



Landslide evaluation applying electrical tomography techniques: case study San José de Aloburo, Pimampiro, Imbabura

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Abstract. Landslides are a significant hazard in mountainous regions, particularly in the Ecuadorian Andes. This study investigates the internal dynamics of a complex rotational landslide in San José de Aloburo, Imbabura Province, using an integrated approach of Electrical Resistivity Tomography (ERT) and geological analysis. Four ERT profiles were acquired across the landslide, reaching depths of up to 40 m, revealing low-resistivity zones (4-45 Ω m). These zones correlate with saturated, poorly consolidated materials and identify potential rupture surfaces. The integration of ERT data with stratigraphic columns and granulometric analysis demonstrates that the landslide instability is driven by a combination of high water content and weak, fine-grained deposits. The findings highlight the effectiveness of this low-cost, multi-method approach for characterizing landslide geometry and assessing failure mechanisms, providing a valuable framework for hazard assessment in similar contexts.

Keywords: Electrical resistivity tomography, Landslide, Geophysical methods.

1 Introduction

The evolution of landforms has been studied through classical theories, such as Davis (1899)'s geographical cycle, Penck (1924)'s slope evolution, and King (1962)'s pediplane model, each of which has emphasized different geomorphic processes. Currently, human activity plays a role so significant in shaping the land surface that it is equated with natural processes (Huggett and Shuttleworth, 2022; Cendrero et al., 2022), an impact known as the human geomorphic footprint. Rivas et al. (2006) highlight this anthropogenic influence on landform transformation, especially in active orogenic belts like the Andes, where it creates steep, unstable slopes that are particularly susceptible to gravitational processes, including landslides (Carrasco et al., 2011; Corominas, 2004).

Over time, landslides contribute significantly to the evolution of landscapes and the transport of sediment from hillslopes to river systems, especially in mountainous regions (Huggett and Shuttleworth, 2022). Among these processes, landslides are key agents of morphological change and pose a major geohazard in populated areas. In Ecuador, the Andean region has a



combination of steep slopes, seasons of high rainfall (García and Carvajal, 2017), and unstable surface geological formations (Egüez et al., 2017). Many of these movements occur in rural areas where urban and agricultural expansion is not always accompanied by adequate assessment.

25 The surface observation alone is often not sufficient to identify underground slip surfaces or water-saturated zones that compromise slope stability. In landslide bodies, key elements of the internal morphology, such as the rupture surface, the displaced mass, and the shear zone separating unstable and stable materials, are not directly observable at the surface and therefore require indirect investigation (Cruden & Varnes, 1996). For this purpose, geophysical tools help interpret the characteristics of the subsoil through the properties of its materials (Metternicht et al., 2005). Whiteley et al. (2019) emphasize the fundamental
30 relevance of these techniques in landslide monitoring, as they allow for the detection of subsurface variations that are key to understanding slope failure processes.

Advanced geophysical interpretation techniques, such as the intercept method and wavefront inversion, enable a reliable estimation of the depth of refractory horizons and contribute to a robust characterization of subsurface conditions in landslide studies (Metternicht et al., 2005). In this context, geophysical methods play a fundamental role in landslide monitoring by
35 revealing subsurface variations associated with hydrological conditions and soil and rock properties, which are critical for understanding slope failure mechanisms and their temporal evolution (Metternicht et al., 2005; Whiteley et al., 2019). Nevertheless, despite recent technological developments, the potential of hillslope geophysics in landslide research remains largely underutilized (Whiteley et al., 2019).

Within this geophysical framework, Electrical Resistivity Tomography (ERT) has been extensively applied in landslide
40 investigations due to its capability to delineate landslide geometry, internal configuration, and rupture surfaces (Drahor, 2006). The effectiveness of ERT lies in its ability to interpret subsurface material properties through contrasts in electrical resistivity, which are commonly observed in areas affected by slope instability (Estrada, 2015; Perrone et al., 2014). In addition, compared to intrusive techniques, ERT is characterized by its efficiency, relatively low cost, and ease of data acquisition, while enabling the identification of stratigraphic features, tectonic lineaments, and phreatic levels that may act as triggering factors for landslide
45 processes (Perrone et al., 2014).

Electrical Resistivity Tomography (ERT) is a non-invasive technique that allows the visualization of resistivity variations related to soil moisture, lithology, and structural characteristics (Loke, 2001). ERT is effective in identifying the subsoil morphology of a landslide, its configuration, and its rupture surface (Brunet et al., 2010). Its usefulness is due to its ability to interpret the properties of subsurface materials through variations in electrical resistivity, as unstable areas often show changes
50 in soil resistivity (Perrone et al., 2014). Based on these methodological advantages, ERT has been widely applied in landslide investigations under different geological settings.

Previous studies have demonstrated the applicability of electrical resistivity tomography (ERT) in landslide investigations, including the Doña Mercía landslide in Córdoba (Quintana, 2013) and the Toleo landslide in Oviedo (Pellicer, 2015), both located in Spain. In these case studies, ERT was effectively applied to delineate rupture surfaces, identify zones of internal
55 deformation, and detect areas with elevated water content. These results confirm the suitability of ERT for characterizing the internal structure of landslides and for supporting their geological interpretation. Furthermore, granulometry helps to under-



stand particle size and the subsoil characteristics in order to correlate them with ERT and interpret their distribution in soils and sediments. This, in turn, controls properties such as porosity, permeability, and water retention, all of which are directly related to soil stability. Fine soils, such as silts and clays, have a greater water retention capacity and lower cohesion, making them more vulnerable to erosion, landslides, and piping processes, where groundwater carries away fine particles, forming channels that compromise stability (Brunet et al., 2010; Parker, 1964). The combination of traditional methods, such as sieving, with advanced technologies like ERT, enables the evaluation of granulometric variability and the identification of areas susceptible to erosion or mass movements. The integration of these analyses provides a comprehensive view of the dynamic processes that affect terrain stability and geological hazards management. (Carrasco et al., 2011; Whiteley et al., 2019).

The primary objective of this research was to evaluate the effectiveness of electrical resistivity tomography (ERT) in conjunction with surface geological analysis, utilizing the construction of stratigraphic columns, to determine the depth and extent of the displaced mass in the San José de Aloburo landslide, located in Pimampiro. This integrated approach aimed to enhance the characterization of the landslide by combining geophysical and geological techniques. Specifically, the study sought to: (i) identify the morphology (rupture plane) and physical characteristics of the displaced materials through ERT analysis; (ii) establish correlations between the apparent resistivity of the subsurface and the granulometric characteristics of the different strata; and (iii) determine a coherent stratigraphic sequence by correlating the ERT method with the stratigraphic columns.

2 Study area

The study area is located in San José de Aloburo, Pimampiro, Ecuador (Figure 1). The main landslide occurred between November 23 and 24, 2021, affecting an area of approximately 25.17 ha and causing serious economic and structural damage, including the destruction of 17 homes, 7 reservoirs, 5 greenhouses, and part of the main road. This event has been classified as a complex rotational landslide, in which the displaced material moved mainly in a NW–SE direction (Vázquez et al., 2021).

In order to fully understand the study area, various additional aspects were considered in Figure 2. From a geological point of view, the area is characterized by volcanic deposits associated with the Angochagua Formation of Quaternary age, consisting of a succession of volcanic deposits mainly andesites, that form tuff, pumice, breccias, and conglomerates of Pliocene age (Egüez et al., 2017; Gobierno Autónomo Descentralizado Municipal San José de Pimampiro (GAD Pimampiro), 2014). Using the classification proposed by Aramburo for the MDT area, the slope in the landslide zone varies between 25° and 35°, which increases susceptibility to mass movements when combined with high rainfall. The climatic conditions correspond to a temperate humid regime, with annual precipitation between 500 and 750 mm (Gobierno Autónomo Descentralizado Municipal San José De Pimampiro (GAD Pimampiro), 2014; García & Carvajal, 2017), especially during the periods of highest precipitation from April to May and October to December (Instituto Nacional de Meteorología e Hidrología de Ecuador (INAMI), 2025), which directly influences the saturation and instability of the slopes.

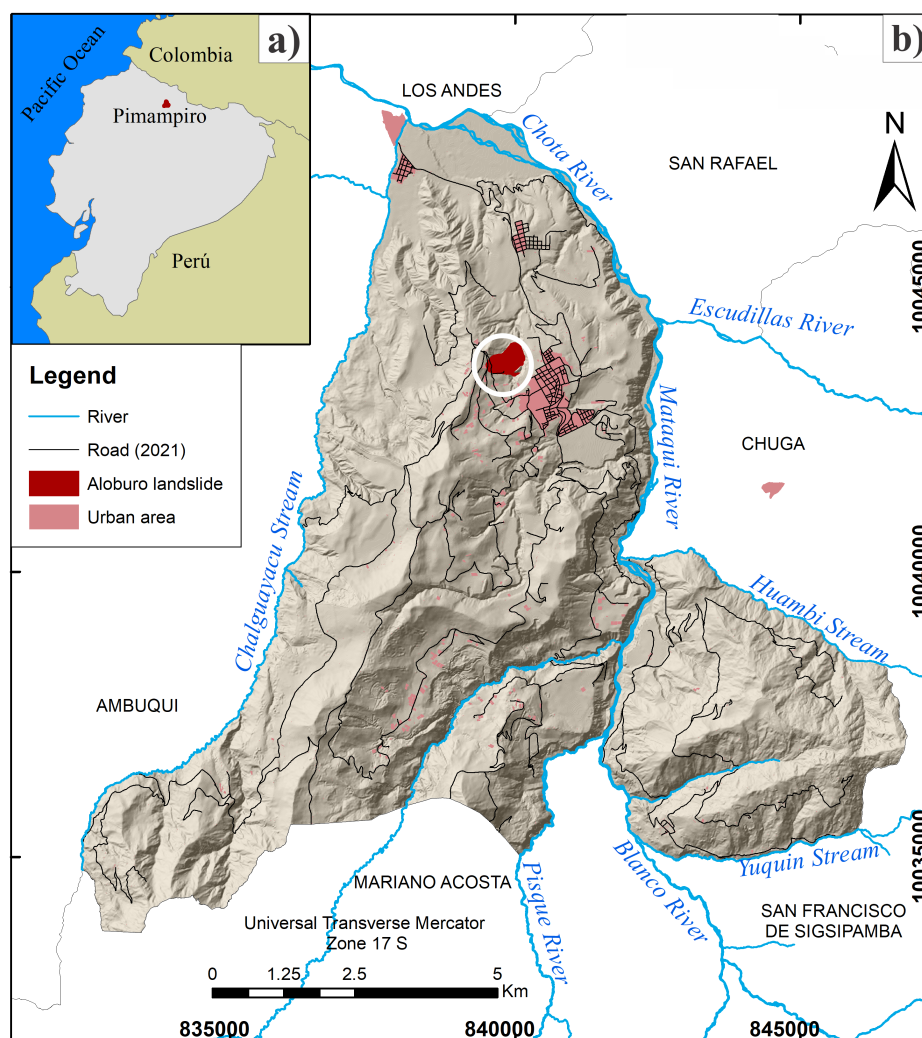


Figure 1. Location map of Pimampiro parish. (a) Ecuador country in northwestern South America, bordered by Colombia on the north, Peru on the east and south, and the Pacific Ocean on the west. (b) Map with the physical boundaries of the parish, including rivers and streams, as well as the adjoining parishes that are the political boundary. The location of the San José de Aloburo landslide is circled in red.

The study area is located within the Mira River basin and the Chota sub-basin, covering 1,867 km², with altitudes ranging from 1,670 to 4,180 meters above sea level and an average flow of 54.56 m³/s (García and Carvajal, 2017). In this area, the so-called disappearance points generate aquifers, constituting a key factor in the geological and hydrological dynamics of the area (Gobierno Autónomo Descentralizado Provincial de Imbabura (GAD Imbabura), 2017; Highland and Bobrowsky, 2008).

Human activities can significantly increase vulnerability to landslides by modifying slope conditions and triggering instability processes (Highland and Bobrowsky, 2008; Corominas, 2004). In the zone, this is mainly reflected in agriculture, considered the predominant economic activity, with permanent crops such as avocado, tomato, blackberry, and tree tomato, irrigated by

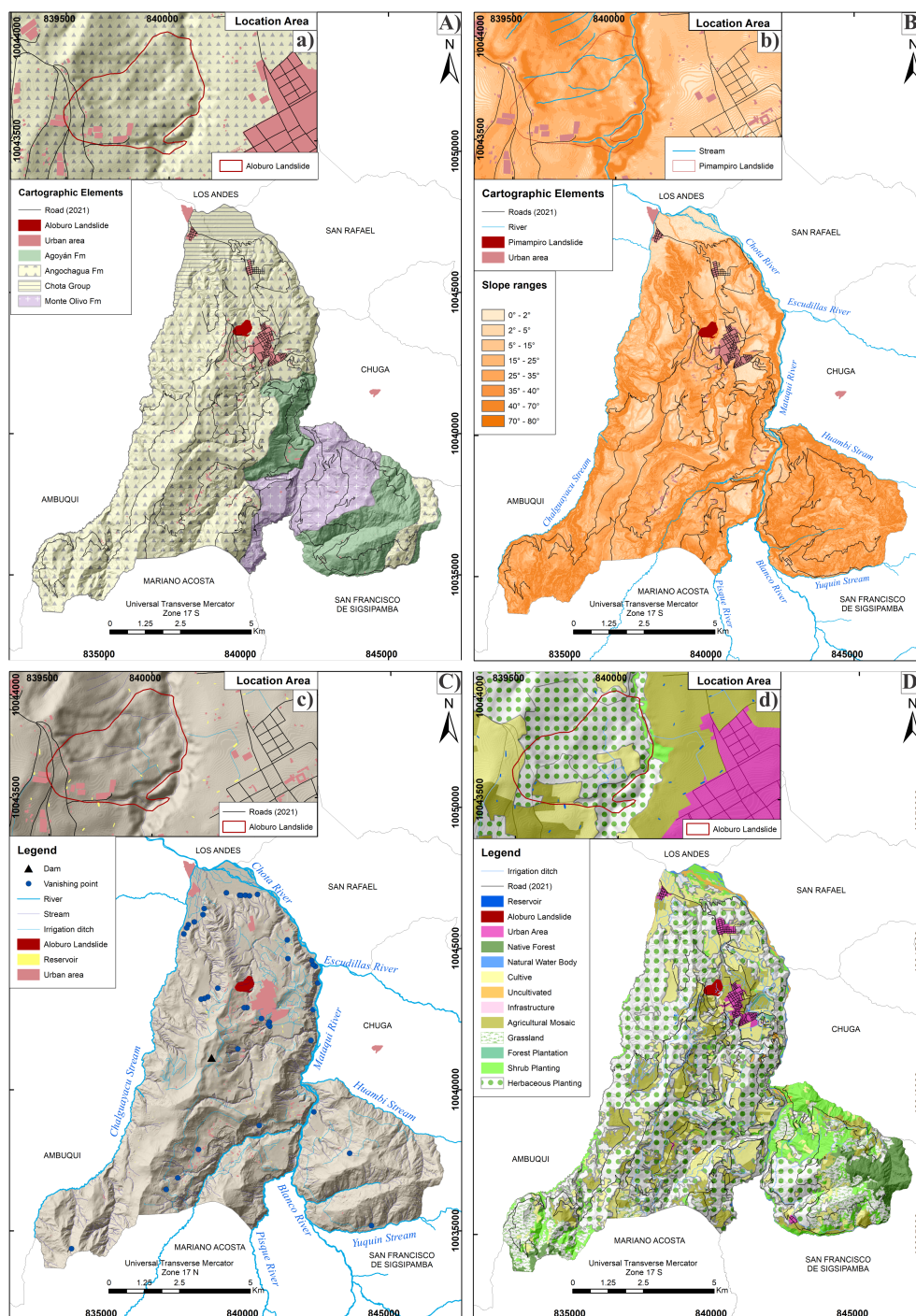


Figure 2. Contextualized cartography of the Pimampiro canton. Capital letters correspond to the parish scale and lowercase letters to the landslide area; (A,a) Modified geological map by Egúez et al. (2017), showing the presence of the Angochagua Formation. (B,b) Classification of slopes according to Aramburo and Escribano (2014). (C,c) Distribution of water bodies based on IGM (2017). (D,d) Anthropogenic activities and land use according to Prefectura de Imbabura (2014)



canals and reservoirs using the flooding technique, many of which lack lining and are in direct contact with the soil (Núñez, 2008; Ministerio de Agricultura, Ganadería, Acuacultura y Pesca (MAGAP), 2015; Mothes, 1987). The area affected by the landslide includes two roads that are important for local residents: one connecting Pimampiro with Mariano Acosta, which has now been reopened, and another that was severely damaged by the 2021 event (Gobierno Autónomo Descentralizado Municipal San José de Pimampiro (GAD Pimampiro), 2014).

3 Data and Methodology

This study employs ERT on the Aloburo landslide, utilizing a workflow that included contextualization of the study area and division of tasks into geophysical and geological components. The geophysical phase consisted of planning, equipment management, data collection, and processing of ERT profiles, while the geological phase involved fieldwork and sample processing. Both aspects were subsequently integrated to produce the final results.

3.1 Geophysical work

3.1.1 Profile planning

Four ERT profiles were planned at the top of the landslide following standard ERT acquisition and inversion principles (Loke, 2001). The first three profiles were planned to measure 250 m in length, and the fourth 210 m, with a separation between electrodes of 5 m; however, after the initial acquisition, Profile 2 and Profile 3 were extended to 270 m with an electrode spacing of 7.5 m. The first three profiles were arranged in parallel with a south-north orientation, while the fourth extended from east to west from the crown of the landslide. The Wenner array type was selected due to its strong signal response and effectiveness in detecting vertical resistivity variations, despite its limited sensitivity to lateral changes, as proposed by Aizebeokhai (2010). The number of points and estimated depth were determined using ZondRes2D software, and data collection was performed manually using field forms designed for each profile, as summarized in Table 1.

ERT	Longitude	Distance of electrodes	# electrodes	# points taken	Direction and pourpuse
Profile 1	250m	5m	51	363	NW-SE, Upper middle part
Profile 2	270m	7.5 m	37	188	N-S, Tranverse to the rown of the zone
Profile 3	270m	7.5 m	37	188	NE-SW, outside the slide
Profile 4	210m	7.5 m	29	111	SW-NE, latitudinal

Table 1. Planning information for each of the lines that were worked in the upper part of the landslide.

To estimate the depth of the profiles in this investigation, the relationship between the length of the profile and the penetration depth described for Wenner arrays (Aizebeokhai, 2010) was considered. In this configuration, effective penetration usually represents a fraction of the total profile length, which is consistent with the dimensions of our lines, which are 250, 270, and 210 m. Given that the final distances between electrodes reached 55 m in Profile 1, 60 m in Profiles 2 and 3, and 37.5 m in



Profile 4, we verified the effective depth using sensitivity analysis performed in ZondRes2D. This evaluation confirmed that the resistivity contrasts remained reliable up to about forty meters, which is consistent with the expected behavior of Wenner arrays.

3.1.2 Equipment

The equipment employed was a low-cost electrical profile tomograph developed at the School of Earth, Energy, and Environmental Sciences with the collaboration of School of Physical Sciences and Nanotechnology at Yachay Tech University (Figure 3). It consists of two cables of 100 m length, two cables of 50 m length, a 12 V battery, two multimeters, a current transformer, and stainless steel electrodes. The system works by converting 12 V direct current into 220 V alternating current to inject energy into the ground through electrodes A and B, while the multimeters record the current between electrodes A and B, and the voltage is measured through the potential electrodes (M and N). Although the separation between electrodes could not exceed 200 m, which restricted measurements at greater depths, this limitation was significantly reduced by using the Wenner configuration.

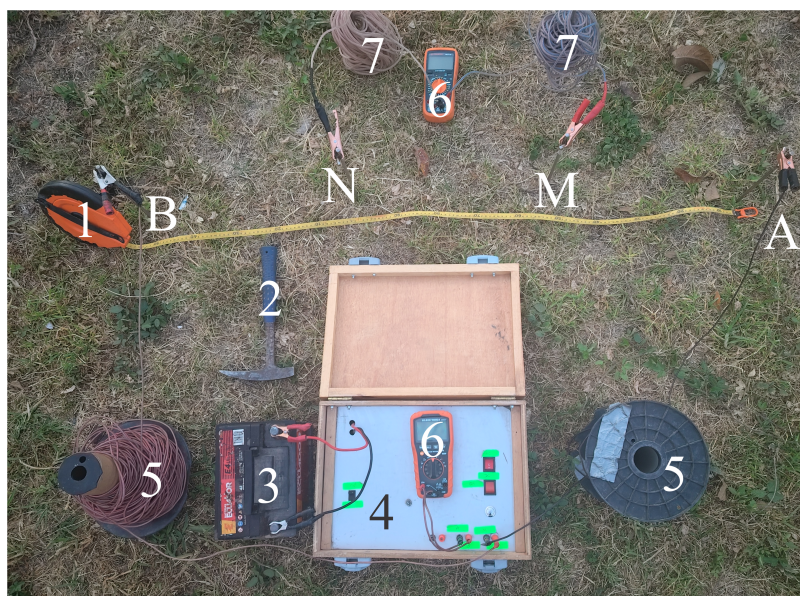


Figure 3. The equipment used to acquire the profiles consists of the following components, with electrodes A, B, M, and N: 1) a measuring tape for precise electrode positioning, 2) a hammer for securing the electrodes, 3) a battery, 4) a current transformer, 5) 100-meter wires, 6) multimeters, and 7) 50-meter wires.

3.1.3 Data collection

Four ERT profiles were obtained at the top of the landslide, strategically arranged according to the terrain morphology and mass movement, characteristics as described in the previous section. Their location and orientation are shown in Figure 4,



which provides a detailed cartographic representation of the study area and the distribution of the profiles. This spatial context was essential for guiding the fieldwork and subsequent interpretation of the data, ensuring consistency between the geological observations and the geophysical study.

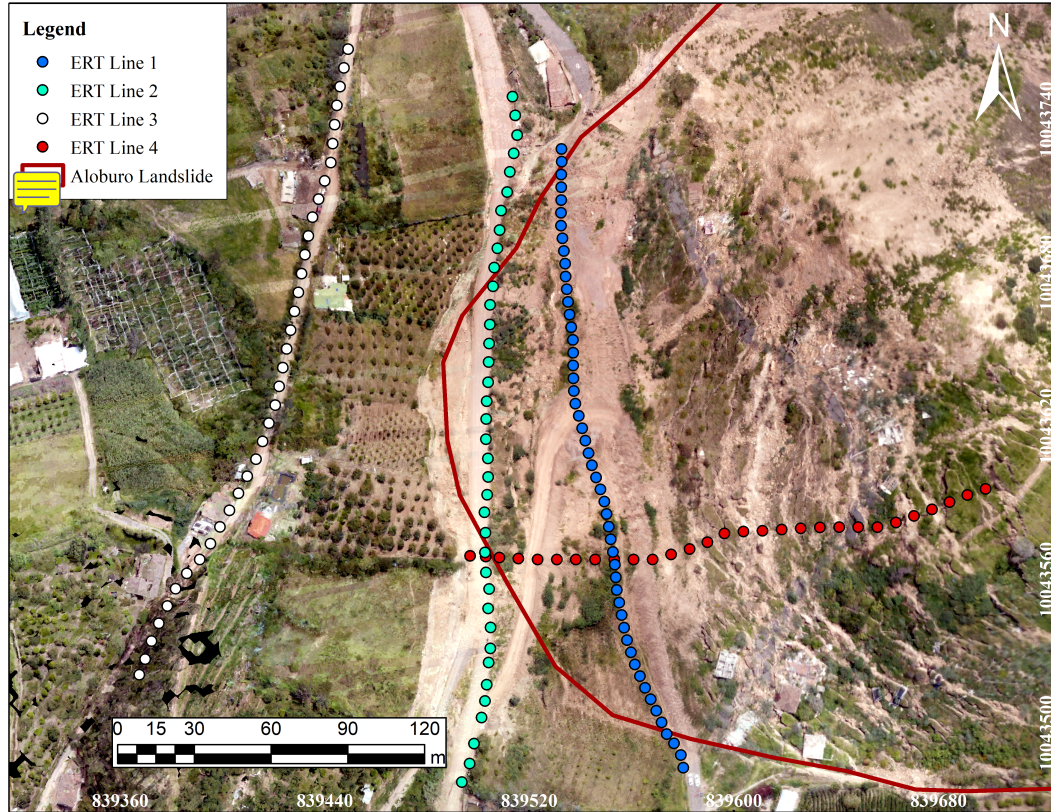


Figure 4. Location map of the four ERT profiles in the study area, San José de Aloburo, Imbabura. The profiles (labeled on the map) show the layout and arrangement of the electrodes used for the resistivity measurement in each section of the terrain. The map is based on a photograph of the landslide area, captured by drone in June 2023 (Collaboration of Freire, 2023).

3.1.4 Processing data

Data collected in the field were digitized in spreadsheets, where the distances between electrodes were calculated and, using the data obtained, the resistivity was determined using the Wenner matrix equation (Eq. 1):

$$\rho = 2\pi a \left(\frac{\Delta V}{I} \right) \quad (1)$$

Where ρ represents the apparent resistivity, a is the distance between electrodes, ΔV is the potential difference (voltage), and I is the current measured in the electrical field.



Subsequently, the start and end points of the four profiles were georeferenced and plotted in ArcMap, while in QGIS, using the Qchainage tool, representative points for each electrode were generated and interpolated with a digital terrain model (DTM) to obtain their elevation and reconstruct the topography of each profile.

145 Following the format recommended by Loke (2001), the files were prepared for the RES2DINV program. This software was used to evaluate the quality of the data, identify and correct noise that could affect the consistency of the results, reducing the error percentage after at least three iterations and incorporating the topography into the profiles (Aizebeokhai, 2010).

To accurately handle the inclined topography, the RES2DINV inversion process utilizes the Finite Element Method (FEM) instead of the standard Finite Difference Method, which is suitable only for flat surfaces. The FEM facilitates the generation of a distorted inversion mesh, composed of non-rectangular or non-triangular elements, in which the vertical coordinates (Z) of the underground nodes are adjusted to precisely match the measured surface slope. This geometric adaptation constitutes the topographic correction, enabling the software to accurately simulate the complex current flow and apparent resistivity distribution within a non-flat medium, thereby resolving the inherent limitations of standard half-space models (Seequent, 2023).

155 To integrate the four profiles into a three-dimensional model, the resistivity values were standardized in 16 intervals within a uniform color scale, allowing for direct comparison of the topographies and minimizing visual discrepancies. This process ensured a consistent and homogeneous representation, facilitating correlation between interpreted lithological boundaries and the subsurface structure within the landslide mass.

3.2 Geological campaign

160 3.2.1 Field work

For the geological characterization of the landslide area and reconstruction of the paleo-relief, three stratigraphic columns were made at key points: one in the eastern sector and two in the northern and southern, respectively (Figure 5). Geological campaigning were carried out on September 5, 2024. It was using a 50 m tape measure, a granulometric scale, and a field notebook. Samples were systematically collected where the grain size in the field was unclear, and these were labeled according to the Angochagua Formation (ANG-U-N-#), where “U” represents the part of the column (top or bottom), “N” the letter of the column from which it was taken, and “#” the sample number. In addition, the inclination of non-horizontal strata was measured with a compass to complement the structural characterization of the sequence.

According to the geological context of the area, there are volcanic deposits, and in order to correctly classify the granulometry of the columns, the classification of Gillespie and Styles (1999) was used, which presents a relationship between volcanic deposits and granulometric measurements. In this division, there are four volcanic deposits: fine ash, coarse ash, bombs, and lapilli. Although Column C was initially planned to be located at the southern limit of the landslide, the displacement of materials in that area forced it to be moved to a nearby stream, where the strata were better preserved. This adjustment ensured the reliability of the stratigraphic record and provided a solid basis for subsequent geological interpretations.



Figure 5. Schematic representation of the three sampling points of stratigraphic columns in the study area, San José de Aloburo, Imbabura. Points A, B and C (indicated on the map) correspond to the sites where the stratigraphic columns were carried out, in order to identify the order and characteristics of the geological strata in the area affected by the mass movement. This figure was generated using as base Google Earth imagery (Google, ©2025 CNES/Airbus, Maxar Technologies).

3.2.2 Samples processing

175 Due to difficulties in observing the grain size variation of some strata in the field, samples were taken and analyzed by sieving at the E2E3 laboratory at Yachay Tech (October 10). The samples was previously crushed in order to separate the sediments without significantly altering the grain size and then weighed on an analytical balance to obtain the total weight of each sample.

Seven filters arranged in descending order of aperture (MESH 10 to 230; 2 mm – 85 μ m) were used, applying vibration to separate the fractions. Each retained fraction was stored and recorded, also considering the loss of material during the process.

180 With these data, the retained, accumulated, and passing percentages were calculated, which allowed the construction of the granulometric curve and the classification of the material according to particle size analysis standards.



4 Results

The integration of electrical resistivity tomography with surface and stratigraphic field data provided a comprehensive framework for interpreting the physical characteristics and internal morphology of the Aloburo landslide. These results reveal key resistivity patterns and sedimentological characteristics that not only improve understanding of the displaced material but also offer a replicable methodology for similar contexts.

4.1 Geophysical outcomes

The results obtained using the ERT method (Figure 6) allowed the characterization of internal morphology of the San José de Aloburo landslide. Four profiles were created, the analysis of which revealed contrasts in resistivity directly related to the saturation of the materials and the consolidation of the subsoil. In general, low resistivity values (4-45 Ω m) were associated with saturated or fractured areas with lower cohesion, while high values (88-297 Ω m) represented more stable or consolidated materials. The average inversion error was 15.78%, which lends reliability to the results.

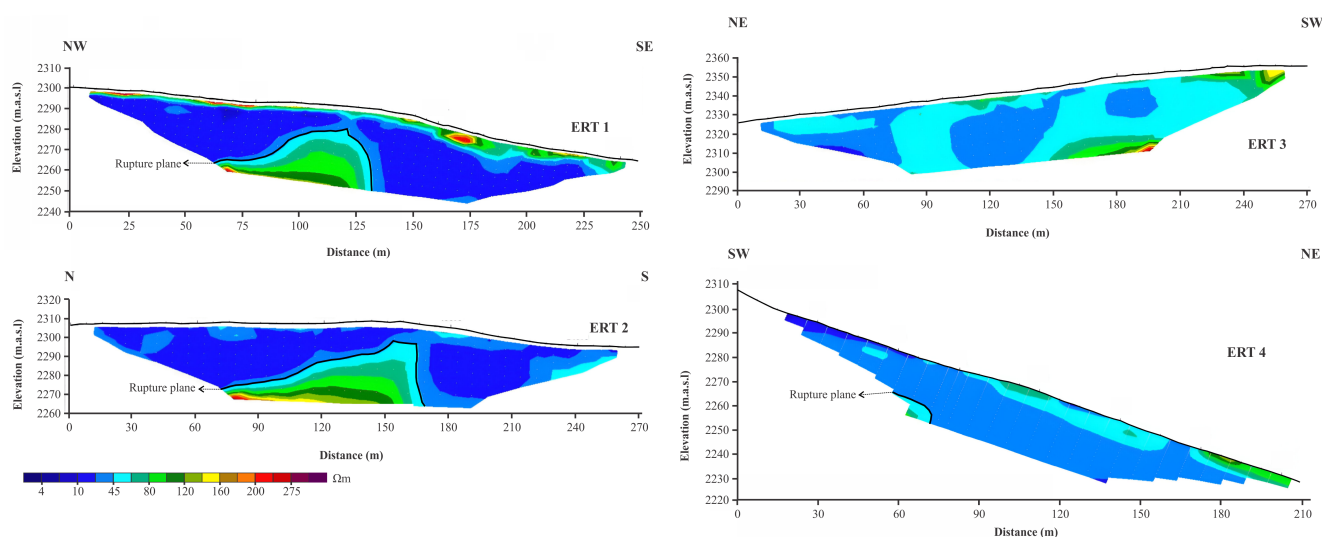


Figure 6. Electrical resistivity tomography (ERT) profiles. On the left, ERT 1 (top) with NW–SE orientation and ERT 2 (bottom) with N–S orientation, both showing the rupture surface. On the right, ERT 3 (top) with NE–SW orientation and ERT 4 (bottom) with SW–NE orientation, the latter highlighting the rupture surface at the bottom of the profile. In all cases, the elevation (m a.s.l.), the distance between electrodes (m), the standardized resistivity scale used in the study are represented and the location of which is shown in Figure 4.

Profiles 1 and 2, with depths of 40 m, showed clear transitions between fractured and more consolidated materials, allowing the approximate location of the rupture plane to be identified. In both cases, the low resistivity zones coincided with topographic depressions, reinforcing the hypothesis of water accumulation as a key factor in the instability of the terrain. The contrast in



the depth of the transitions reflects local differences in the morphology of the landslide, providing essential information on the internal dynamics of the movement with the rupture plane between 10 and 35 m deep

Profiles 3 and 4, on the other hand, showed complementary characteristics. Profile 3 reached a depth of 40 m and showed mainly saturated materials in the central part, while more consolidated and resistant layers appeared at the ends. Profile 4, with a penetration of 35 m, showed marked heterogeneous unstable areas near the landslide escarpment with low resistivity values and more stable sectors towards the center and lower end. Taken together, the four profiles confirmed that water accumulation and lithological variability are the main factors controlling slope stability.

4.1.1 3D Profile Compounding

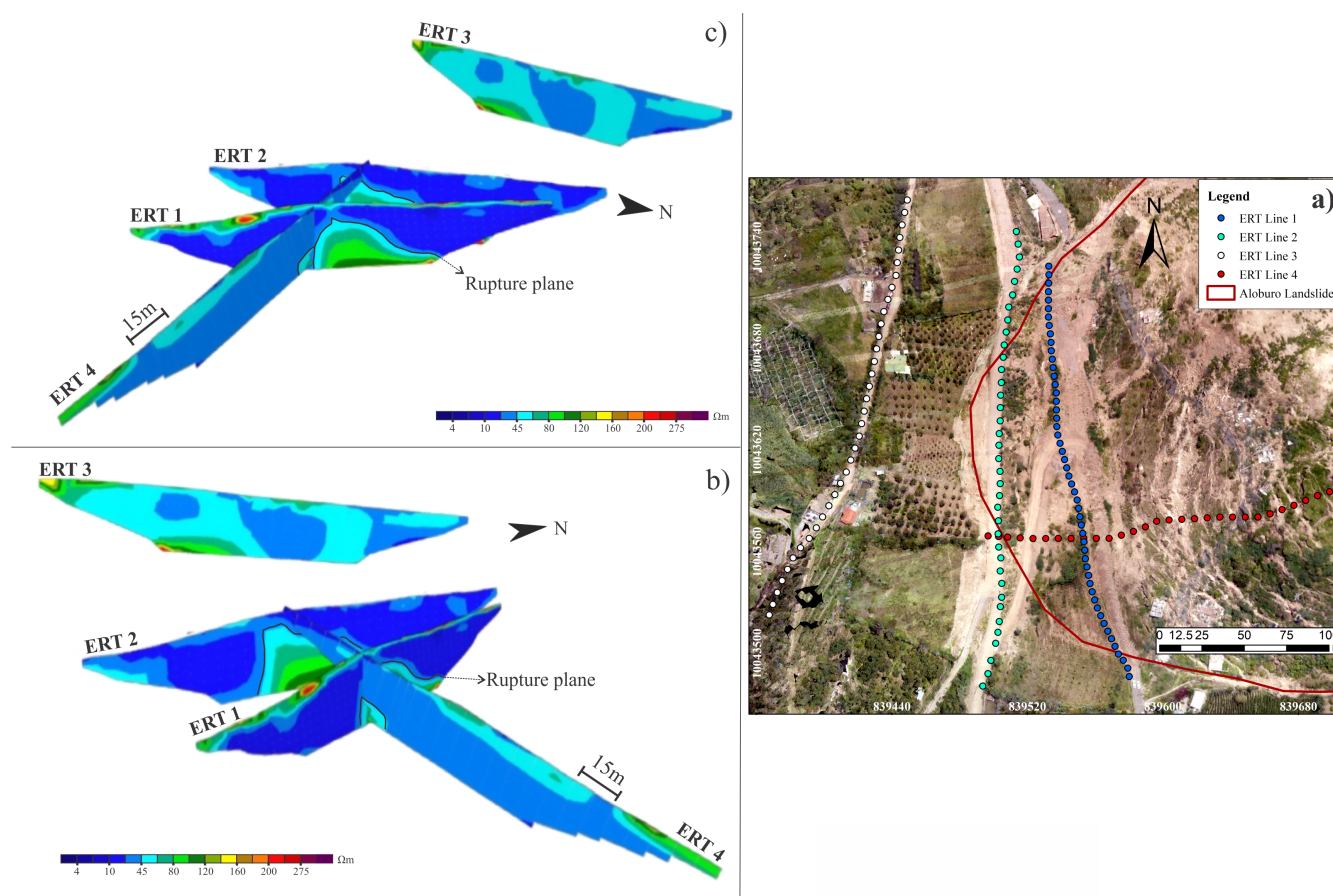


Figure 7. 3D composite view of the four electrical resistivity tomography profiles. a) Map of the location of the ERT profiles in an orthophoto taken of the Aloburo landslide in June 2023 (Collaboration of Freire, 2023), b) Composite view of the three-dimensional profiles in SE-NW direction showing in plane of rupture in the ERTs that are in the slip, c) Composite view of the three-dimensional profiles in NE-SW direction showing in plane of rupture in ERTs 1, 2 and 4.



A three-dimensional model was generated from the tomographic profiles obtained (Figure 7), which allowed the interpretation of the San José de Aloburo landslide, identifying the main subsurface characteristics. In this model, areas of high resistivity (reddish tones) correspond to more compact materials or those with lower moisture content, while areas of low resistivity (blue tones) reflect saturated or poorly consolidated materials; between the two, the colorimetric transition zones indicate the possible rupture zone. The 3D visualization facilitated the analysis of the continuity and spatial arrangement of the strata, highlighting areas with potential groundwater accumulation, factors that may have contributed to the instability of the slope.

4.2 Geological outcomes

The geological results included three stratigraphic columns and a grain size study, which clarified the distribution and behavior of the displaced materials.

4.2.1 Stratigraphic columns

In this investigation, three stratigraphic columns (A, B, and C) were developed to analyze the sequential arrangement of geological strata in the study area (Figure 5).

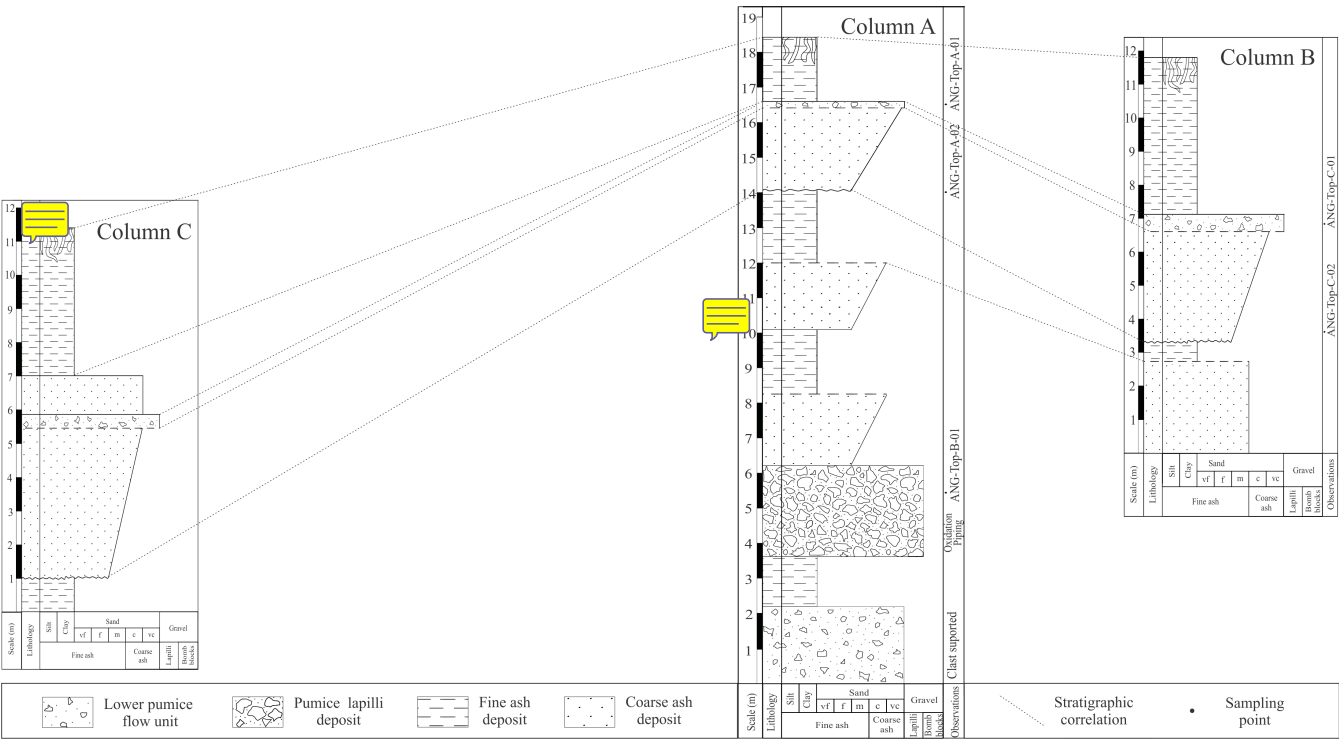


Figure 8. Stratigraphic correlation of columns A, B, and C at the edges of the San José de Aloburo landslide, showing the main strata identified and the sampling or observation points.



Column A, located in the western part of the Aloburo landslide, shows deposits of pumice and ash of different grain sizes deposited rhythmically, with layers of pumiceous lapilli with high permeability and water retention capacity, as well as fine units that act as barriers to water flow. These characteristics allow the interpretation of the depositional history and help to understand instability factors associated with material saturation in the study area and its relationship with the presence of rupture planes.

Column B, located on the northern flank, comprises five depositional levels similar to those observed in Column A, reinforcing the interpretation of shared eruptive processes in the area. Sequences of fine ash with a fining-upward trend and pumice deposits with graded bedding are identified, associated with higher-energy depositional conditions. The uppermost deposit corresponds to a layer of fine ash covered by vegetation, suggesting low-energy conditions and progressive accumulation.

Column C, located to the south and outside the landslide area, complements the analysis by showing greater thicknesses in some units observed in column B, as well as presenting a layer of coarse ash absent in the other columns. The correlation between the three columns shows the stratification of the Angochagua Formation, reflecting the dynamics of volcanic events and variations in paleotopographic relief. These differences in layer thickness and inclination are key to understanding the evolution of the terrain and assessing the stability of the slope in the affected area.

4.2.2 Granulometry

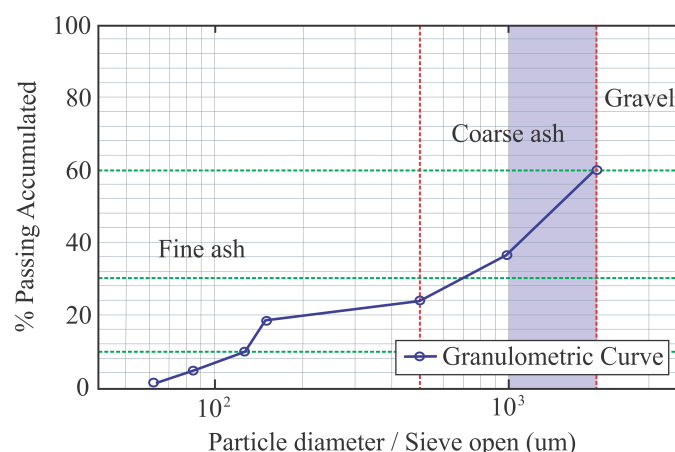


Figure 9. Particle size distribution curve of the ANG-Top-B-01 sample where the particle diameter is contrasted with the percentage of passing accumulated. The table was divided with red lines to delimit the zones between fine ash, coarse ash and gravel.

Sample ANG-TOP-B-01 was the only sample for which grain size could not be clearly identified either in the field or in the laboratory. This sample was collected from the base of the first stratigraphic column and subjected to granulometric analysis by sieving, with an initial weight of 396.19 g, of which 1.35% was lost during the process. The results indicate that most of the material was retained in the 2 mm (40.28%) and 1 mm (23.34%) sieves, evidencing a predominance of coarse particles. As



235 sieve aperture decreased, the retained percentage progressively diminished and the cumulative passing percentage increased, with only a small fraction (1.36%) passing through the finest sieve (85 μm), reflecting the scarcity of very fine particles.

The resulting grain size curve confirms that the material is predominantly composed of coarse particles, with a low proportion of fine fractions, indicating high permeability and low cohesion. This behavior is consistent with the evidence of piping observed in the field within this stratum. According to the volcanic deposit classification proposed by Gillespie and Styles
240 (1999), the material corresponds to a coarse-grained volcanoclastic deposit composed mainly of lapilli with an ash matrix. This granulometric distribution promotes efficient drainage and, when considered in relation to the surrounding strata of column A, contributes to slope instability by facilitating water movement over underlying less permeable layers, thereby increasing the likelihood of differential settlement or localized collapse within the analyzed unit.

5 Discussion

245 The San José de Aloburo landslide exhibits particular characteristics that favored the integration of stratigraphic profiles and electrical resistivity tomography (ERT). It has been classified as a complex landslide by Vázquez et al. (2021), characterized by a rotational component in the upper sector and a partial flow in the lower zone. The moderate moisture content of the displaced materials allowed clear resistivity contrasts to be obtained, facilitating the identification of stratigraphic boundaries and the rupture zone. Furthermore, the limited presence of flow-like materials reduced signal interference, enabling a more reliable
250 interpretation of the internal structure and movement dynamics of the landslide.

ERT was conducted using low-cost equipment and a Wenner configuration, which is well suited for detecting vertical variations in resistivity and subsoil discontinuities. This electrode arrangement proved effective in identifying saturated soils and fissured zones, achieving penetration depths between 35 and 40 m, depending on profile geometry. Although the Wenner array has limited sensitivity to lateral resistivity variations, it was appropriate for this study due to its adequate resolution and its
255 capacity to delineate critical zones within the landslide body.

The ERT results clearly delineated the rupture zones within the landslide area. In profiles 1 and 2, these zones were identified at depths between 10 and 35 m, whereas in profile 4 they appeared at a shallower depth, around 20 m. In contrast, profile 3, located outside the displaced area, preserved the original stratigraphic arrangement, providing key reference information on pre-failure resistivity conditions and allowing comparison with the changes induced by material fracturing during the landslide.

260 ERT complemented the information obtained from stratigraphic profiles and granulometric analyses by enabling the assessment of the lateral continuity of subsurface materials. This integrated approach facilitated the identification of near-surface pumice deposits, zones of water accumulation, and fractured areas that may evolve into future rupture zones. Its capacity to detect morphological discontinuities and variations in material cohesion highlights ERT as a key tool for the characterization and monitoring of unstable slopes.

265 The correlation between the stratigraphic columns and the electrical resistivity profiles revealed a direct relationship between high resistivity values and compact, coarse-grained strata, as well as between low resistivity values and loose or saturated



sediments. This relationship highlights how the physical properties of the strata influence slope instability and reinforces the importance of integrating geological and geophysical methods in the analysis of mass movements.

The strata exhibiting an upward increase in grain size identified in the stratigraphic columns are not attributed to primary ash-fall deposition, but rather to secondary processes related to material redistribution. This reorganization, characteristic of gravitational flows and paleo-landslides, is reflected in the accumulation of coarser particles at the upper parts of certain levels. Additional geomorphological evidence, such as scars and depressions, supports the interpretation that the area has been affected by recurrent landslide events in the past.

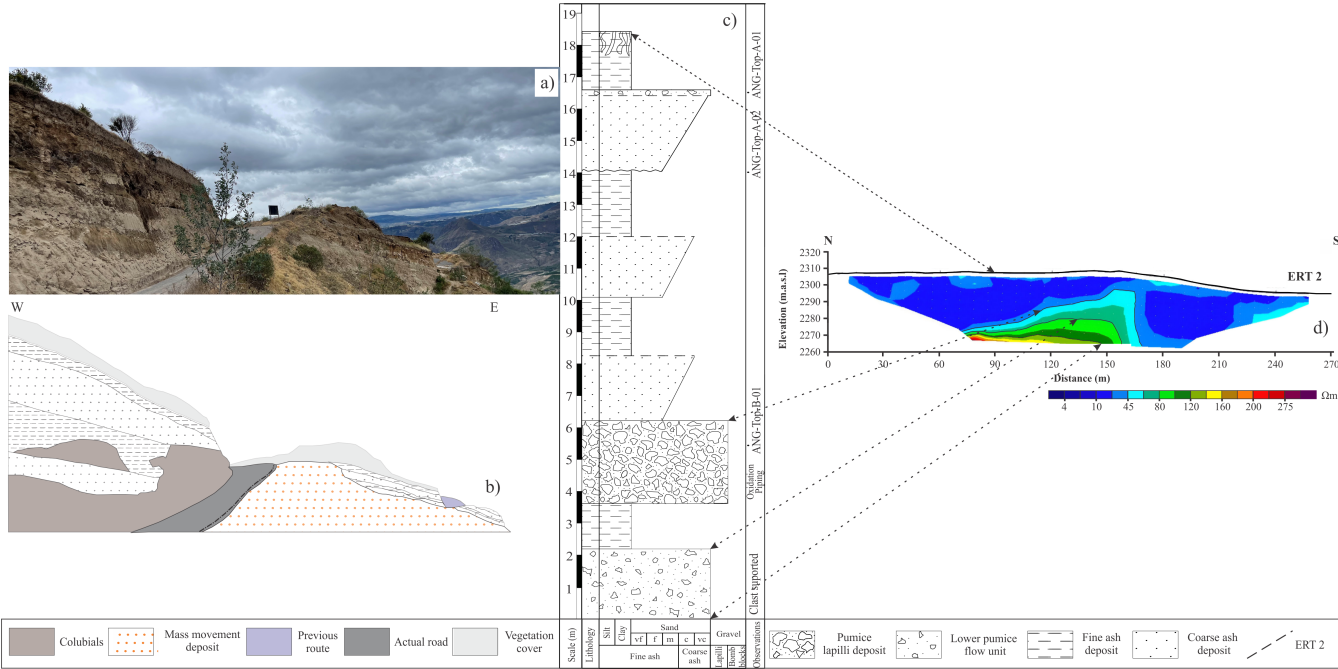


Figure 10. Integration of results in the analysis of mass movement. (a) Picture showing the current conditions of the slope. (b) Sketch of the arrangement of the strata on the slope. (c) Stratigraphic column A, detailing the lithological traces and their relationships. The joint image allows to interpret and relate the results to identify the rupture plane and the associated stratum. (d) Electrical Resistivity Profile 2, showing variations in the properties of the subsoil.

Finally, a discrepancy was identified between the stratigraphic data and the resistivity profiles, as a thin layer approximately 1.3 m thick was not resolved by the ERT results. This limitation is likely related to the low resistivity contrast of the material, such as ash or silt, which reduces the ability of the method to distinguish it from adjacent layers. This observation underscores the importance of complementing geophysical techniques with direct field observations and stratigraphic analysis to achieve more robust and accurate interpretations of subsurface conditions.



6 Conclusions

280 The resistivity profile showed significant variations between strata, associated with differences in grain size, cohesion, and degree of saturation. The low resistivity zones coincided with fine, poorly consolidated materials with high water retention capacity, which validated the correlation with the grain size data and confirmed the effectiveness of the combined approach to understanding the distribution of the material and its role in slope instability.

The integration of ERT with stratigraphic columns enabled the characterization of the landslide morphology in San José
285 de Aloburo, revealing the depth and extent of the displaced mass and identifying the rupture zone. The geophysical profiles reached penetrations of up to 40 meters, identifying the rupture zones in different sectors of the slope, which provided a clear map of the affected materials and their internal dynamics.

Finally, a discrepancy was identified between the stratigraphic data and the resistivity profiles, as a thin layer approximately 1.3 m thick was not resolved by the ERT results. This limitation is likely related to the low resistivity contrast of the material,
290 such as ash or silt, which reduces the ability of the method to distinguish it from adjacent layers. This observation underscores the importance of complementing geophysical techniques with direct field observations and stratigraphic analysis to achieve more robust and accurate interpretations of subsurface conditions.

Data availability. All the data are maintained by the corresponding authors and will be available on reasonable request.

Author contributions. During the development of this project, the coauthors provided valuable comments and suggestions through in-depth
295 discussions. In addition, specific contributions include the following: BMS: study conceptualization, methodology development, data collection and analysis, article writing, review, and editing. RTT: study conceptualization, data collection, review, and editing. RPR: study conceptualization, equipment calibration, methodology development, data collection, review, and editing. WB: equipment calibration, review, and editing.

Competing interests. The authors declare that they have no conflict of interest.

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