# Multi-Variable Analysis For Fault Identification And Hydraulic Characterization

Manuel Gutierrez[1], Laura Tapias[2]

[1]*Itasca Chile, Providencia, Santiago, Chile. manuel.gutierrez@oneitasca.com*

[2]*Itasca Chile, Providencia, Santiago, Chile. laura.tapias@oneitasca.com*

**Abstract**

Fractured aquifers, especially those containing faults, pose significant challenges in hydrogeological studies. This study investigates a tailing storage facility overlying a fault system potentially acting as a preferential flow path. A comprehensive review of existing geological, hydrochemical, geophysical, and piezometric data, collected over several years, was conducted to identify the presence of a potential fault. Results indicate distinct geological units on either side of the fault, confirmed by both geological models and geophysics. Hydrochemical and piezometric data suggest the fault acts as a barrier to regional groundwater flow. This multi-variable approach demonstrates the value of integrating diverse datasets for fault identification and characterization, informing risk assessments and mitigation strategies.

**Keywords:** Fractured Aquifers, Field Data, Geophysics, Tailings.

## Introduction

Fractured rock aquifers represent complex hydrogeological systems where groundwater flow is predominantly governed by the intricate network of fractures and faults (Beale & Read 2013). A thorough understanding of the geometry and hydraulic properties of these features is essential for effective groundwater management, particularly when considering potential contamination from sources such as tailings storage facilities (TSFs).

Faults, depending on factors like their internal structure, the degree of fracturing, and the surrounding stress field, can function as either conduit for preferential groundwater flow or barriers to groundwater movement. In the present study, a TSF located above a suspected fault system raises concerns regarding potential preferential flow paths for infiltration.

While regional geological maps may indicate the presence of faults, detailed characterization of these features is often lacking. This paper addresses this gap by presenting a multi-variable approach. This approach integrates diverse datasets collected over several years to identify, characterize, and ultimately understand the hydraulic role of the fault system situated beneath the TSF.

## The Challenge of Fault Characterization in Hydrogeology

Characterizing faults within hydrogeological investigations presents a multitude of challenges. Traditional methods, while valuable, often fall short in providing the comprehensive understanding needed for effective groundwater management. Geological mapping and core drilling, for example, offer valuable insights into fault locations and lithological characteristics, but these methods are often limited in their spatial extent and can be prohibitively expensive, especially when investigating deep or complex fault zones. As described by Fetter (2001), spatial variability of hydraulic conductivity in fractured rock is difficult to characterize This limitation becomes particularly acute when dealing with faults, which can exhibit significant variations in hydraulic properties along their strike and dip.

Furthermore, these traditional methods may not adequately capture the complex three-dimensional geometry of fault systems. Faults rarely exist as simple, planar features; they are often comprised of multiple interconnected fractures, brecciated zones, and gouge material, creating intricate pathways for groundwater flow. The geometry of fractures is highly variable and complex, making it difficult to describe mathematically (Freeze and Cherry 1979). This complexity makes it challenging to accurately represent faults in groundwater flow models (Fig 1), leading to uncertainty in predictions of groundwater flow paths and contaminant transport.

Moreover, these methods may struggle to fully characterize the hydraulic properties of faults, such as their transmissivity and storativity. These properties, which govern the rate and volume of groundwater flow through the fault zone, are crucial for assessing the potential for contaminant migration.

The lack of detailed information regarding fault geometry and hydraulic properties creates significant uncertainty in groundwater flow models (Fig. 2). This uncertainty makes it difficult to accurately assess the potential for contaminant migration along faults, particularly in situations like the present study where a TSF is situated above a suspected fault system. To address these challenges, this study adopts a multi-faceted approach, integrating multiple data sources. These include geological data from existing maps and reports, water level and piezometric data from monitoring wells, hydrochemical data to identify potential flow paths and mixing zones, and geophysical data, such as seismic surveys and electrical resistivity tomography, to provide insights into the subsurface structure and geometry of the fault system. By integrating these diverse datasets, the study aims to provide a more comprehensive and robust understanding of the fault system beneath the TSF, ultimately improving the assessment of potential risks and informing effective groundwater management strategies.

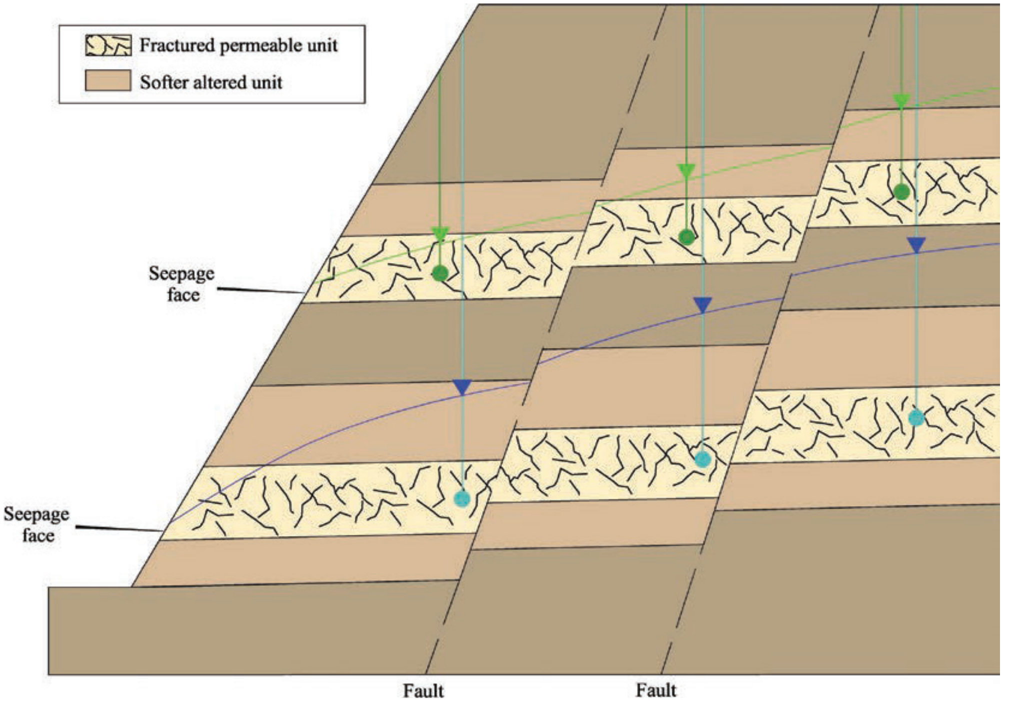


*Figure 1 llustration of vertical and lateral compartmentalization due to faults and bedding planes (Beale & Read 2013).*

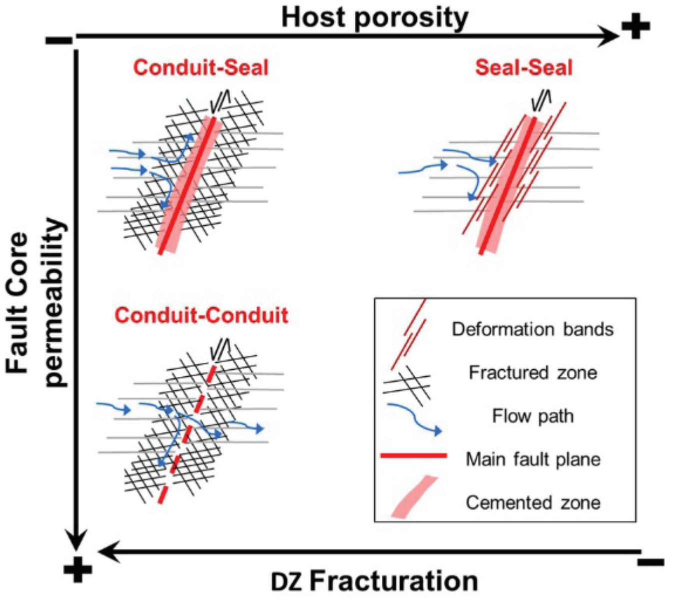


*Figure 2 Classification of main conceptual models for fault zone's representation (Rohmer et al. 2015).*

## Multi-Variable Approach and Data Integration

This study involved a comprehensive review of existing data collected over several years with varying objectives. The review process focused on identifying relevant and high-quality data for fault characterization. The following datasets were integrated:

- Geological Characterization: Data from geological mapping, drill core logs, and surface exposures were used to identify different geological units and their spatial relationships. This information was crucial for determining the fault's geometry and identifying the materials juxtaposed across the fault plane.
- Water Levels and Piezometry: Water level data from monitoring wells and piezometers provided insights into the groundwater flow patterns and hydraulic head distribution in the area. This information was used to assess the potential for the fault to act as a barrier to groundwater flow.
- Hydrochemistry: Hydrochemical data, including major ion concentrations and isotopic signatures, were used to identify distinct groundwater sources and flow paths. Differences in water chemistry across the fault could indicate hydraulic isolation.
- Geophysics: Geophysical data, such as seismic surveys or electrical resistivity tomography, can provide information about subsurface structures, including faults. These data were used to map the location and extent of the fault system.

## Results and Discussion

The integration of these diverse datasets yielded valuable insights into the fault system.

- Fault Geometry: The combined geological (Fig. 3) and geophysical (Fig. 4) data allowed for the delineation of the fault's geometry The presence of distinct geological units on either side of the fault, identified in both geological models and geophysical surveys, provided clear evidence of fault displacement.
- Hydraulic Barrier: Analysis of water level and piezometric data revealed a significant difference in hydraulic head across the fault (Fig. 3), suggesting that the fault acts as a barrier to regional groundwater flow. This interpretation was supported by hydrochemical data (Fig. 4), which showed distinct water chemistry signatures on either side of

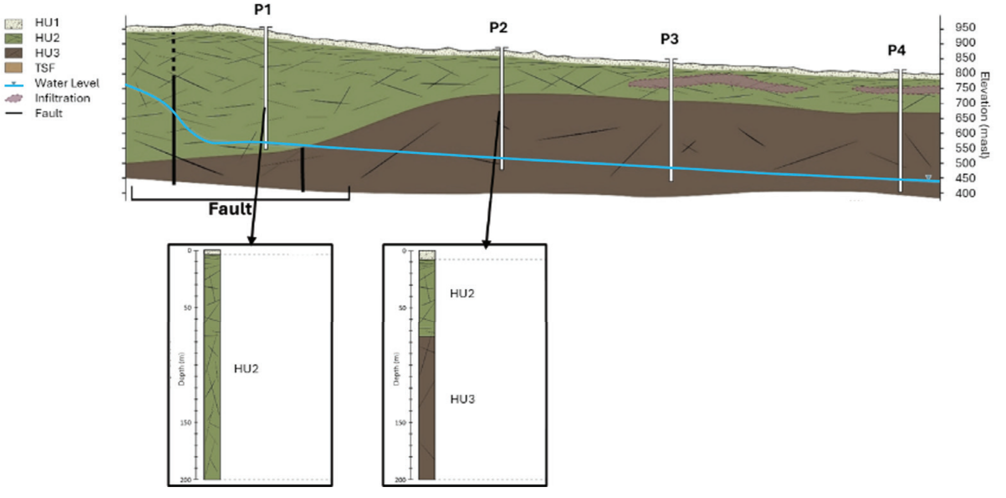


*Figure 3* Geological interpretation.

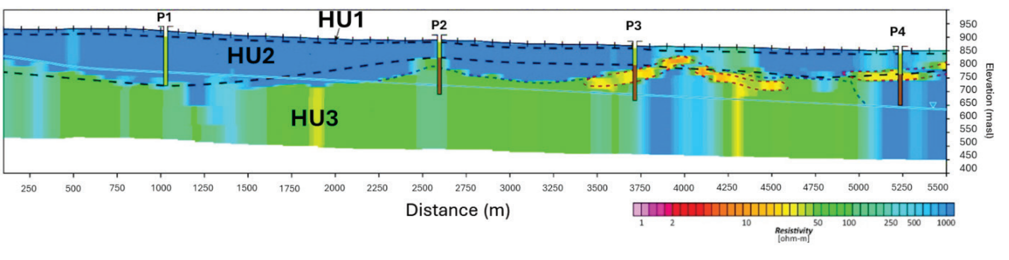


*Figure 4* Geophysical survey.

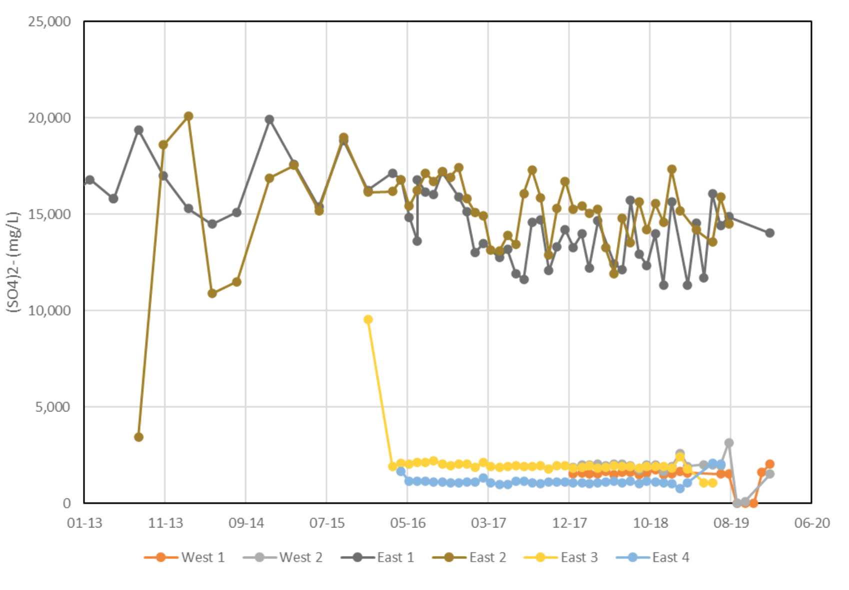


*Figure 5* Sulfate concentrations in east and west bores.

the fault, indicating limited groundwater mixing. These findings suggest that the fault may be impeding groundwater flow and potentially influencing the migration of infiltration from the TSF.

## Implications for Risk Assessment and Mitigation:

The detailed characterization of the fault system has important implications for risk assessment and mitigation related to the TSF. Understanding the fault's geometry and hydraulic properties allows for a more accurate assessment of the potential for contaminant migration along the fault. The finding that the fault acts as a hydraulic barrier suggests that infiltration from the TSF may be preferentially channelled along the fault zone, potentially affecting specific areas. This information can be used to inform the design and placement of monitoring wells and to develop targeted mitigation strategies to prevent groundwater contamination.

## Conclusions

This study demonstrates the value of a multi-variable approach for characterizing complex hydrogeological systems, particularly in the presence of faults. By integrating diverse data sources, this work has provided valuable insights into the geometry and hydraulic properties of a fault system beneath a TSF. The findings highlight the importance of considering fault structures in groundwater flow models and risk assessments related to potential contamination. The results of this study can inform current and future management strategies for the TSF and contribute to the protection of groundwater resources. Further research could explore the use of numerical modelling to simulate groundwater flow and contaminant transport along the characterized fault system.

## References


Barnett *et al.* (2012). Australian groundwater modelling guidelines, Waterlines report, National Water Commission, Canberra.

Beale, G., Read, J. (2013) Guidelines for evaluating water in pit slope stability. CSIRO Publishing, Collingwood.

Fetter, C.W. (2001). Applied Hydrogeology. 4th Edition. Prentice-Hall Inc.

Freeze, R.A. and Cherry, J.A. (1979) Groundwater. Prentice-Hall Inc., Englewood Cliffs, Vol. 7632, 604.

Rohmer, Jérémy & Nguyen, Trung-Kien & Torabi, Anita. (2015). Off-fault shear failure potential enhanced by high-stiff/low-permeable damage zone during fluid injection in porous reservoirs. Geophysical Journal International. 202. 10.1093/gji/ggv225.