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Research Article

Comprehensive Examination of Gypsum Deposits and Identification of Karstic Cavities Utilizing Ground Penetrating Radar in the Bala Region (Ankara-Türkiye)

Cihan Yalcin*

GMK Yenilenebilir Enerji Mühendislik İmalat San.ve Tic. Aydın, Türkiye

*Corresponding author: cihanyalcinjeo@gmail.com

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Abstract:

This research used the Ground Penetrating Radar (GPR) technology to elucidate the geological and structural attributes of gypsum deposits in the Bala area of Ankara. Ground Penetrating Radar (GPR) is a prevalent method for high-resolution imaging of subsurface formations, identifying discrepancies in electrical characteristics attributable to lithology and groundwater concentration. Ground Penetrating Radar (GPR) measurements were conducted along 19 profiles inside the research region, and the underlying structures in these profiles were meticulously studied. The collected data were analysed to delineate the thickness and distribution of gypsum deposits and their effects on groundwater. Regions with elevated resistivity indicates gypsum formations, while regions of reduced resistivity correspond to clay strata and water-saturated sediments. Specifically, karst cavities were absent in the majority of the profiles, suggesting that the gypsum deposits in the region exhibit resistance to karstification. Furthermore, it was determined that the gypsum resources are commercially viable and appropriate for extraction. This study pointed out that Ground Penetrating Radar (GPR) is a proficient method for delineating gypsum deposits in intricate evaporitic settings, with maximal deposit thicknesses of up to 10 meters in certain profiles and an absence of substantial karstic cavities, hence enhancing operating safety.

Keywords: Georadar; Gypsum deposits; Karstic cavities; Resistivity; Bala-Ankara

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1. Introduction

Gypsum is an essential industrial mineral used in the building, agricultural, and manufacturing industries globally. It is mostly used in plaster, wallboard, and cement. Turkey, a prominent producer, has significant deposits in the Bala area of Central Anatolia, catering to both local and international markets. Gypsum is used in agriculture as a soil conditioner and in industry for ceramics and fertilizers. The grade and purity of Turkish gypsum resources enhance its worldwide competitiveness. Comprehensive exploration and mapping are crucial for optimizing extraction and ensuring sustainable output.

The Bala (Ankara) area is a significant gypsum deposit in Turkey, presenting substantial economic potential for the mining industry (Pérez-López et al., 2023). In regions with gypsum resources, precise and comprehensive mapping of subterranean structures have become essential for both mining operations and environmental hazards. Karstic cavities, fracture systems, and weak structural zones in gypsum formation regions may provide significant operational hazards (Ortí & Rosell, 2007). These hazards may result in cave-ins and fracture-related incidents, particularly during open-pit mining operations (Stafford et al., 2017). Numerous geophysical techniques have been developed to delineate underlying formations and alleviate these hazards (Telford et al., 1990). While techniques like Electrical Resistivity Tomography (ERT) and Vertical Electrical Drilling (VED) are proficient in analyzing deep structures, they may encounter limitations in identifying delicate formations such as near-surface structures and karstic cavities (Guinea et al., 2012; Guinea et al., 2010; Loke, 2002; Loke & Barker, 1996; Saadat et al., 2023) Consequently, high-resolution subsurface imaging techniques like Ground Penetrating Radar (GPR) provide significant benefits for comprehensive structural analyses, particularly in gypsum deposits (Ashrafi et al., 2024; Zhao et al., 2024). The high resolution and substantial data-collecting capability of GPR provide millimeter-level analysis of near-surface structures, enabling precise assessment of purity, thickness, and the existence of karst formations in gypsum deposits (Pérez-López et al., 2023).

Using geophysical methods is crucial for mineral resource mapping and operational safety. In open-pit mines, incidents resulting from lithology and subsurface fracture systems might compromise the safety and sustainability of operations (Sevila et al., 2017). Consequently, using methods like Ground Penetrating Radar (GPR) for identifying near-surface structural issues may aid in accident prevention throughout operating operations and provide a more detailed assessment of the site's structural conditions (Jehangir Khan et al., 2021; Stafford et al., 2017). This research aims to meticulously examine the gypsum deposits and associated karstic cavities in the Bala area of Ankara using Ground Penetrating Radar (GPR). The benefits of GPR were assessed relative to prior research using ERT and VES technologies, yielding more accurate data on subsurface structures. This research illustrates the detection of near-surface structural issues and the efficacy of Ground Penetrating Radar (GPR) in enhancing operating safety inside gypsum deposits.

2. Materials and Methods

2.1 Location of work

This research investigated gypsum deposits in the Bala area of Central Anatolia, Turkey, concentrating on Neogene evaporite and sedimentary rocks, including gypsum and anhydrite minerals, as well as karstic cavities and cracks.

2.2 Methodology

The research used Ground Penetrating Radar (GPR) to detect gypsum deposits and karst cavities in the Bala area of Ankara. Ground Penetrating Radar (GPR) delivers high-resolution subsurface imaging, yielding essential data on the thickness of deposits, fracture systems, and karst cavities, particularly inside gypsum deposits (Stafford et al., 2017; Zhao et al., 2024). The Cobra GPR equipment used in the study was favored for seeing subterranean structures (Figure 1). The Cobra GPR system is distinguished by its wireless real-time sampling capability and its interoperability with all SE antenna variants. The specifications of the devices used in the investigation are as follows:

Figure 1. Measurement with Cobra GPR

- Cobra Plug-In MF GPR System: Delivers profound GPR penetration. The system functions at an 800 ns depth range and has a mass of 1.4 kg. It can function continuously for 16 hours with a built-in 94 Wh Li-Ion battery.
- Antennas: The SE model antennas are used (Selectable models: SE-40, SE-70, SE-150). Data was gathered in the research region using antennas operating at frequencies of 200, 400, and 800 MHz.
- Data Acquisition Software: Data was acquired using Cobra DAQ software, and further analysis was conducted using the 3D export module PRISM.
- Positioning: Precise positional data was acquired with the Geode GNSS system. Utilizing Bluetooth locations and a GNSS positioning system that supports GPS, SBAS, and GLONASS, an accuracy of 30 cm RMS was attained.

2.3 Geology

The Bala region in Turkey, located within the Salt Lake Basin, is a geological area characterised by notable evaporite and sedimentary rocks from the Neogene era (Koçyiğit et al., 2024; Oztan & Süzen, 2009). The area is affected by dynamic intraplate deformation mechanisms, notably the Tuz Gölü Fault Zone, which contributes to the development of subterranean structures and the Obruk earthquake source (Koçyiğit et al.,

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2024). The stratigraphic units in the area are defined by Neogene evaporite deposits, mostly consisting of high-purity gypsum and connected with karstic formations. The fundamental lithologic units of the area consist of conglomerate and sandstone at the base, followed by marl and clay units in the higher strata, which impede groundwater movement (Figure 2).

Geophysical research has enabled accurate mapping of gypsum deposits by magnetotelluric and electrical resistivity tomography methods (Akça et al., 2022). Elevated resistivity levels are attributed to high purity ratios and karstic characteristics. Remote sensing techniques provide a comprehensive investigation of gypsum surface distribution and the effects of erosion (Akça et al., 2022).

A strike-slip fault was identified in the mine (Figure 3a). In this fault zone, evaporite deposits are located at the lower strata, whereas mudstone and sandstone are found at the top strata (Figure 3b). A pond was created at the mine site entrance owing to the impermeability of the clay layers (Figure 3c).

Close stacks were investigated for mining geology. The superficial terrestrial clasts and the evaporite transition are readily identifiable (Figure 4a). The hues white and greyish white signifies the transition to evaporitic strata in the stack. Upon meticulous examination, gypsum bands and sporadic conversions to anhydrite were noted (Figure 4b). The hand sample exhibits clear, sliced gypsum (Figure 4c).

3. Results

The study of the georadar profiles facilitated the precise mapping of gypsum deposits and their related geological features in the Bala area of Ankara. The data acquired from 19 profiles (Figure 5) provide significant insights into the distribution of clay, gypsum, and karstic cavities, as well as the identification of subsurface structures. A thorough examination and extensive review of the georadar data based on the overall structure of each profile is shown below.

The findings from Georadar Profiles 1 and 8 indicate an appearent existence of surface clay layers and their impact on georadar signals (Figure 6). The water saturation of the clay strata resulted in regions of low resistivity (shown by black colouration), which were interpreted as water-saturated clay deposits rather than karstic cavities. Clay diminishes georadar signals because of its elevated dielectric constant, suggesting that low resistivity regions have extensive surface dispersion. The regions of elevated resistivity shown in red indicate the existence of gypsum formations. The gypsum units, prominently seen in Profiles 1, 3, and 5, exhibit thicknesses of 5-10 meters and are more clearly identified by georadar signals than clay layers (Figure 6). Areas with elevated resistivity provides significant insights for identifying commercially viable gypsum resources in the region.

The research by (Akça et al., 2022). in the Bala area validates the elevated resistivity of gypsum deposits, providing significant data for the economic assessment of the region's gypsum reserves.

The research indicated that gypsum deposits in Profiles 9-16 were linked to water-saturated clays and sediments, exhibiting increased thickness and a lack of karstic cavities (Figure 6). The sediments exhibited resistance to karstification (Pérez-López et al., 2023). Regions with high resistivity suggest substantial deposits, signifying their economic viability. Georadar data clearly identified gypsum units, although the surrounding clay that attenuated signals. This substantiates the efficacy of geophysical techniques in delineating gypsum deposits, as shown by the research of (Guinea et al., 2014). The presence of clay around gypsum deposits attenuated the signals.

Georadar Profiles 17-19 (Figure 7), situated to the south and east of the research region, indicate gypsum deposits nearer to the surface. Clay strata persist in affecting these profiles, resulting in low resistivity areas. Nevertheless, the thickness of these deposits have diminished, especially in Profile 19, where a 5-meter thick gypsum layer was seen. No karst formations were detected, and clay resulted in reduced resistivity values in the georadar data.

A geophysical survey of gypsum deposits in the Bala district of Ankara has shown that low resistivity regions correlate with water-saturated clay layers, while high resistivity areas signify high-purity gypsum resources. These results are essential for the economic assessment of gypsum reserves in the sector. Elevated resistivity gypsum deposits in Profiles 10, 13, and 15 suggest extensive deposits and a little danger of karst cavities, facilitating secure operational procedures. This aligns with prior research (Drahor, 2019; Guinea et al., 2014).

The research indicates that regions of low resistivity in profiles are associated with clay layers and water-saturated zones, corroborating findings from other studies (Guinea et al., 2014; Pérez-López et al., 2023). High-purity gypsum deposits were detected in Profiles 10, 13, and 19, exhibiting elevated resistivity values (Akça et al., 2022). The lack of karstic cavities indicates that the gypsum deposits were not exposed to karstification, consistent with geophysical evidence. These results correspond with georadar investigations in analogous evaporite areas and elucidate the geological configuration of the gypsum deposits in the Bala region ((Drahor, 2019; Ozel & Darıcı, 2020). In-depth examination of underlying geological formations is essential for mitigating possible karst hazards and guaranteeing the secure extraction of commercially significant gypsum reserves.

4. Discussion

This research conducted comprehensive geophysical mapping of gypsum deposits in the Bala (Ankara) area and assessed the efficacy of ground-penetrating radar (GPR) data in detecting underlying structures. This research is crucial for assessing the economic potential of the region, given the thickness of gypsum deposits, water-saturated clay layers, and resistivity vari-

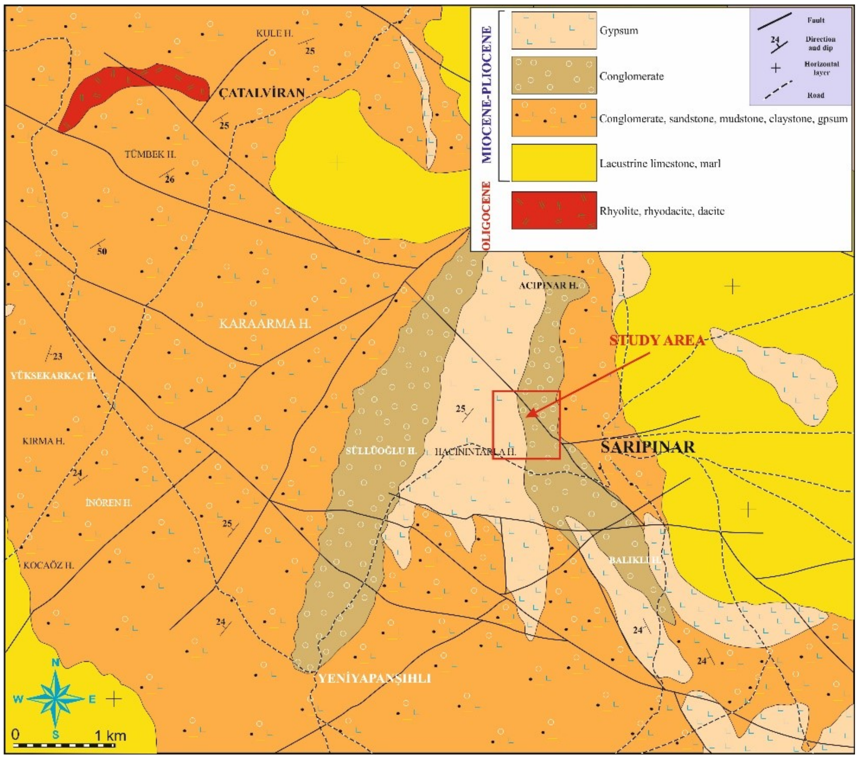

Figure 2. Geology map of the study area (Modified from MTA J30-a2 sheet)

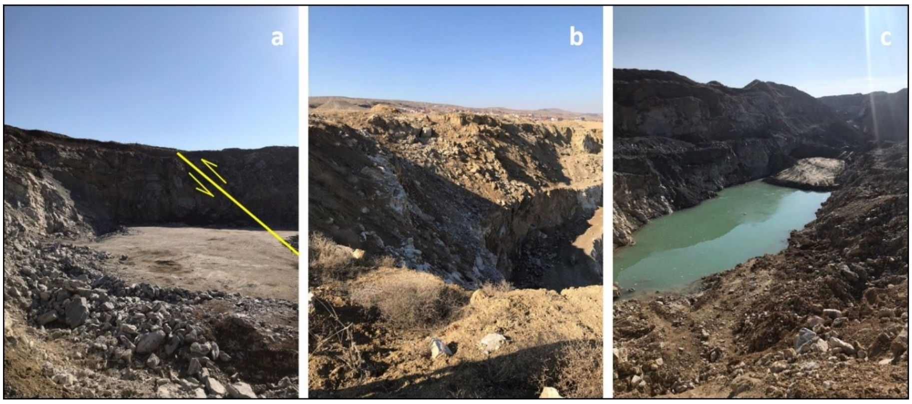

Figure 3. General view of the gypsum quarry

Figure 4. Surface characteristics of gypsum

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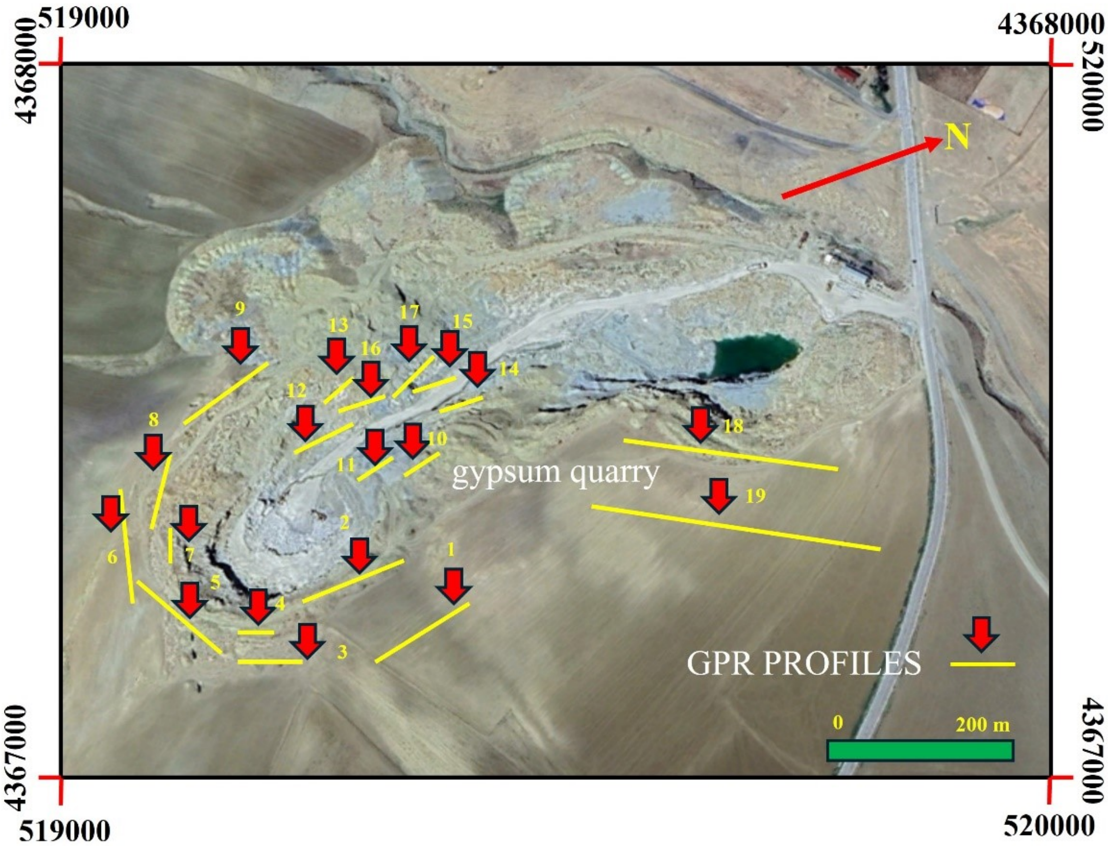

Figure 5. GPR profiles of the study area

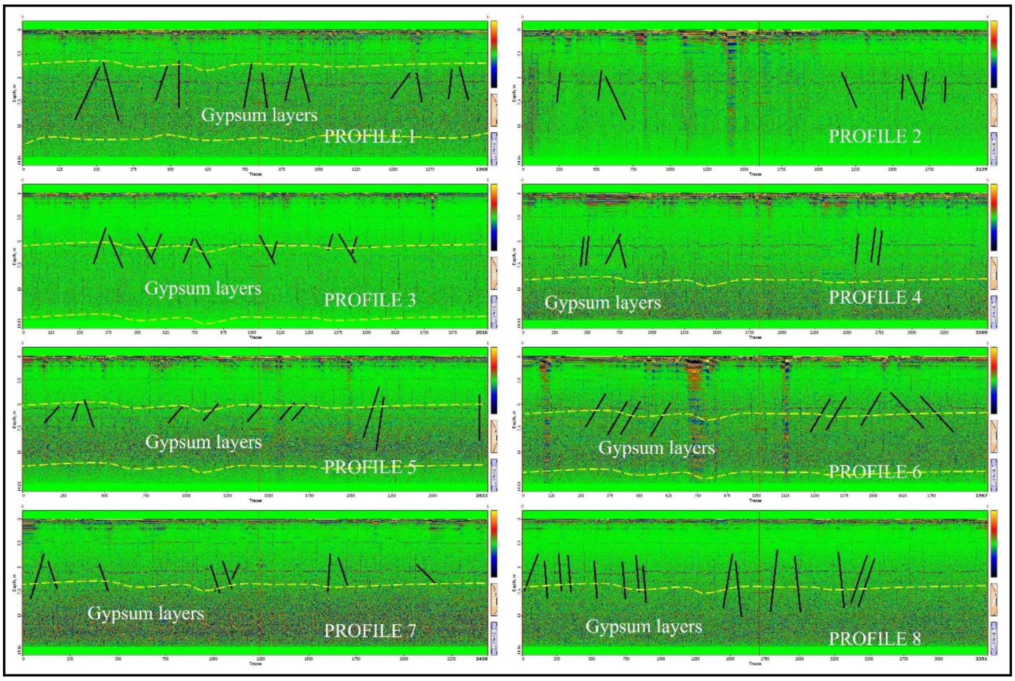

Figure 5. GPR profiles (1-8)

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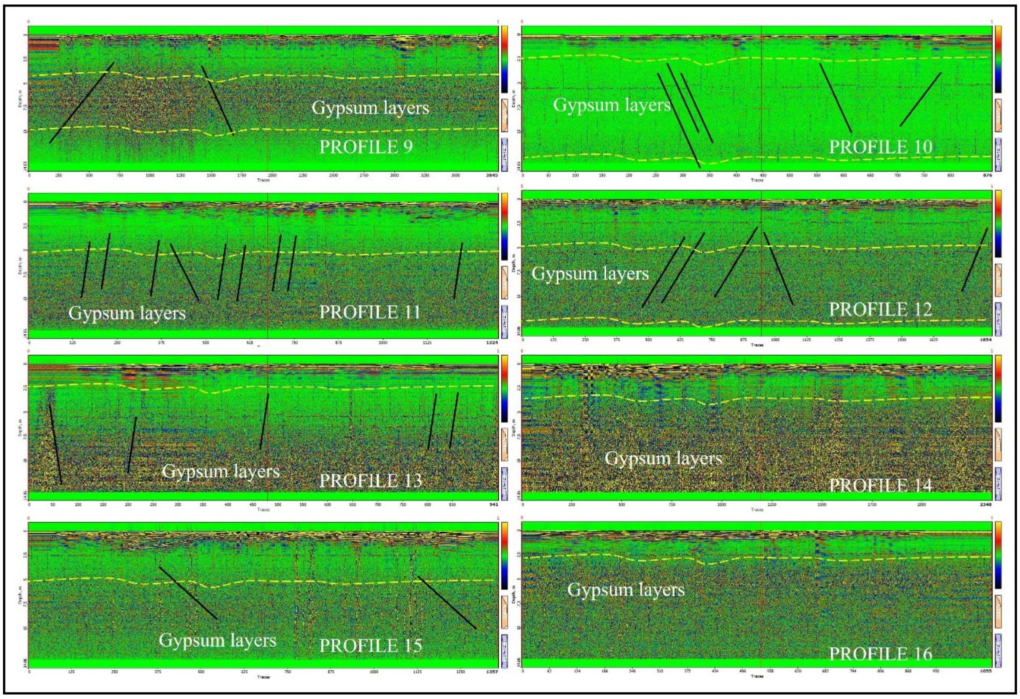

Figure 6. GPR profiles (9-16)

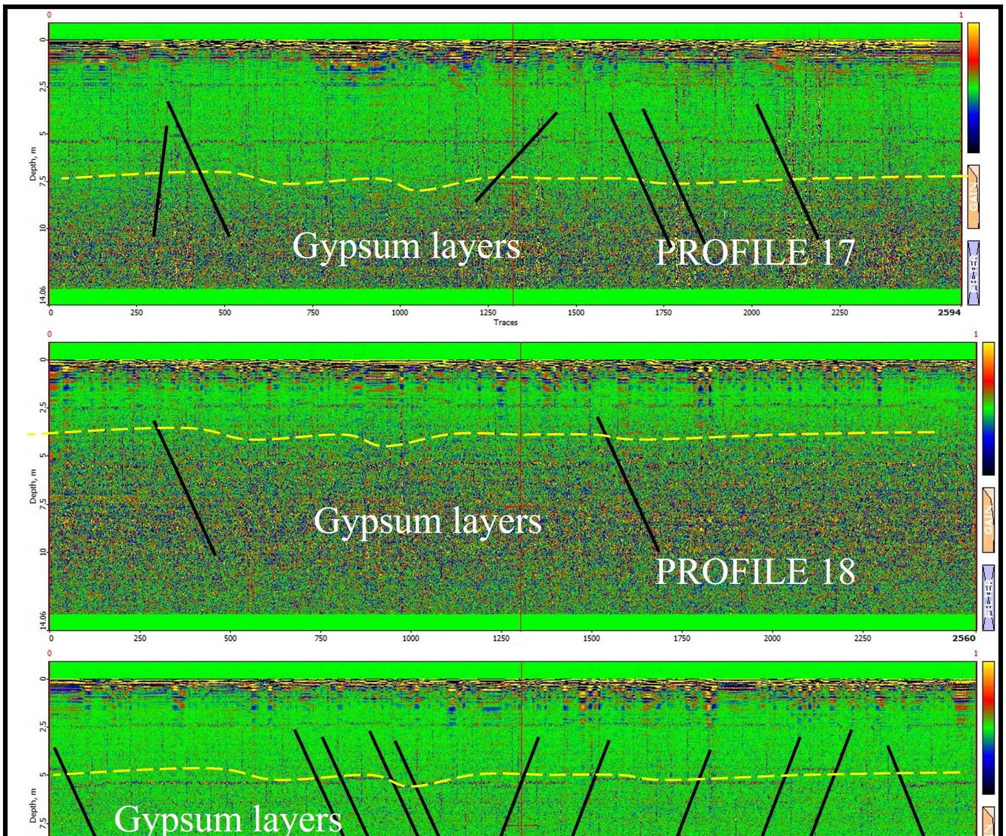

Figure 7. GPR profiles (9-16)

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ations among gypsum units. Geophysical approaches, including GPR and ERT, have been shown in the literature as effective instruments for detecting and mapping evaporite deposits (Drahor, 2019; Ozel & Darıcı, 2020; Pérez-López et al., 2023). The results acquired in this context align with the findings of other research and indicate that the geological structure in the Bala area warrants economic evaluation.

Utilizing Georadar for Subsurface Structure Mapping

Georadar has achieved significant recognition in the literature as a technique for high-resolution imaging of subsurface structures (Drahor, 2019; Guinea et al., 2014). The GPR data used in this investigation enabled a definitive identification of gypsum deposits in the field. The correlation between low resistivity zones and water-saturated clay strata aligns with prior research (Akça et al., 2022; Pérez-López et al., 2023). Likewise, the regions with elevated resistivity strongly indicate the existence of gypsum deposits. The results validate the efficacy of the GPR approach in assessing the thickness and distribution of gypsum deposits (Al-Fares et al., 2023). The saturation of clay layers with water results in the attenuation of georadar signals, resulting in a broad surface distribution of low resistivity zones. (Drahor, 2019; Ozel & Darıcı, 2020) reported the same results, indicating that clay layers induce signal attenuation in subsurface imaging methods. The impact of clay was clearly apparent in the Bala area.

Economic Significance of Gypsum Deposits and Lack of Karstic Cavities

The lack of karst cavities in this study's research indicates that the geological structure of the area is not subjected to karstification, hence ensuring safer operational procedures. The significance of the GPR approach in identifying karst structures has been highlighted in the literature, and the absence of identified cavities indicates that the gypsum deposits in the area are resistant to karstification (Drahor, 2019; Moslemi et al., 2023; Pérez-López et al., 2023). The discovery of high-purity gypsum deposits suggests that these reserves need economic evaluation. (Al-Fares et al., 2023) underscored the significance of assessing the economic viability of gypsum resources by geophysical techniques, with similar findings reported in this research.

Furthermore, research by (Akça et al., 2022) in the Bala region demonstrated the presence of high-purity gypsum resources that may be used commercially. This research corroborates similar results and demonstrates that the distribution and thickness of gypsum deposits may be assessed inexpensively. The lack of karstic cavities suggests that extraction procedures would entail less risk (Pérez-López et al., 2023).

Current Studies and Future Proposals

Research from 2024 indicates that Ground Penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT) techniques are gaining use in mining and subterranean structure identification. Alam and Ahmed (2024) identified GPR as an excellent instrument for high-resolution subsurface imaging in mining regions. The results of this investigation demonstrate that GPR is an efficient technique for delineating subsurface features in the Bala area. Furthermore, the findings of this study align with those of previous research conducted in other evaporite areas within the worldwide literature (Drahor, 2019; Guinea et al., 2014).

Future research should conduct more comprehensive examinations of gypsum deposits in the Bala area to identify possible karst cavities and evaluate groundwater flow. Moreover, the combined use of geophysical techniques, including GPR and ERT, can elucidate the geological formations in these regions with greater precision and mitigate the dangers linked to the extraction of these resources (Alam & Ahmed, 2024; Guinea et al., 2014).

The research effectively delineated gypsum deposits in the Bala area with Ground Penetrating Radar, providing high-resolution data for subsurface structural characterization. Clay strata diminished signals, exposing low resistivity zones and high resistivity deposits, signifying secure karst risk extraction.

5. Conclusion

This research used the georadar (GPR) technique to ascertain the thickness and distribution of gypsum deposits in the Bala area of Ankara. The acquired data indicated that the gypsum deposits in the region exhibit thicknesses between 5 and 10 meters, with some locations exceeding 10 meters. Low resistivity zones were detected when the clay was saturated with water, whereas high resistivity regions clearly delineated the gypsum deposits. Moreover, the lack of karst cavities indicates that the geological formation at the location is impervious to karstification. The findings indicate that georadar is a proficient technique for delineating gypsum deposits and evaluating karst hazards, highlighting the potential for economic exploitation of gypsum resources in the area.

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Authors contributions
CY fieldwork, geology, mapping, analysis and interpretation of the data, drafting the manuscript, critical revision. The author read and approved the manuscript.
Availability of data and materials
All data generated or analysed during this study are included in this published article.
Conflict of interests
Conflict of interest the authors declare that they have no competing interests.

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