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Göllü Polye and Lake Van: Geomorphological and Hydrological Connections

Göllü Polyesi ve Van Gölü: Jeomorfolojik ve Hidrolojik Bağlantılar

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A B S T R A C T / *Ö Z*

The Göllü Polje holds a significant position for seeking answers to research problems due to its geomorphological features and its proximity to the level of Lake Van. Particularly, the elevation studies of the polje floor are among the reasons for the concentration of research in this area. The studies conducted in the Göllü Polje area aim to determine the geomorphological roles played by the polje in reaching the highest level of Lake Van in past periods and how and to what extent it was affected by these level changes. Additionally, it has been addressed which findings could be used to explain the changes in the level of Lake Van and to understand what kind of connection the lake has with other open basins, how the hydrological balance within the Polje area is established, and what effects it was subjected to in later periods. It has been decided to conduct core drilling studies and investigate the validity of this hypothesis that Lake Van might have overflowed into the polje and lake sediments might have accumulated within the polje. A total of 84 samples were taken for the determination of the mineralogical contents of the sediments obtained from the cores, and carbonate (calcite, aragonite, and dolomite) and quartz contents were examined and analyzed. When the core analyses together with all clay, quartz carbonate, and organic carbon mineral data and graphs are evaluated, it is understood that slope erosion intensified and there was an increase in the deposition of minerals such as kaolinite and illite in certain periods within the polje. It is also understood that during periods when slope erosion slowed down and the polje took the form of a lake, disrupting river drainage, montmorillonite mineral precipitated, and these periods followed each other in phases.

Göllü Polyesi, jeomorfolojik özellikleri ve Van Gölü seviyesiyle olan yakınlığı nedeniyle araştırma problemlerine yanıt aramada önemli bir konumda yer almaktadır. Özellikle, Polye tabanının yükselti çalışmaları, bu alandaki araştırmaların yoğunlaşmasının nedenleri arasındadır. Göllü Polyesi alanında yapılan çalışmalar, Polyenin geçmiş dönemlerde Van Gölü'nün en yüksek seviyesine ulaşmasındaki jeomorfolojik rollerini ve bu seviye değişimlerinden ne ölçüde etkilendiğini belirlemeyi amaçlamaktadır. Ayrıca, Van Gölü seviyesindeki değişiklikleri açıklamak için hangi bulguların kullanılabileceği ve gölün diğer açık havzalarla nasıl bir bağlantısı olduğu, Polye alanındaki hidrolojik dengenin nasıl kurulduğu ve sonraki dönemlerde hangi etkilere maruz kaldığı ele alınmıştır. Van Gölü'nün Polyeye taşmış olabileceği ve göl tortullarının Polye içinde birikmiş olabileceği hipotezinin geçerliliğini araştırmak amacıyla karot sondaj çalışmalarının yapılmasına karar verilmiştir. Karotlardan elde edilen tortulardaki mineralojik içeriklerin belirlenmesi için toplamda 84 örnek alınmış, karbonat (kalsit, aragonit ve dolomit) ve kuvars içerikleri incelenmiştir. Karot analizleri ile birlikte tüm kil, kuvars karbonat ve organik karbon mineral verileri ve grafikler değerlendirildiğinde, Polye içinde belirli dönemlerde eğim erozyonunun yoğunlaştığı ve kaolinit ve illit gibi minerallerin birikiminin arttığı anlaşılmaktadır. Ayrıca, eğim erozyonunun yavaşladığı ve Polyenin bir göl formunu aldığı, nehir drenajının bozulduğu dönemlerde montmorillonit mineralinin çökeltiği ve bu dönemlerin birbirini takip eden fazlar halinde gerçekleştiği de anlaşılmaktadır.

1. Introduction

Polje, seen in karst regions, are large, flat, or slightly sloping, enclosed depressions. These depressions gradually form over time through the dissolution of soluble rocks such as limestone by water. Poljes are one of the most typical surface forms in karst areas and are generally surrounded by surrounding mountains. Occasionally, these depressions can be filled by temporary or permanent lakes, agricultural areas, or underground rivers. A polje plays a significant role within aquifer systems, accumulating underground water and being an important component for the hydrogeology of karst areas (Pekcan, 1999; Closson et al., 2003; Crawford, 1984; Ford, D., Williams, P. 2007; Öztürk et al., 2018, Öztürk et al., 2020; Şimşek et al., 2021; Doğan, 2003). The bases of poljes are generally situated a few hundred meters below their surrounding landscapes and are characteristically flat. However, they can be marshy or even temporarily covered by lakes, depending on the underground drainage conditions and groundwater levels. During periods when the groundwater level rises, the base of the polje may flood; conversely, it dries out when the groundwater level falls. Streams that originate from the surrounding higher elevations often flow into the polje, but these may disappear either at the base or at the edges of the polje. Additionally, the bases or slopes of the surrounding hills often feature cave entrances. These caves, also known as dolines or ponors, act as portals for underground watercourses that drain water from the polje. Ponor systems, frequently observed at the juncture of valley floors and slopes, typically develop along fracture systems (Figure 8). The Göllü basin, situated at an average elevation of 1900 meters, features a valley floor at 1707 meters and a gentle slope of approximately 3 degrees from south to north. It is surrounded by peaks, with elevations reaching up to 2200 meters. Notable heights include Cemin Mountain at 2073 meters to the northeast, Karver Hill at 2026 meters to the northwest, and Tapiran Hill at 2188 meters and Yanık Mountain at 2190 meters to the south. Other significant elevations include Güliksan Hill at 2134 meters to the southeast, Kayalı Hill at 1966 meters, Ambar Hill at 1794 meters to the west, and Ahılhar Hill at 1933 meters and Kelhuçk Hill at 1829 meters to the north. The basin also hosts small settlements like Göllü, Çanakdüzü, Harmanlı, and Kuruyaka villages. The largest watercourse in the Göllü Basin is Çay Deresi (Figure 1, 5, 8).

1.1. The Geology of Polje Areas

The majority of the basin is composed of schists and gneisses with varying characteristics. Within the regional structure, the metamorphic series includes rocks ranging from green schists to amphibolite facies. Overlying these are Permian-aged crystalline limestones, which in places display a gray or yellowish dolomitic structure. The youngest geological unit in the area is Quaternary-aged alluvium, predominantly surrounding Göllü Village. This alluvial deposit, comprising a mixture of clay and sand, blankets the Göllü Basin. Characteristically nearly circular in shape, the basin forms a flat-bottomed polje (Figure 3).

The main river within the Göllü polje, Çay Deresi, is formed by the confluence of Hınıs Deresi from the southwest and Selim Deresi from the west. It flows northward. In spring, increased rainfall and snowmelt cause the polje to submerge. Within the Göllü polje, five sinkholes have been identified. Notably, a tunnel was constructed in an area previously occupied by an active sinkhole to facilitate drainage. This tunnel, opened by the State Hydraulic Works in 1959, allows water from the basin to flow towards Lake Van, passing between Tunnel Hill and Kelhuck Hill to the north. Thanks to this engineering intervention, the basin is protected from prolonged submersion due to floods from Çay Deresi. All sinkholes within the polje are classified as edge sinkholes, located at the junction of the basin and the slopes. The formation and evolution of the polje are significantly influenced by karstification of the surrounding slopes and by erosion and sedimentation, which lead to their recession.

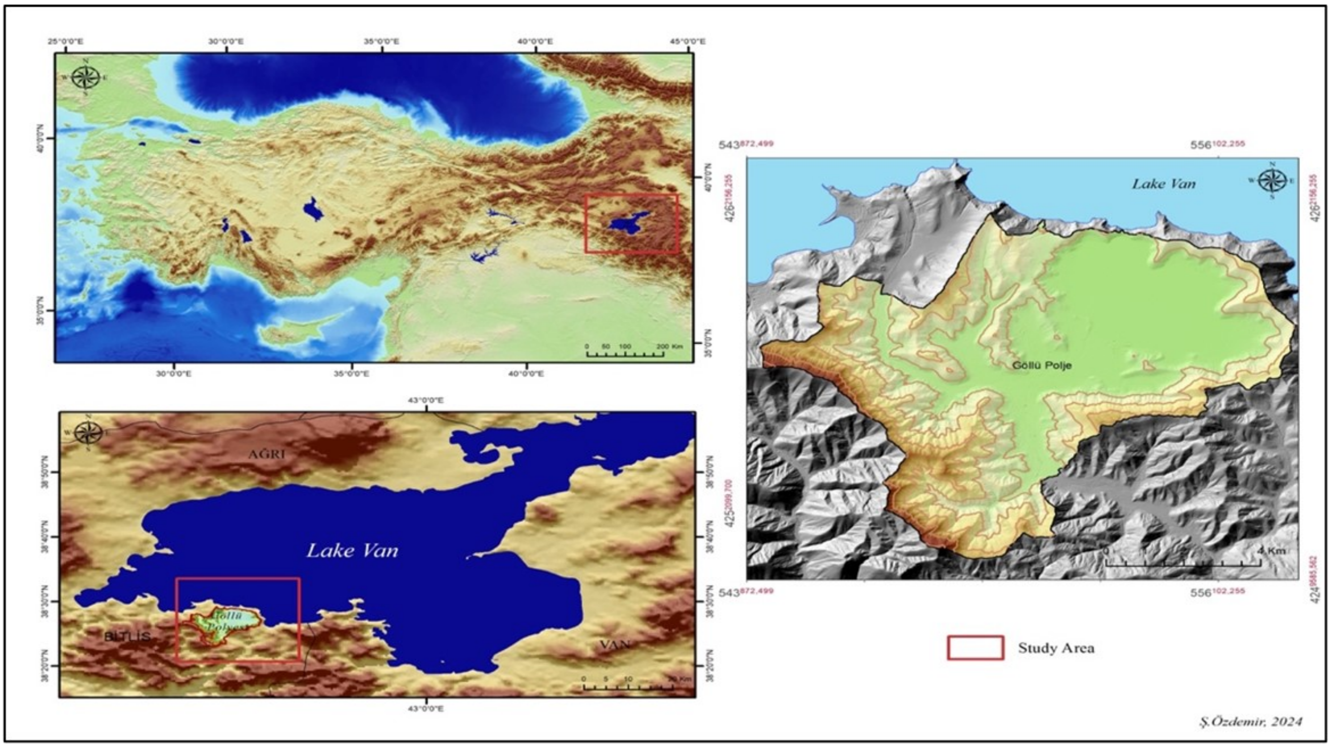

Figure 1. Göllü Polje location map.

However, given the polje's location and climatic conditions, these processes are neither simple nor rapid. Inside the polje, southeast of Göllü Village, stands Kale Tepe at 1809 meters, a relic of erosion composed of Paleozoic limestone (Figure 3).

1.2. Possible Lake Thresholds in the Göllü Polyesi Basin

Van Lake and Göllü Polje are separated by limestone formations averaging an elevation of 1800 meters. Two topographic thresholds have been identified around the polje, potentially allowing the lake to connect and form an open basin at these points. The first threshold, a neck point, is located between Kelhuçk Hill (1829 m) to the north of the polje and Tünel Hill (1809 m), with an elevation of 1740 m. This point is only 92 m above the current level of Lake Van. The second threshold is situated to the south of the polje, where the watershed line that separates the Göllü basin from the Dicle basin reaches an elevation of 1765 m.

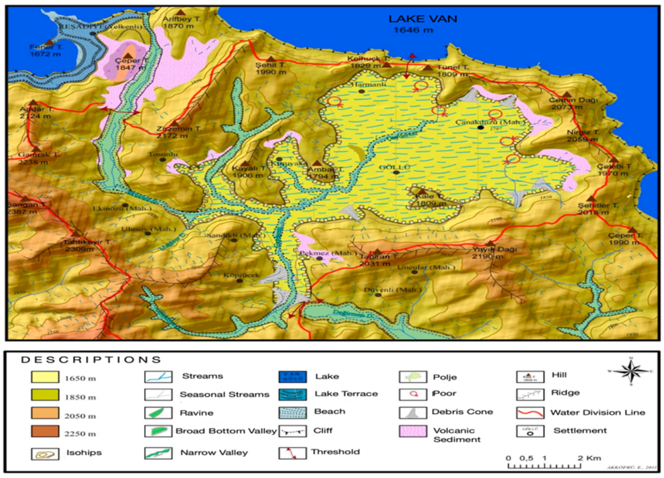

Figure 2. Göllü Polje Basin jeomorphology map (Akköprü, 2011).

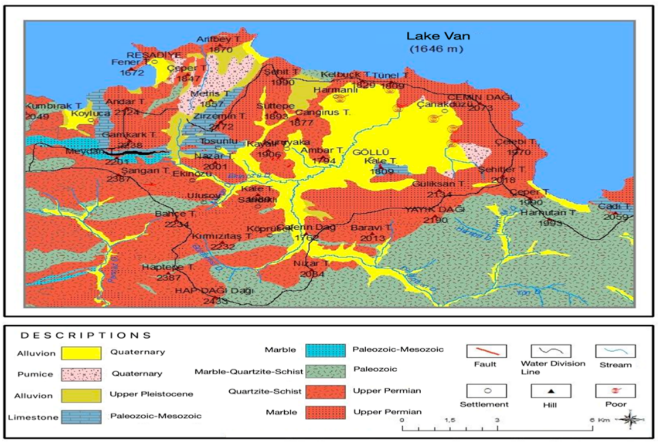

Figure 3. Göllü Polje Basin jeology map (Akköprü, 2011).

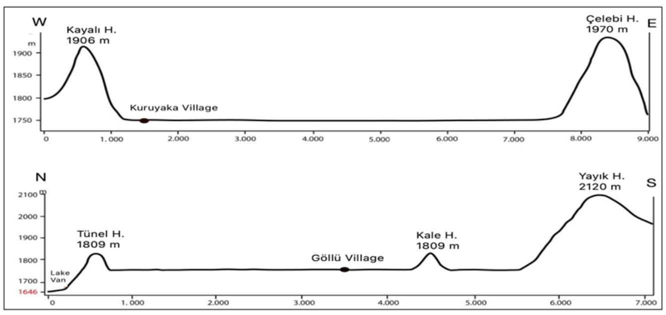

Figure 4. Schematic profiles of Göllü polye (Akköprü, 2011).

<u>*During the rise of Lake Van's water level, the role of the polyoles around Göllü Polje is significant.*</u>

Several thresholds around Lake Van have comparable elevations that significantly influence the lake's hydrology:

• The first threshold is located between the source points of the Ortaklar Stream and the Güzeldere Stream, at an elevation of 1735 m. When the waters of Lake Van rise within the Kotum Valley, they exceed this elevation and subsequently flow into the Güzeldere Valley, effectively entering the Dicle basin.

• The second threshold, previously mentioned, is a neck point on the northern slope of Göllü Polje, at an elevation of 1740 m. If lake waters overflow this point, the Göllü Polje area could become an extension of Lake Van.

• A third threshold, situated south of Göllü Polje within a valley, lies at an elevation of 1765 m. This threshold is expected to function once lake waters, having already flooded the polje from Lake Van via the 1740 m threshold, reach and surpass this elevation, eventually joining the Dicle basin.

• The remaining two thresholds are almost at the same elevation: one at 1785 m on the southern foothills of Mount Nemrut, formed by ignimbrite flows, and another at 1783 m between Göllü and Reşadiye, to the northwest of Göllü Polje.

Within Göllü Polje, the presence of sinkholes at the junction between the valley floor and the slopes has been previously noted. It is hypothesized that during fluctuations in Lake Van's water level, these sinkholes could have functioned in reverse, allowing lake waters to inundate the polje. Specifically, there is a possibility that the lake waters might have filled the polje through these sinkholes, bypassing the need for water to overflow established thresholds. If Lake Van's waters reached the elevation of 1707 m and filled the polje through these sinkholes, Göllü Polje would effectively become part of the Lake Van Basin without reaching the threshold elevation of 1740 m.

1.3. Paleoenvironmental Features of Göllü Polje

The geomorphological characteristics and strategic location of Göllü Polje make it a critical site for addressing our research questions. Notably, the proximity of the polje floor's elevation to the level of Lake Van intensifies our focus on this area, as it offers unique insights into the interactions between karst landscapes and regional hydrology.

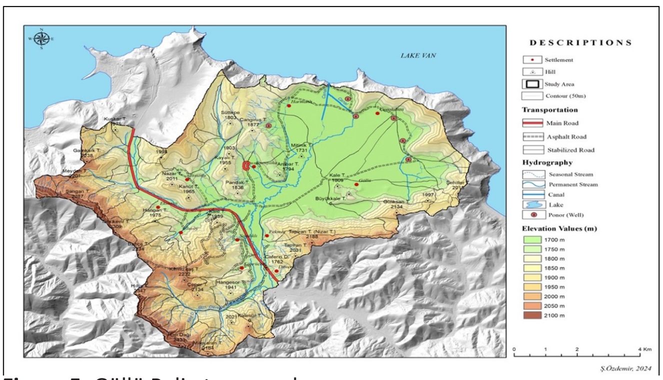

Figure 5. Göllü Polje topography map.

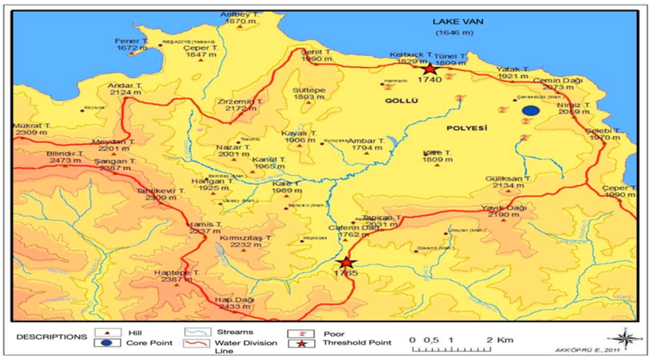

Figure 6. Lake sills and coring point around Göllü Polje (Akköprü, 2011).

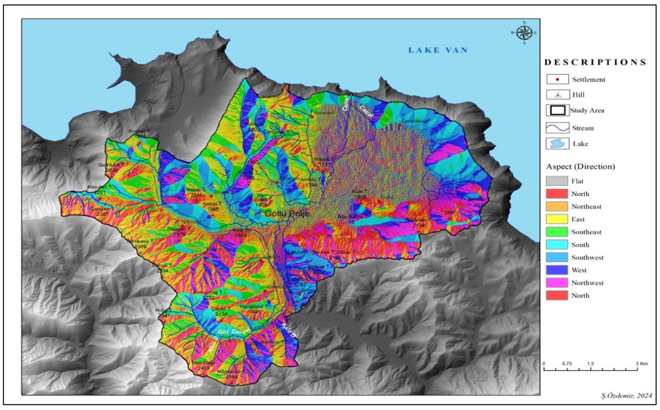

Figure 7. Göllü Polje aspect map.

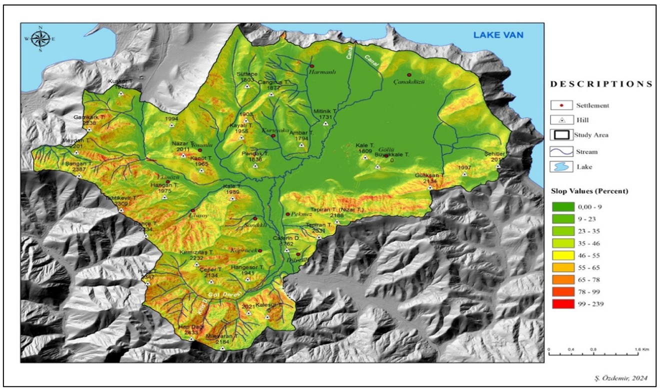

Figure 8. Göllü Polje slope map.

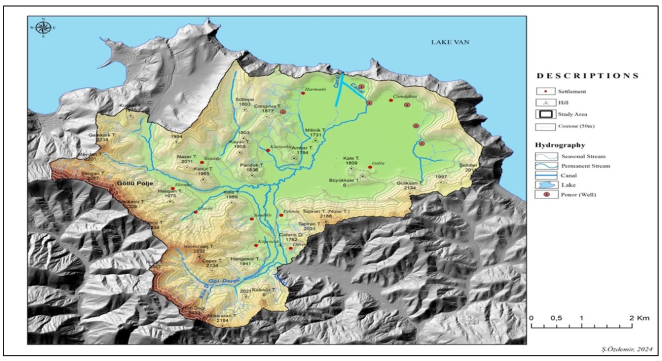

Figure 9. Göllü Polje hidrography map.

Different types of sediments have been identified in the polje area and its surroundings through field studies. These include volcanic deposits, lacustrine sediments, and alluvial deposits. In the following section, the characteristics of each sediment type and the conducted studies will be described in detail.

2. Purpose and Method

Numerous studies have been conducted on the lacustrine deposits within the Van Lake basin, which preserve records of ancient lake levels. A significant focus of these investigations has been on the Göllü Polje, aiming to explore the traces of lake level fluctuations and to clarify the area's relative stratigraphy, chronology, and paleotopography. To achieve this, specific research methods were established, and a comprehensive fieldwork program was organized.

From April 2006 to August 2009, extensive fieldwork was undertaken, involving scientific and technical examinations, laboratory analyses, and desk studies. Until 2008, this work was part of a collaborative effort with Turkish and French scientists under the project 'Late Pleistocene and Holocene Evolution of Eastern Anatolia, Van Lake Basin: Volcanism, Environment and Climate Changes, and Human Communities,' supported by TUBITAK, CNRS, and YYU. The field studies prioritized sedimentary environments ideal for sample collection that would aid in understanding the geological and geomorphological evolution of the area. Special attention was given to exposures in road cuts, small stream channels, and the steep slopes of rivers and lake terraces. Additionally, detailed mapping notes were taken during the surveys, and precise positioning and elevation measurements were recorded using GPS/DGPS. Elevation measurements were particularly accurate, conducted using the WEGM-96 system with a high data quality standard (error margin < 5cm).

Core drilling operations were conducted in the flat area in front of Çanakdüzü Village, located within the Göllü Plain. Three core drill holes, named Çan1, Çan2, and Çan3, were established. These holes, which were parallel to each other, accessed the same sedimentary sequence. Open-ended rods ranging in diameter from 66 to 27 mm (Gujlar-gauge) were employed for core sampling. Subsequently, a significant portion of the research shifted to laboratory analysis. A vast array of samples, collected from various locations and believed to enhance the understanding of the paleoenvironment and assist in dating studies, were sent to the Physical Geography Laboratory at CNRS/Paris 1 University in Meudon, France. Upon arrival, all samples were sorted based on the analytical methods to be applied. These classified samples were then dispatched to the appropriate laboratories for further analysis. The specific methods used for these analyses and the names of the laboratories are detailed below:

-Sedimentology: Grain Size Analysis - CNRS- LGP UMR 8591-Meudon

-Geochemical Analyses:

1. Total Carbon-Nitrogen, Organic Carbon - LGP UMR 8591-Meudon

2. WDS (Wavelength Dispersive Spectrometry) – Paris 6- Jussieu University Camparis Laboratory

-Mineralogical Analyses: IR (Infrared Spectrometry) - (Quartz, Aragonite, Dolomite, Calcite) CNRS- LGP UMR 8591- Meudon

-Dating Analyses: C14, K-Ar, Ar-Ar, U-Th- CNRS- GIF Sur Yvette and Saclay

-Clay Analyses: RX Diffractometry, CNRS- GIF Sur Yvette- Cedex.

-ICP-AES (Inductively Coupled Plasma and Atomic Emission Spectrometry) analysis was carried out at the "Service d'analyse des roches et minéraux" (CNRS, Nancy) laboratories.

3. Results

3.1. Lacustrine and Fluvial Sediments

Core drilling studies have been planned to explore the hypothesis that Lake Van may have overflowed into the polje, leading to the accumulation of lacustrine sediments within it. This initiative aims to rigorously test the validity of this hypothesis

Core Drilling Studies

During the fieldwork conducted within the polje near Çanakdüzü Village, careful consideration was given to selecting the drilling site. The location chosen was the lowest point of the polje, which was also in close proximity to the sinkholes, as confirmed by DGPS measurements. This spot in front of Çanakdüzü Village was deemed ideal for drilling. Three parallel core drillings, named Çan1, Çan2, and Çan3, were carried out. Of these, Çan3 was the deepest, reaching a depth of 7.44 meters. Due to technical errors, the data from Çan2 was excluded from the evaluation. The Çan1 borehole reached a depth of 6.6 meters. Analysis of the borehole logs revealed three distinct stratigraphic units (Figure 10).

The first unit, which is observed at a depth of 2 meters, comprises silty and sandy deposits that contain organic matter. This matter has been stored as a result of periodic floods on the polje floor, extending from the surface down to 1.6 meters (0-1.6 m).

The second unit, found at a depth of 1.5 meters, consists of organic matter-rich, massive brown clay, indicative of a shallow freshwater environment (1.8-4.3 m). The third unit is composed of massive blue clay, which is visible in the last 4 meters of the core (4.3-7.73 m). Additionally, four tephra layers were identified within all the cores at depths of -2.5 m, 3.5 m, 6.4 m, and 7.3 m. The Çan3 borehole is notably terminated with a tephra layer (Figure 10).

Photo 1. Göllü Polyesi dore drilling studies (Akköprü, 2011).

3.1.1. Examined sediments

A total of 84 samples were analyzed to determine the mineralogical composition of the sediments obtained from the cores, focusing on carbonate minerals (calcite, aragonite, and dolomite) as well as quartz content. Additionally, clay mineral analyses—including kaolinite, illite, and montmorillonite—were conducted on 15 of these samples. Although pollen analyses were initially planned, they could not be performed due to time and resource constraints (Figure 10).

During the mineral analyses, special attention was given to the detection of aragonite, which, according to Khoo et al., is the only mineral that precipitates in the waters of Lake Van. The presence of carbonate minerals in the samples provided insights into past moisture levels and climate variations, while the clay minerals offered clues about slope erosion processes. Additionally, the occurrence of quartz minerals indicated fluvial sediment accumulation (Figure 10).

Khoo and colleagues published a seminal study on the geochemistry of Lake Van sediments, indicating that the clay fraction is predominantly composed of mixed-layer clay, a combination of illite and montmorillonite. This mixed-layer clay is believed to have formed from the alteration of clay minerals transported into the lake.

3.1.2. Results of clay mineral analysis

Clay minerals are defined as secondary aluminum silicates with a hydrous component, having a size less than 2 microns in the clay fraction. Their compositions may include varying amounts of iron, magnesium, calcium, potassium, and sodium. These minerals typically form through the chemical weathering of primary minerals, such as feldspars, micas, amphiboles, and pyroxenes (Mater, 1998, p. 36). Analyses of the clay content in the core samples were performed on 15 samples using X-ray diffractometry. The analyses were conducted by Christophe Colin at the LSCE laboratory in France, in April 2008, as detailed in Table 10.

The clay minerals found in the polje cores, along with the values derived from the analyses, are presented in Table 1. Graphs were created for each mineral to facilitate the examination of their correlations and comparisons (see Figure 11). Analysis of the graphs reveals that illite and kaolinite exhibit similar patterns, suggesting they may have been transported into the polje through erosion on the surrounding slopes or by fluvial action from the watershed. The depths at which these patterns peak suggest periods of intense erosion. Conversely, montmorillonite displays an inverse trend compared to the other minerals. Being a clay mineral that forms over time in poorly drained water environments, the peaks of the montmorillonite curve indicate disrupted drainage within the polje, potentially leading to the formation of a seasonal lake during those times (Khoo et al., 1978:84).

When the clay minerals are compared on the graph, it becomes clear that there are distinct periods in the polje characterized by intensified slope erosion, which leads to increased deposition of minerals such as kaolinite and illite.

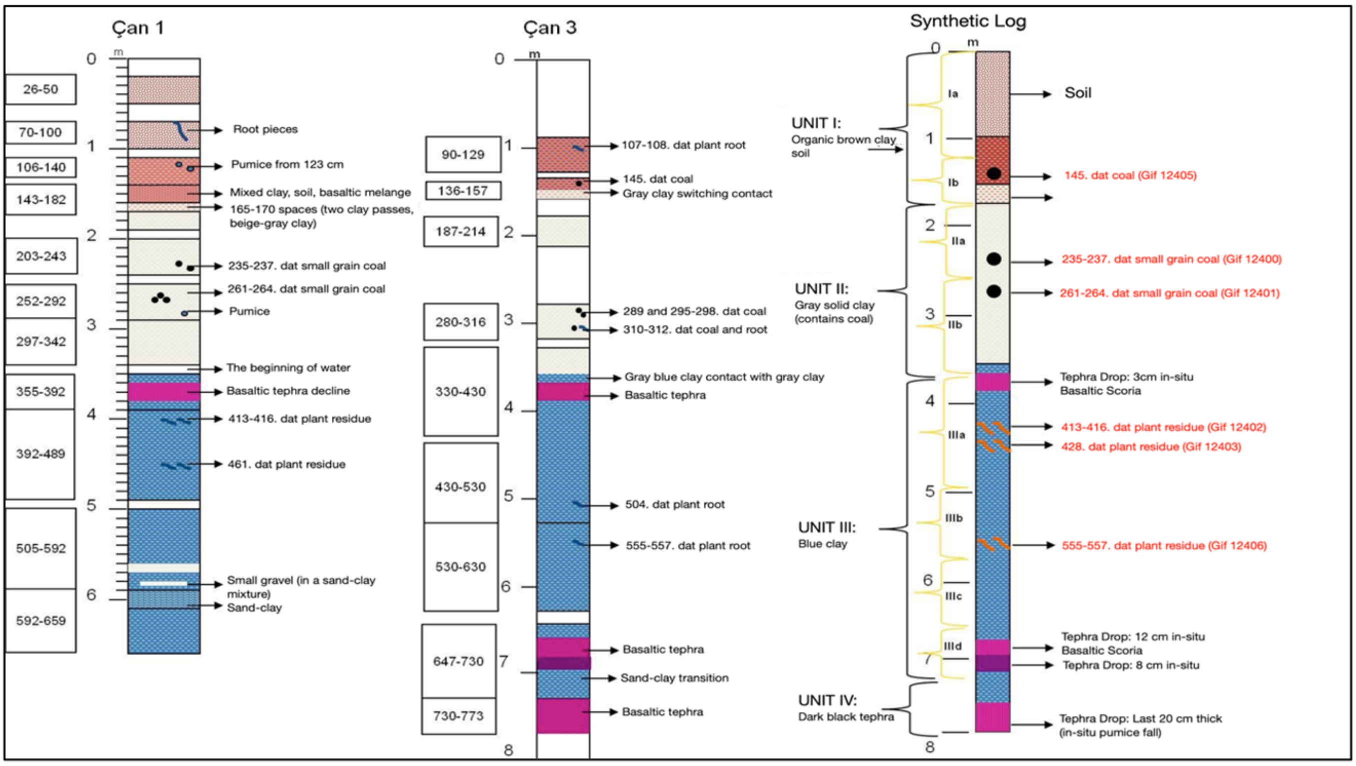

Figure 10. Göllü Polyesi core well logs (Akköprü, 2011).

Table 1. Göllü Polyesi core clay minerals and their values (Akköprü, 2011).

Sample Number	Depth	Smectite %	Illite %	Kaolinite %	Klorite	Montmorillonite
CAN1A/3	38	78,8	14,8	4,7	1,7	4,8
CAN1A/7	78	77,7	16,2	4,8	1,3	4,4
CAN3A/12	123	90,4	6,5	2,3	0,7	12,5
CAN1A/25	149	77,4	15,1	4,5	3	4,3
CAN1B/33	179	89,4	6,2	2,4	2	10,9
CAN3B/23	193	90,4	5,7	2,3	1,7	12,3
CAN1B/41	224	68,1	25,7	2,2	4	2,3
CAN1B/55	273	50,2	39,9	4	5,8	1,1
CAN1B/71	324	75,6	19,1	2,3	3	3,4
CAN1C/101	425	66,9	27,2	2,1	3,8	2,2
CAN3C/55	478	82,3	13	1,7	3,1	5,1
CAN1C/128	518	60,4	32,4	2,1	5,2	1,6
CAN1C/145	572	84,2	12,5	1,3	2	5,8
CAN1C/171	649	71	23,5	2,2	3,3	2,6
CAN3D/87	714	57,2	36,5	2,7	3,6	1,4

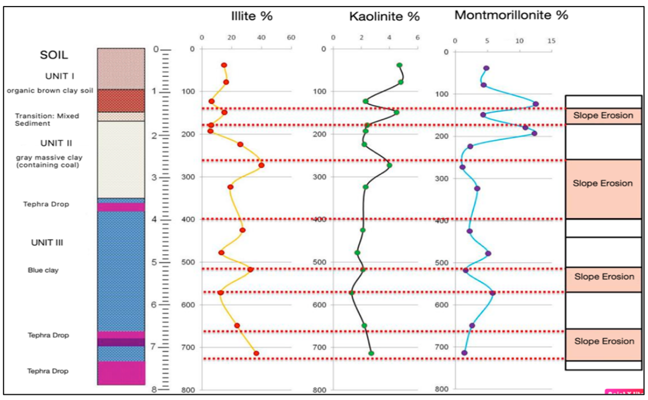

Figure 11. Graphs of Göllü Polyesi core clay minerals (Akköprü, 2011).

Conversely, during periods of reduced slope erosion, when the polje transitions to a lake and river drainage is disrupted, montmorillonite mineral deposits tend to form. These phases appear to alternate in succession.

3.1.3. Quartz mineral analysis results

Quartz mineral content was analyzed using IR spectroscopy on a total of 81 samples at the CNRS-LGP UMR 8591-Meudon laboratory. The results from these analyses were graphically represented and interpreted, as shown in Figure 12. The data from the graph indicate a high proportion of quartz in the sediment cores from the polje, signifying substantial quartz deposition. The peaks of quartz concentration in the core samples correlate with significant sediment influx from the metamorphic watershed into the polje. These peaks are likely associated with periods of heavy rainfall, snowmelt, high river discharge, and strong transport forces. An integrated interpretation of both the clay and quartz data suggests that the high input phases from slope erosion within the polje coincide with the accumulation of river sediments.

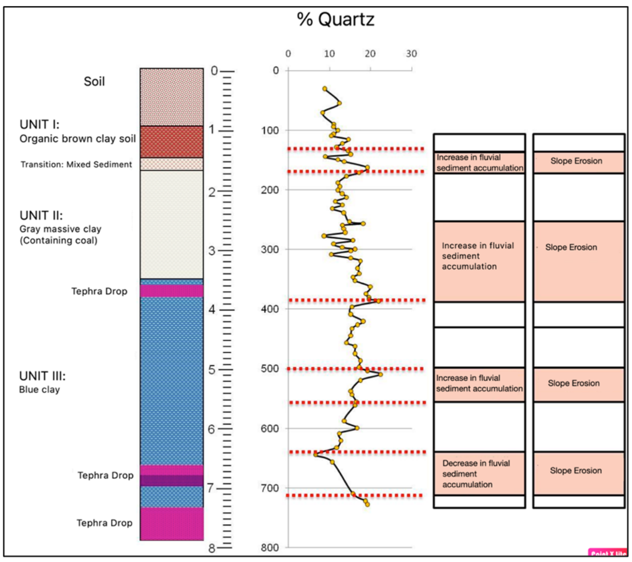

Figure 12. Graph of quartz mineral in Göllü Polyesi core (Akköprü, 2011).

As can be understood from the graph, the proportion of quartz in the sediment extracted from the core is high. This indicates that quartz deposition within the polje is significant. The periods where quartz peaks in the core indicate a substantial input of sediments from the metamorphic watershed into the polje. It can be said that the quartz content increases during periods of heavy rainfall and snowmelt, high river discharge, and strong transport forces. When the clay values and quartz values are interpreted together, it is understood that the periods of high input due to slope erosion within the polje coincide with the periods when river sediments accumulate.

3.1.4. Carbon and Carbonate analysis results

Like quartz, carbonate analyses were performed on 81 samples to identify the types of carbonate minerals present, utilizing IR spectroscopy at the CNRS-LGP UMR 8591 laboratory. The IR spectroscopic analysis was specifically conducted to detect calcite, aragonite, and dolomite in the core samples, but calcite was the only mineral found. Total carbon (C) and nitrogen (N) levels were measured via C/N spectrometry at LGP. HCl was applied to determine total carbonate content, defined as inorganic C, while organic carbon levels were ascertained by subtracting inorganic C from the total sample content.

In Unit III (729-398 cm), represented in Figure 19, the calcite and organic carbon curves show similar patterns. However, in the latter part of Unit II (398-253 cm), the trends diverge, with calcite content increasing and organic C content decreasing. Further up in Unit II (253-170 cm IIa), a rapid and significant rise in calcite levels is observed, whereas organic C content remains consistently low. Unit I (170-30 cm) is characterized by rich organic carbon deposits and very high, abrupt calcite concentrations.

4. Assessment

The presence of calcite in the core samples suggests there were periods with deep-water environments within the polje, as calcite precipitates in deep-water settings at approximately 4°C (Khoo, 1978:89). Variations in the core's calcite content, such as the observed decreases, hint at the formation of shallow and temporary lake environments within the polje. Specifically, the notably low levels of calcite at the 5th-meter mark of the core suggest a lack of a lake environment, indicating the polje may have been completely dry at the end of Units IIIb and IIb. This could have led to the initiation of soil development, as evidenced by plant residues found within the core. The transition points between shallow lake conditions and the beginning of soil formation are marked within the core at depths of 572 cm (base of IIIb), 497 cm (just above IIIb), and 398 cm (base of IIb).

The joint interpretation of the clay, quartz, carbonate, and organic carbon mineral data from core analyses reveal distinct periodic events in the polje's evolution. The synthetic graph, which compiles these data, outlines the phases of mineral deposition associated with each unit. Each identified phase commences with conditions indicative of a deep freshwater lake environment, during which lower temperatures and increased precipitation lead to reduced evaporation. Subsequently, a transitional period forms a seasonal and shallow lake environment, characterized by higher temperatures and increased evaporation. The end of a phase is marked by intense river and slope erosion, suggesting periods of considerable rainfall and temperatures favorable for snowmelt. These cyclical phases appear to have occurred numerous times in succession. The polje's current alluvial plain is a cumulative outcome of these repetitive lacustrine episodes, combined with the terrestrial impacts brought about by climatic variations.

The lack of aragonite in the carbonate analyses from the core samples suggests that Lake Van's waters did not overflow into the polje. This implies that throughout the Pleistocene epoch, despite the water level fluctuations in Lake Van, the lake did not discharge into the Tigris Basin through the surrounding thresholds of the polje.

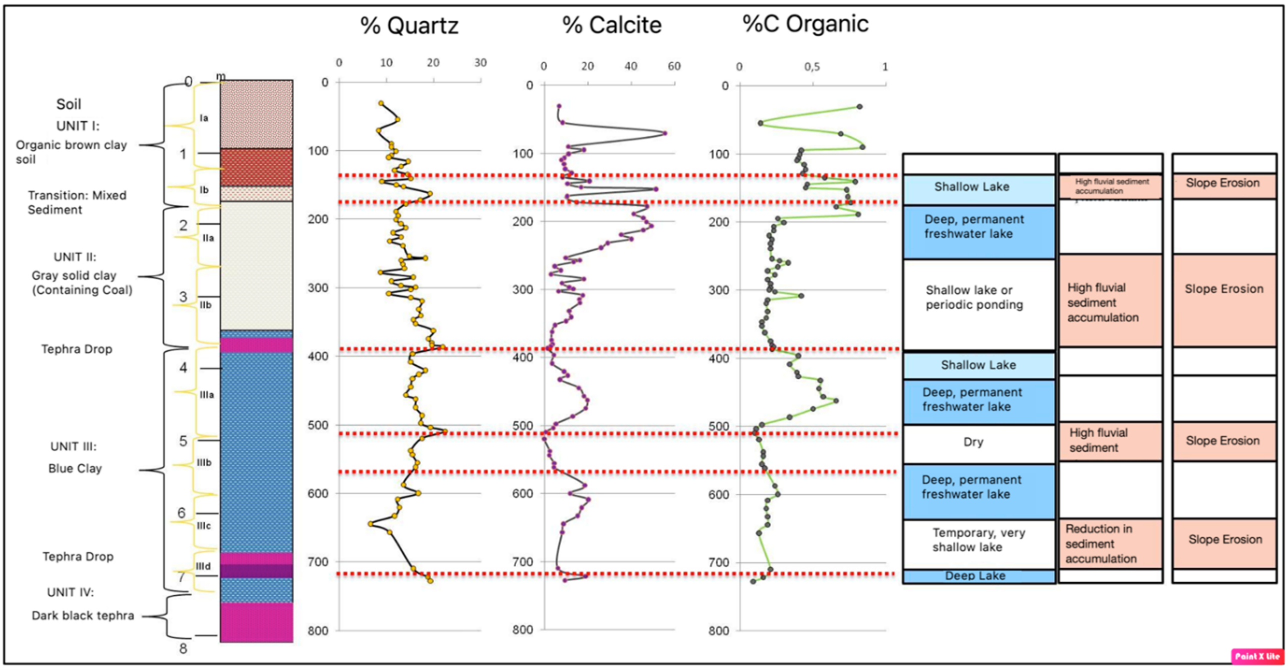

Figure 13. Comparison of Calcite, Quartz and Organic Carbon graphs of Göllü Polyesi core (Akköprü, 2011).

4.1. Dating

A total of 11 core samples were designated for C14 analysis, but only 6 were deemed viable. The analyses were carried out by Specialist Michel Fontugne at the LSCE, Gif Sur Yvette, and the ARTEMIS AMS spectrometry laboratories. The C14 dating results revealed discrepancies between the core depths and the ages, indicating potential issues with using the ages to determine the timeline of sediment deposition on the polje floor.

For instance, the ages attributed to samples Gif 12400 and 12401 likely represent the time of organic material (such as charcoal) that was transported from the slopes by wind or river erosion rather than the time of sediment accumulation. These samples, extracted from depths of -235/237 cm and 261/264 cm, are associated with the transition from a dry period to the establishment of a lacustrine environment on the polje floor. Conversely, the ages of samples Gif 12402 (-413/416 cm) and Gif 12403 (-428 cm) display an inverted relationship. The layer from which sample Gif 12403 was taken marks the onset of soil formation on the polje floor, and it contained plant roots, leaves, and branches, which are considered ideal for providing reliable radiocarbon dates.

For a comprehensive interpretation of Göllü Polje's chronology, it was essential to combine all analytical results. An initial assessment integrated the quartz and carbonate analysis with the C14 dating data. This was followed by a comparison with varve sediment analysis from Lake Van, as documented by Lemcke and Sturm in 1997, to correlate the chronologies from both sites.

The C14 dating of the Göllü Polje cores, in conjunction with the mineral analysis at corresponding depths, suggests that the soil formation period identified between -428 to -439 cm dates back to around 9000 BP. This was cross-verified by comparing carbonate analysis from the Lake Van floor with Göllü Polje's carbonate data. The comparative analysis revealed nearly identical graph curves, thus validating the C14 age for sample Gif 12403 (-428 to -439 cm) and corroborating its antiquity of approximately 9100 BP.

Furthermore, analysis alignments indicated that phase IIIa (-497 to -398 cm) from the Göllü Polje soil formation coincides with an average varve age of 10600 to 8300 BP. This timeframe aligns with the onset of the Holocene period in Central Anatolia, identified by Kuzucuoğlu et al. in 1997 as between 10.6 ka and 8.2 ka.

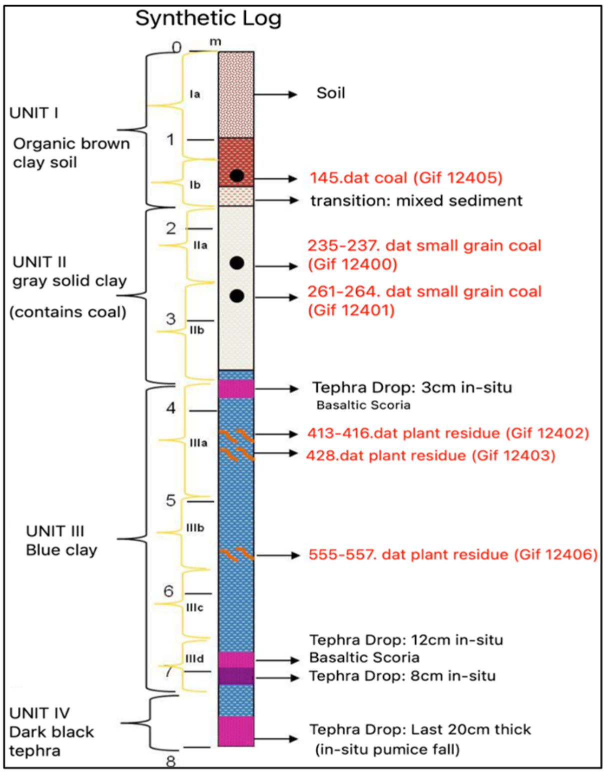

Figure 14. Location of C14 Samples in the core log of Göllü Polyesi (Akköprü, 2011).

The elevated ratios of quartz and carbonates in Lake Van's sedimentary deposits have been dated to the Younger Dryas period (10,600-11,800 varve years), which coincides with phase IIIb (497-572 cm) of the Göllü Polje sediment profiles, a period characterized by arid conditions. Furthermore, in the graphs from Göllü Polje, phase IIIc (572-652 cm) aligns with a period on Lake Van basin graphs, as indicated by Lemcke and Sturm, with varve ages between 11,800 and 13,000 years. This period is marked by an elevated calcite ratio in the polje's graphs, signifying a warming trend leading to snowmelt and subsequent water deposition on the polje floor, while vegetation was still largely confined to slopes.

Radiocarbon dating of sediment cores from Göllü Polje reveals that only the age determination of sample Gif 12403 can be reliably used to represent the chronological sequence of the polje floor. The older ages obtained from the other samples do not reflect the sediment deposition chronology of the polje floor directly. Instead, these samples date the eroded materials that originated from surrounding slopes and were subsequently deposited onto the polje floor.

Table 2. C14 Dating Analysis Results of Göllü Polje (Akköprü, 2011).

Lab. Ref. Number	Sample Number	Aged Material	Organic Content	d13C	C^{14} BP Conventional Age	Calibrated Age BP	%68 Calibration Range BP	Average Calibrated Age BP	Comment
			(%)	‰					
Gif12405	Can3/145	Coal	1,3	-26,00	5550±30	6351±36	6315-6387	~6360	Normal
Gif12400	Can1/235-237	Coal soil	0,34	-28,50	11600±45	13478±112	13366-13590	~12500±100	Too old
Gif12401	Can1/261-264	Coal soil	0,27	-28,60	15490±70	18716±164	18551-18880	~18700±150	Too old
Gif12402	Can1/413-416	Plant residue	0,97	-27,80	9955±40	11403±102	11300-11505	~11400±100	Opposite
Gif12403	Can1/428	Plant residue	1,5	-26,90	8130±35	9070±41	9028-9111	~9075±40	Opposite
Gif12406	Can3/555-557	Plant residue	0,53	-26,70	12950±70	15763±407	15356-16170	~15750±400	Normal

(Calibration http://www.calpal-online.de- Copyright 2003-2007 made accordingly.)

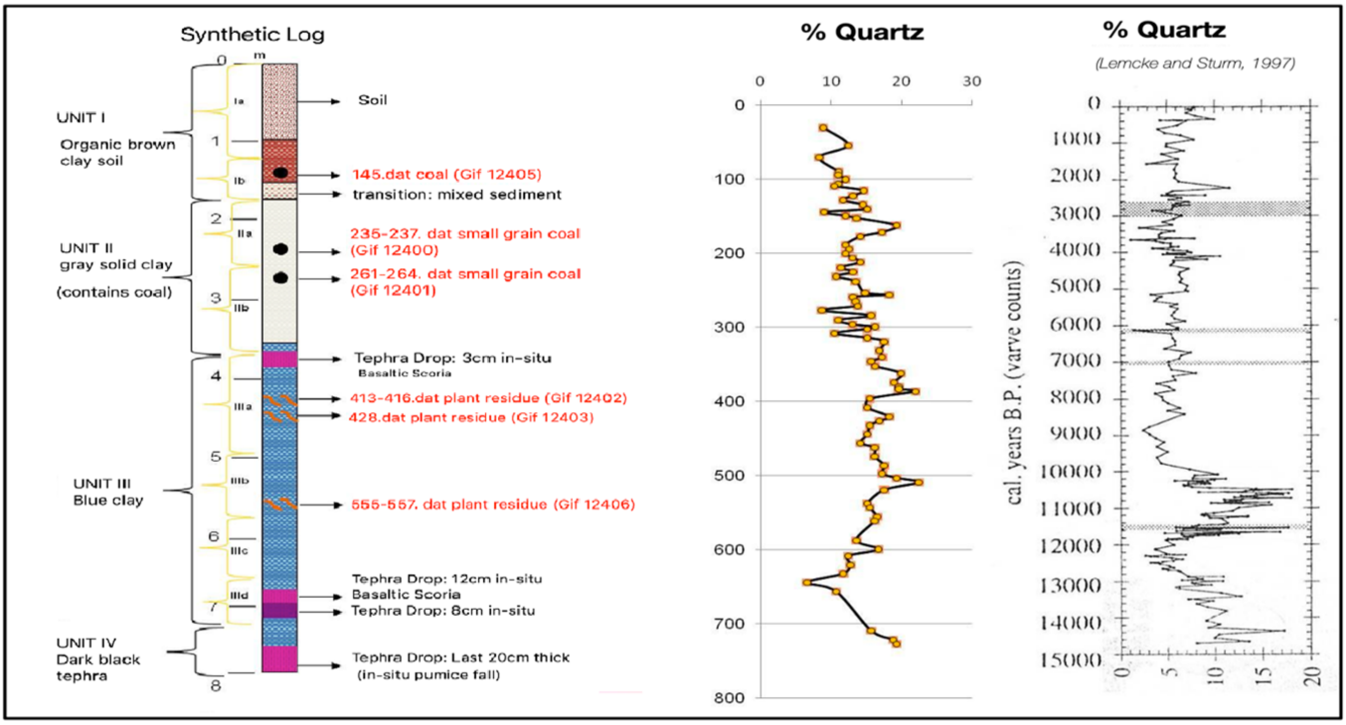

Figure 15. Comparison of the quartz mineral ratio at the bottom of Lake Van and the base of Lake Göllü Polje (Akköprü, 2011).

4.1.1. Volcanic deposits

Basaltic scoria deposits underlain by light-colored, altered pumice have been identified on the northern slope of Göllü Polje, indicative of the area's volcanic activity. Comparable strata of volcanic material are also evident on various slopes encircling the polje as well as within the valley interiors.

In the sediment cores from Göllü Polje, distinctive layers with pumice remnants were identified at depths of -127-133 cm, -524-527 cm, -572-575 cm, and 672-689 cm, suggesting multiple volcanic events. The core from the Çan3 well concludes with a 43 cm thick volcanic deposit between -730-773 cm, distinguished by scoria and basaltic characteristics.

4.1.2. Origin of Volcanic Deposits in Göllü Polje

Located approximately 20 km west of Göllü Polje is the İncekaya volcanic area, while the Nemrut Volcano stands 35 km to the northwest. The geological impact of these volcanoes is strongly manifested in the sedimentary layers within Göllü Polje, as evidenced by widespread volcanic deposits observed throughout the study area.

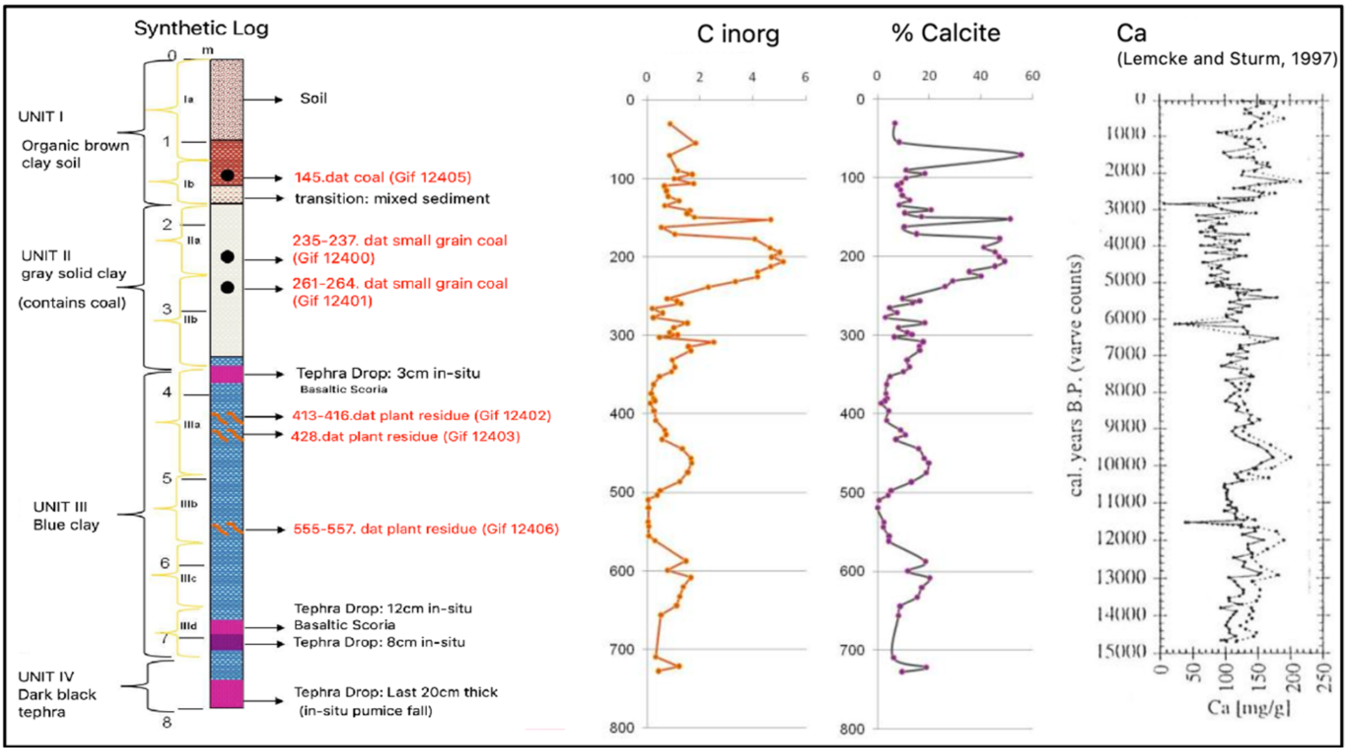

Figure 16. Comparison of the carbonate mineral ratio at the bottom of Lake Van and the base of Göllü Polje (Akköprü, 2011).

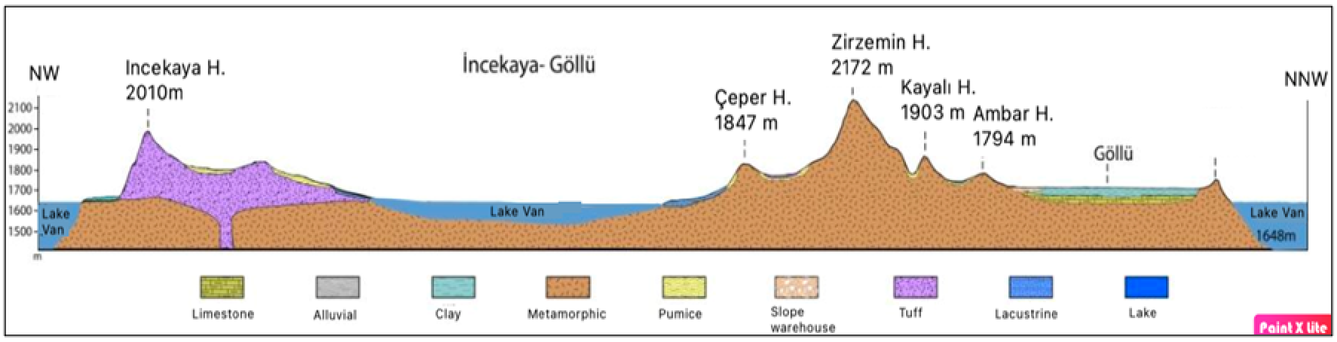

Figure 17. Geological profile and cross-section of the area between İncekaya and Göllü (Akköprü, 2011).

Geological cross-sections were constructed to depict the dispersal of tephra layers around Göllü Polje, as illustrated in Figures 18-19. The selection of section lines was meticulously planned to intersect zones where pumice distribution had been observed firsthand during field investigations.

In various sections around Göllü Polje, it was noted that the upper strata of pumice layers are often overlaid with alluvial deposits. Specifically, in a section northeast of a coring location within the polje, a basaltic scoria deposit capped by pumice fall was documented. From this section, two distinct samples were collected, labeled Van 07-21 for the pumice and Van 07-21a for the basaltic scoria.

Figure 18. Map showing the cross-sectional lines of the Göllü Polyesi (Akköprü, 2011).

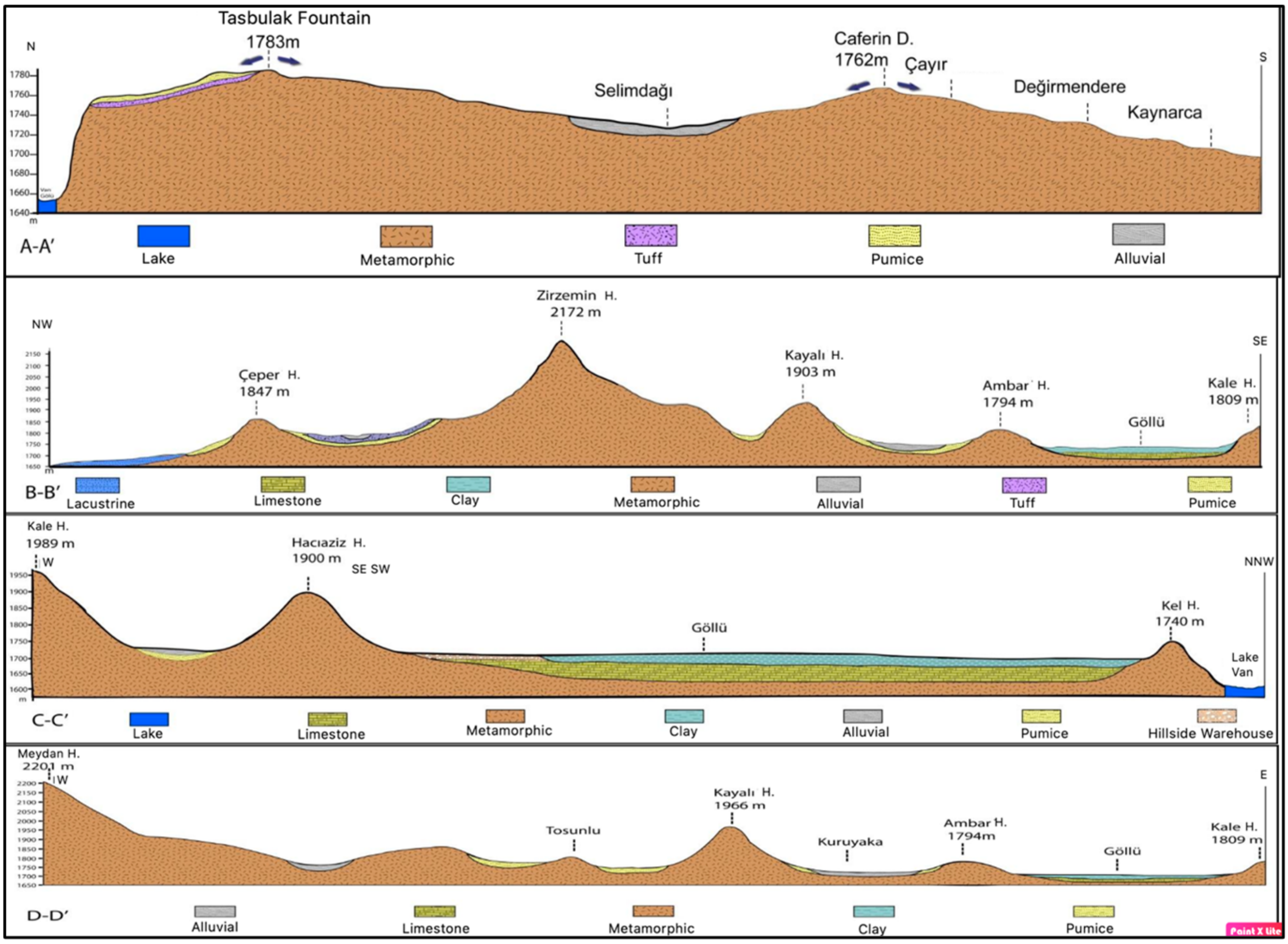

Figure 19. Geological sections of Göllü Polyesi (Akköprü, 2011).

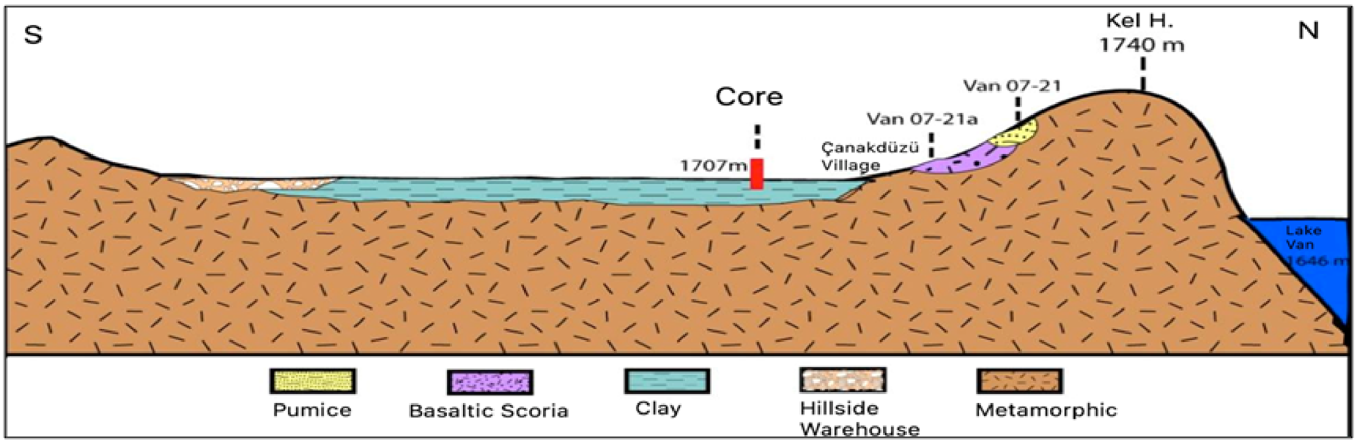

Figure 20. Geological section showing the core point of Göllü Polje and the location of the samples taken from the slope (Akköprü, 2011).

Geochemical Analysis Results of Nemrut and İncekaya Volcanic Materials in and Around Göllü Polje

From the Göllü core, seven tephra samples were collected and identified as suitable for geochemical analysis, with their locations indicated in the core log. The preparation of these samples for analysis of feldspar and volcanic glass minerals was performed at the LGP laboratories, and the actual Wavelength Dispersive Spectrometry analyses took place at the Camparis Laboratory, University of Paris-Jussieu, from January 2009 to February 2010.

Based on the feldspar geochemistry, an AFM ternary diagram was constructed, revealing that the majority of samples, once thought to be basaltic—including those from the northern slopes and within the cores—are composed primarily of anorthoclase. Exceptionally, the sample CAN1/C145 sourced from a depth of -127-133 cm exhibits a composition of both labradorite and anorthoclase. The separate sample Van 07-21a, collected from the slope, also falls into the labradorite category, which suggests that the CAN1/C145 sample has been contaminated with basaltic materials from the slopes.

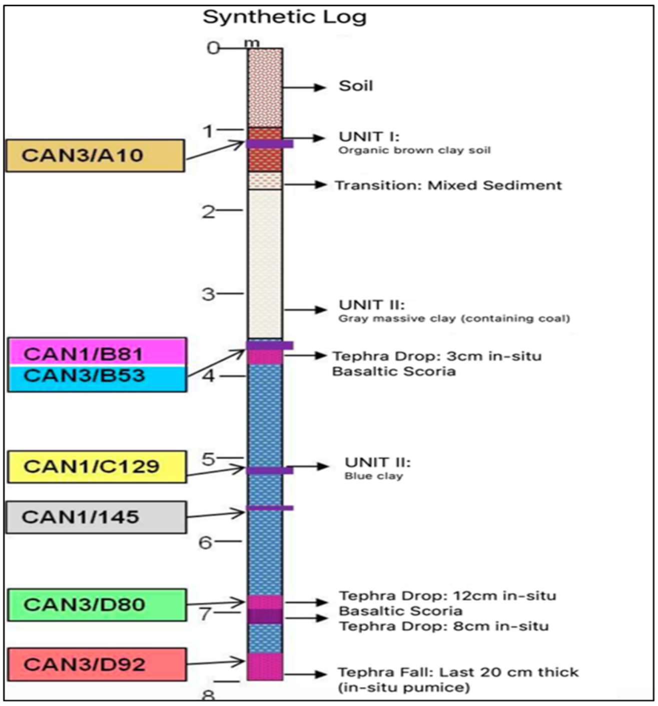

Figure 21. Location of Tephra samples in the core log of Göllü Polje (Akköprü, 2011).

Out of all the samples from the Göllü core, volcanic glass minerals could be geochemically analyzed in only one, labeled as CAN3/D80, derived from a depth of -672-689 cm and associated with a feature indicative of an in situ tephra fall. Further geochemical analyses were performed on tephra from surrounding slopes with matching characteristics to that of sample CAN3/D80. The geochemical data from these analyses have been plotted on a TAS diagram, which is depicted in Figure 23. According to the diagram, the tephra is geochemically identified as trachytic.

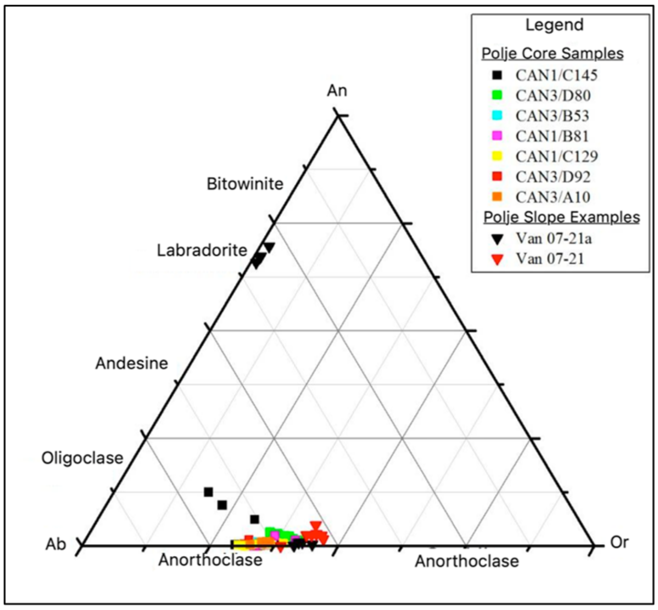

Figure 22. Ternary diagram showing the geochemical properties of feldspar mineral in Göllü Polye volcanic deposits (Akköprü, 2011).

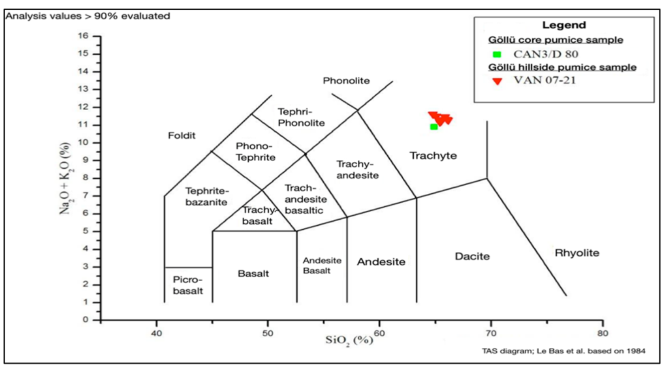

Figure 23. TAS diagram showing the geochemical characteristics of volcanic glass minerals in Göllü Polje samples. (Akköprü, 2011).

5. Discussion

This study examines the geomorphological features of Göllü Polje and its possible hydrological connections with Lake Van. The research aims to understand how Göllü Polje responded to historical changes in Lake Van's water levels and the impacts of these processes on the polje.

The findings indicate that Göllü Polje has been affected by fluctuations in Lake Van's water levels. Mineral analyses from core samples reveal that during certain periods, slope erosion increased, leading to the deposition of minerals such as kaolinite and illite within the polje. These findings suggest that the rise in Lake Van's water levels increased the amount of sediment transported to Göllü Polje. Additionally, the precipitation of montmorillonite mineral was observed during periods when the polje transitioned into a lake form. This indicates that drainage was disrupted during these periods, which occurred cyclically.

However, the absence of aragonite minerals in Göllü Polje indicates that Lake Van's water levels did not exceed the current threshold within the polje, and the lake waters did not directly flow into the polje area. This finding suggests that, despite fluctuations in Lake Van's water levels, the polje has maintained an independent hydrological system.

6. Conclusion

This study on the geomorphological and hydrological connections between Göllü Polje and Lake Van reveals that the polje responded to past fluctuations in the lake's water levels, leaving significant geomorphological traces in the polje area. The findings show that although the polje does not have a direct hydrological connection with Lake Van, it is indirectly affected by changes in the lake's water levels.

The results of this study provide important insights into the geological processes and water level changes around Lake Van. Future research should focus on a more detailed examination of the geomorphological evolution of Göllü Polje and its potential hydrological connections with Lake Van to better understand how these areas respond to environmental and climatic changes.

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Confilict of Interest / *Çıkar Çatışması*

The authors declare that there is no conflict of interest. *Yazarlar herhangi bir çıkar çatışması olmadığını beyan eder.*

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