Hypogene karst in hydrothermal travertines and high mountain gypsum karst in the Huambo area, Central Andes of Peru

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Abstract

The Peruvian Andes contain extensive Cretaceous carbonate formations, covering approximately 13% of the region. These formations, particularly in the northern and central parts of the Andes, host significant karst landscapes and cave systems. Recent studies have identified hypogene karst features, including sulfuric acid speleogenesis. Until recently, no caves were documented near Huambo in the Caylloma Province. However, new research has identified several caves within the Mulapampa travertines, some ranking among the deepest known travertine caves worldwide. This study presents preliminary findings on karst geomorphology and speleogenesis in the region, emphasizing the role of volcanic and geothermal activity in the development of these unique subterranean features.

1. Introduction

Cretaceous-age carbonate rocks cover approximately 13% of the total surface area of the Peruvian Andes, occurring in two narrow tectonic belts extending over 2,000 km (EVANS, 2015). Most karst areas and caves are located in the northern (Amazonas and Cajamarca provinces) and central regions. Due to its geodynamic setting and evolutionary history, including widespread Late Miocene magmatism and intrusions into older carbonate sedimentary sequences, the Peruvian Andes is a region with potentially extensive hypogene karst development. Recent studies by KLIMCHOUK et al. (2022, 2023) have documented hypogene karst in the Peruvian high Andes, while DE WAELE et al. (2024) provided evidence of sulfuric acid speleogenesis, including Brujas Cave in Argentina.

Before the study by TYC et al. (2024), which described three caves in the Mulapampa travertines, no caves were known in the vicinity of Huambo, Caylloma Province (Central Andes, southern Peru). The entire province was not recognized as a karstic region, though a few small caves (maximum length of 50 m) with indigenous artifacts were documented (http://cuevasdelperu.org). This study presents preliminary results on karst geomorphology and speleogenesis in the vast area surrounding Huambo. South of Huambo, Cretaceous carbonate and evaporite rocks, part of the western belt of the Peruvian Andes, are exposed. An intriguing high-mountain gypsum karst, previously unstudied, is found in the locally known Los Altos area. The upper section of the Huambo River valley is occupied by thick Mulapampa travertines, featuring large collapse sinkholes linked to speleogenetic processes, including hypogene activity, in the underlying Cretaceous limestones.

2. Materials and methods

Fieldwork in the Huambo area was conducted during four field campaigns: in September 2017 as part of the Polish Scientific Expedition to Peru, and in June/July 2022, 2023, and 2024 as part of a research project funded by the National Science Centre of Poland. The study of karst and caves in the Huambo area was carried out in conjunction with research on phenomena associated with active tectonic processes in the Colca River basin.

To characterize and understand the karst in the study area, we employed multiple complementary methods, including cave inventory and exploration, as well as geomorphological and geological mapping at both surface and subsurface levels. Geomorphological mapping involved landform analysis using remote sensing imagery, digital elevation models, and detailed field surveys and measurements to interpret landscape evolution. Geological mapping, based on field observations, lithological sampling, and structural measurements—supplemented by aerial photography, satellite imagery, and literature data—was used to delineate rock units and geological structures.

As a result of these techniques, we identified three caves developed in travertine in 2017: Gruta con Lago, Gruta Campana, and Gruta Lechuza (TYC et al., 2024). These caves were further explored using standard speleological methods, including detailed surveying, 3D mapping, and lithological sampling, as well as chemical analyses of speleothems to document passage networks and internal cave morphology. Together, these approaches provide a comprehensive understanding of both surface and subsurface geological features.

The results of geochemical and mineralogical studies of water, rock, and sediment samples from Gruta con Lago were published by TYC et al. (2024).

3. Results and discussion

The study area lies in the central section of the Huambo River valley, a left-bank tributary of the Colca River in the Western Cordillera of the Central Andes (Fig. 1A). The valley is filled with thick thermogene travertines (sensu PENTECOST, 2005) of Pleistocene age (TYC et al., 2024), covering over 11 km^2 and extending from 2,970 m a.s.l. near Huambo village to approximately 3,950 m a.s.l. The eastern peripheries reach up to 4,000 m a.s.l., where they merge with colluvial deposits (Figs. 1 and 2).

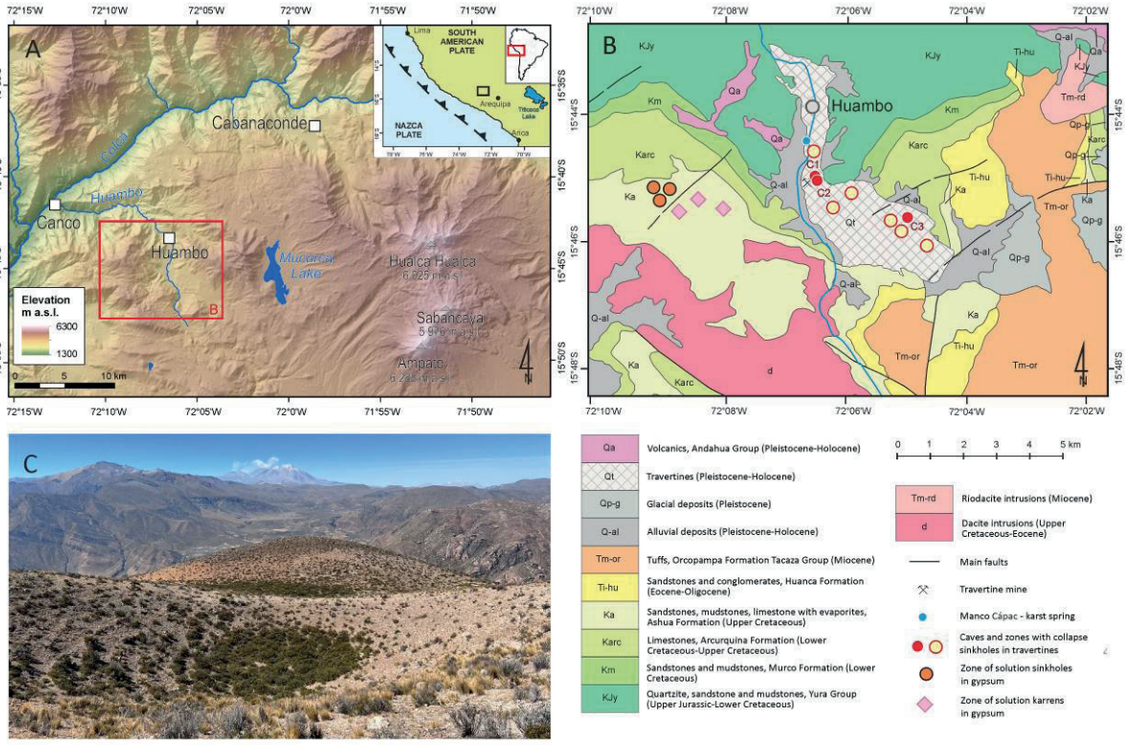

Figure 1 : *Location of the study area. A – general location of the Huambo area in the central Colca River basin (shaded relief map based on 30 m resolution digital elevation model, DEM from Shuttle Radar Topography Mission, SRTM https://earthexplorer.usgs.gov); B – geological settings of the Huambo area (based on CALDAS, 1993 and ROMERO FERNÁNDEZ & TICONA TURPO, 2003, modified) with location of caves and zones of collapse sinkholes in the Mulapampa travertines (Gruta con Lago – C1, Gruta Campana – C2, Gruta Lechuza – C3), the main karst spring (Manco Cápac), and the Los Altos gypsum karst; C – solution sinkhole in gypsum of Los Altos (4,150 m a.s.l.; foreground) overlooking the Ampato- Sabancaya Volcanic Complex (ASVC), with active Sabancaya volcano and Mulapampa travertines in the middle (view from NW to SE).*

The oldest formations in the study area include Upper Jurassic-Cretaceous sedimentary rocks of the Yura, Murco, Arcurquina, and Ashua Formations (Fig. 1B; CALDAS, 1993; ROMERO FERNÁNDEZ & TICONA TURPO, 2003). The Arcurquina and Ashua Formations' carbonates and evaporites are particularly significant for karst development. A thick (500–700 m) carbonate sequence from the Arcurquina Formation underlies the Mulapampa travertines. Upper Cretaceous–Eocene dacite intrusions have altered these sedimentary deposits (Fig. 1B; CALDAS, 1993; ROMERO FERNÁNDEZ & TICONA TURPO, 2003).

The travertine cover is characterized by numerous deep collapse sinkholes (Figs. 1, 2, and 3). Three caves were identified during field studies focused on the geomorphology and origin of these sinkholes. These caves were already known to the local community. The entrances to Gruta con Lago and Gruta Campana (C1 and C2 in Fig. 1B; Fig. 2) are located at elevations of 3,447 m and 3,463 m a.s.l., respectively. The entrance to Gruta con Lago features a deep, cylindrical collapse sinkhole (Fig. 4A), while Gruta Campana exhibits a bell-shaped collapse. The caves contain steep cones of collapsed travertine blocks leading to their bottoms. Gruta con Lago, reaching a depth of 38 m, contains a small lake and water pools among gypsum deposits. Gruta Campana has been explored to a depth of 40 m. The deepest known cave in the area, Gruta Lechuza, lies at the edge of the uppermost travertine terrace (C3 in Fig. 1B; Fig. 2), with a cave bottom nearly 85 m below the surface (Fig. 4B). According to GRADZIŃSKI et al. (2019) and UNESCO data (https://whc.unesco.org), this depth places these caves among the deepest known travertine caves in the world, comparable to Zedan-el-Soleyman in Iran (DAMM, 1968).

Figure 2 : *Location of caves and collapse sinkholes in the Mulapampa travertines above the Huambo village (Maps Data: Google Earth Pro, ©2025 Airbus).*

Figure 3 : *Collapse sinkholes on the uppermost terrace of the Mulapampa travertine.*

TYC et al. (2024) proposed a conceptual model for speleogenesis in the region, considering sulfuric acid speleogenesis (SAS) and its association with travertine deposition over carbonate formations. The Ampato-Sabancaya Volcanic Complex (ASVC) and its geothermal system play a crucial role. The extensive carbonate formations (Arcurquina Formation) overlying a magma chamber, combined with active fault zones, are particularly significant for karst development (TYC et al., 2022, 2024).

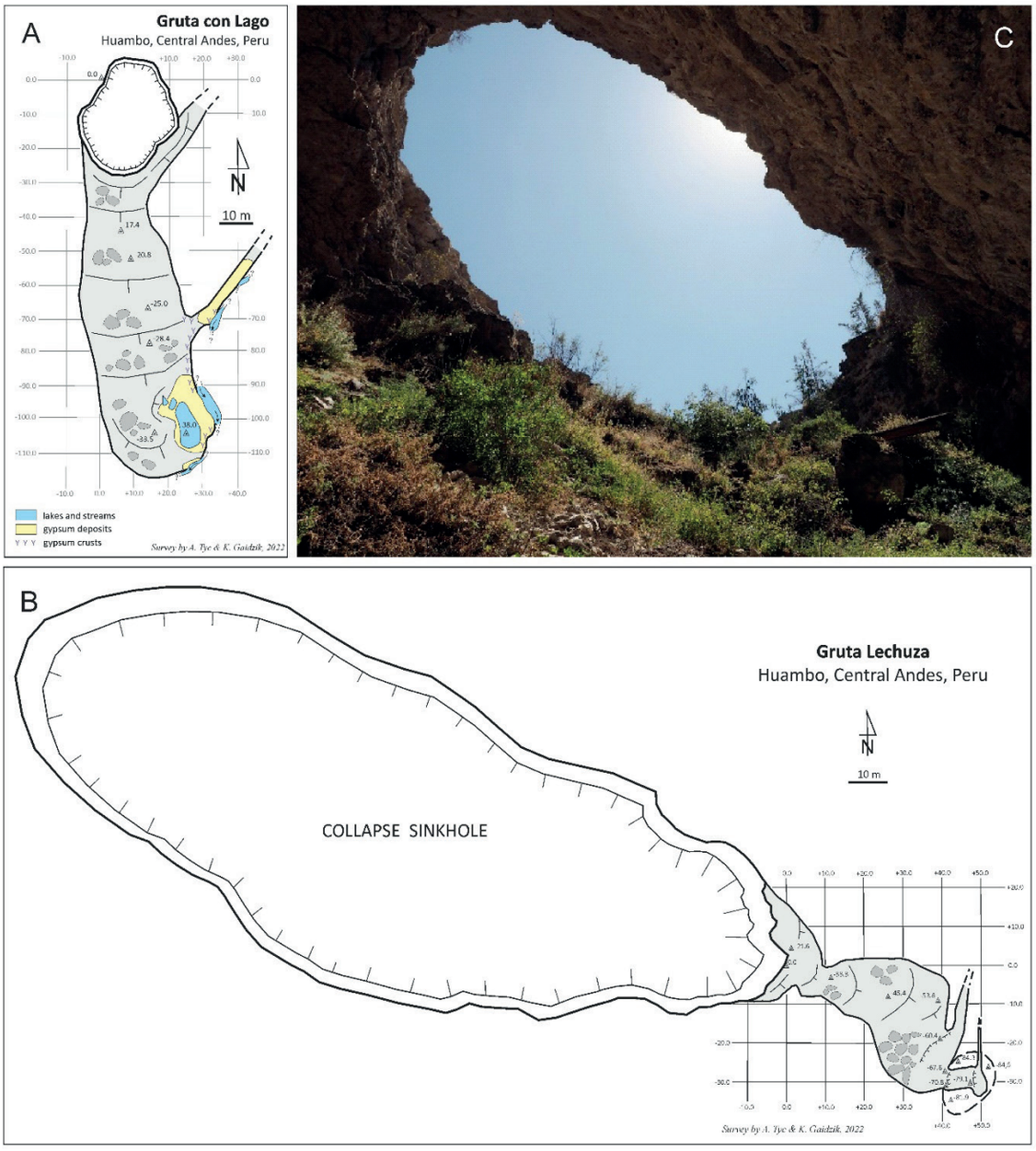

Figure 4 : *Surveys of caves in the Mulapampa travertines (TYC et al., 2024, modified). A – Gruta con Lago; B – Gruta Lechuza; C – entrance of the Grura Leczuza, view from the inner part of the cave.*

4. Conclusion

Several years of research in the Huambo area have unexpectedly provided valuable new data on the karst and caves of this region of the Peruvian Andes. Detailed geological and geomorphological studies are essential to understanding the origin and age of karst development in the Mulapampa travertines, including the specific stages of speleogenesis.

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