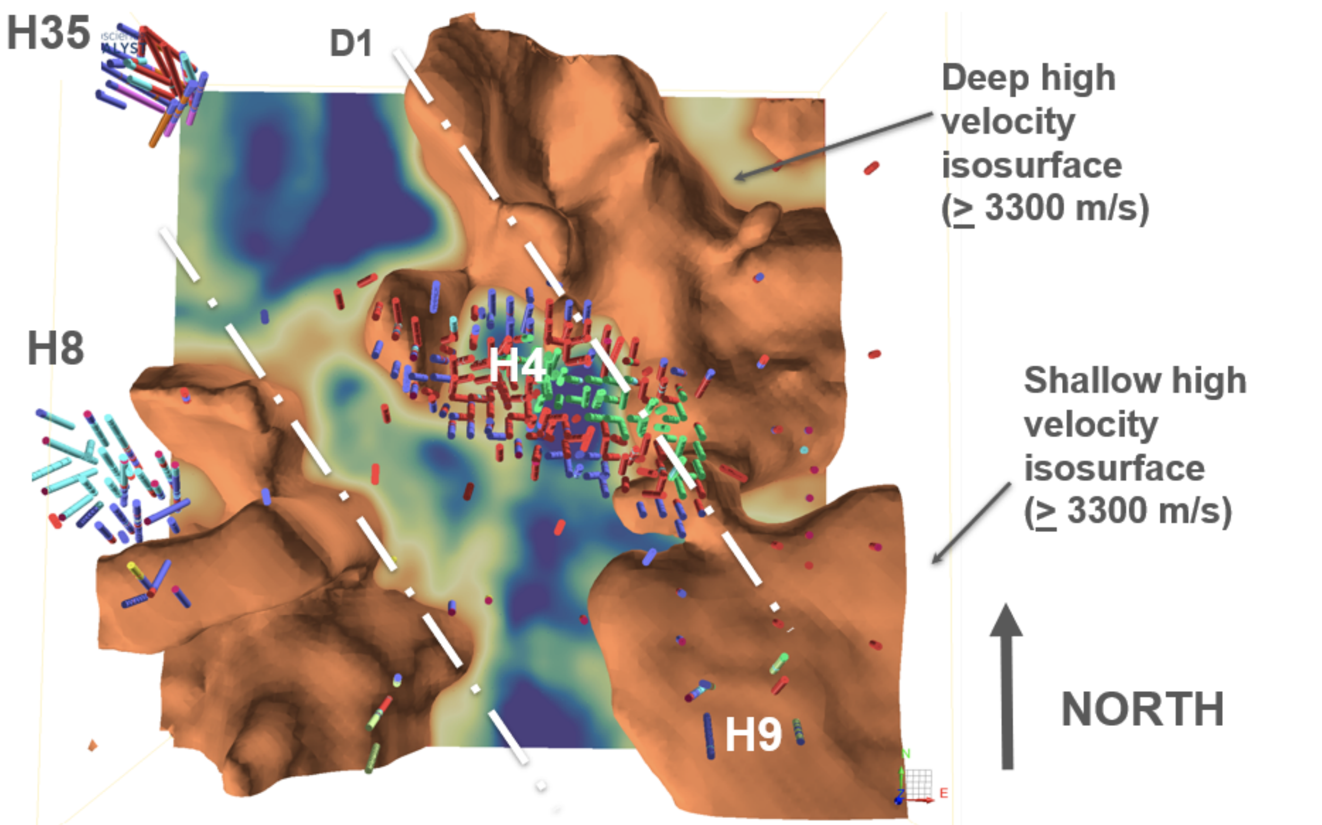

Figure 6 - Plan view of the Tanjeel Velocity Model showing the shallow supergene Tanjeel (H4) deposit within a D1 structural zone (NW-trending) that overlies a deep, high velocity zone (≥ 3300 m/s). A shallower high velocity zone is located beneath the neighbouring H9 porphyry intrusion, and a similar zone bounds the nearby H8 porphyry intrusion.

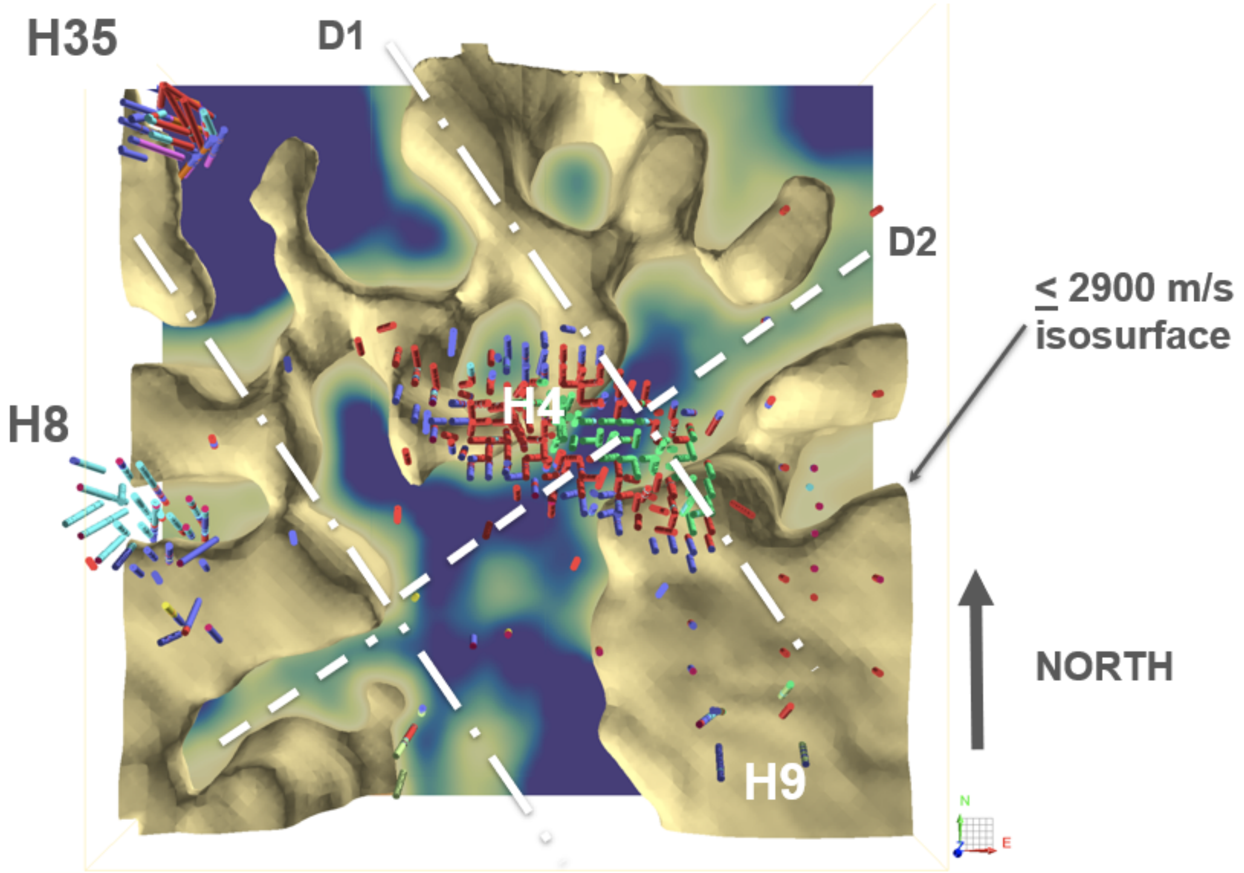

Figure 7 - Plan view of the Tanjeel Velocity Model showing the complex distribution of intermediate velocity zones (≤ 2900 m/s) beneath the Tanjeel (H4) deposit. D1 (NW-trending) and D2 (NNE-trending) structural zones are interpreted.

KEY FINDINGS

The ANT survey conducted by Fleet for RDMC at the Reko Diq Project successfully produced detailed 3D subsurface velocity models of the porphyry complex. Deployment of the Geode sensor network was efficiently supported by the nearby project camp and the assistance of the RDMC field team. The survey met its key technical objectives, including the identification of the major D1 and D2 structural trends and the detection of potential hypogene feeders linked to mineralisation.

The key findings of the ANT surveys include:

- Identification of Key Geological Structures: The velocity models clearly delineated the regional D1 and D2 structures, providing valuable information for understanding the structural framework controlling mineralisation.
- Potential Alteration Zones: Anomalous velocity zones identified in the models correlate with potential alteration haloes surrounding the targeted porphyry systems.
- Delineation of High-Velocity Zones: High-velocity zones within the models correspond to known porphyry targets, and may indicate the presence of hypogene feeders, providing a geophysical signature for potentially mineralised zones.
- Estimation of Underlying Batholith Depth: The regional velocity model provided an estimation of the depth to the underlying batholith, a critical factor in understanding the magmatic evolution of the porphyry complex.
- Identification of Structural Lineaments: Lineaments observed in the velocity models may represent fault zones or other structural discontinuities that could have influenced fluid flow and mineralisation.

The detailed subsurface velocity models generated through this ANT survey provide a valuable dataset for RDMC in their ongoing exploration and development of the world-class Reko Diq copper-gold porphyry project.

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