Türkiye Jeoloji Bülteni
Geological Bulletin of Turkey
68 (2025) 205—224
doi: 10.25288/tjb.1646179

Gürlevik Tufa Waterfall: Facies Characteristics, Depositional Systems and Geoheritage Potential (Erzincan, East Anatolia)

Gürlevik Tufa Şelalesi: Fasiyes Özellikleri, Depolanma Sistemleri ve Jeomiras Potansiyeli (Erzincan, Doğu Anadolu)

Yakup Çelik[1], Ezher Tagliasacchi[2*]

[1] *Istanbul University-Cerrahpasa, Faculty of Engineering, Department of Geological Engineering, İstanbul, Türkiye*
[2] *Pamukkale University, Faculty of Engineering, Department of Geological Engineering, Denizli, Türkiye*

• Geliş/Received: 25.02.2025 • Düzeltilmiş Metin Geliş/Revised Manuscript Received: 11.03.2025 • Kabul/Accepted: 12.03.2025
• Çevrimiçi Yayın/Available online: 16.04.2025 • Baskı/Printed: 30.04.2025

Araştırma Makalesi/Research Article *Türkiye Jeol. Bül. / Geol. Bull. Turkey*

Abstract: Gürlevik tufa, located in the southeast of the Erzincan (East Anatolia) pull-apart basin, represents a typical cascade/waterfall deposit developed in a fluvial environment. Calcareous tufa formed at three different levels. However, the facies properties and depositional system of the Gürlevik tufa formation remain unknown. This study aims to investigate the evolution of the tufa deposits and to clarify their facies changes in this tectonically active basin. For this purpose, seven measured sedimentary logs were obtained from field studies, and the lithofacies were described and interpreted based on their morphological properties, microscopic and biological contents. According to facies analysis, six lithofacies were identified and two depositional systems (perched springline/cascade and barrage-dammed) were determined. The monumental cascade/waterfall tufa accumulation is a consequence active tectonic and climatic factors in the region. Gürlevik tufa deposits are located in a protected natural site. This preliminary study draws attention to the geological importance of these sedimentary rocks, which record climate changes with high precision, as well as their geological heritage potential, that should be preserved and transferred to future generations.

Keywords: Depositional system, East Anatolia, Erzincan, Gürlevik fluvial tufa, lithofacies.

Öz: *Erzincan (Doğu Anadolu) çek-ayır havzasının güneydoğusunda yer alan Gürlevik tufaları, akarsu ortamında gelişmiş karakteristik bir şelale tipi depolanma ürünüdür. Tufalar, üç farklı seviyede basamaklar şeklinde oluşmuştur. Ancak, Gürlevik tufa çökellerinin fasiyes özellikleri ve depolanma sistemi tam olarak bilinememektedir. Bu çalışma, tektonik olarak aktif olan bu havzada tufa çökellerinin gelişimini araştırmayı ve fasiyes değişimlerini aydınlatmayı amaçlamaktadır. Bu amaçla, arazi çalışmaları kapsamında yedi adet ölçülü stratigrafik kesit alınmış ve bu ölçülü stratigrafik kesitlerden litofasiyesler morfolojik özellikleri, mikroskobik ve biyolojik içerikleri temel alınarak tanımlanmış ve yorumlanmıştır. Fasiyes analizlerine göre, altı litofasiyes tanımlanmış ve iki çökelme sistemi (tünek tipi/şelale ve baraj-set) belirlenmiştir. Anıtsal bir görünüm sunan bu şelale tufa birikimi, bölgedeki aktif tektonizma (diri faylar) ve iklimsel faktörlerin bir sonucudur. Gürlevik tufaları, doğal sit alanı olup koruma altına alınmıştır. Gerçekleştirilen bu ön çalışma iklim değişikliklerini yüksek hassasiyette kayıt altına alan bu sedimanter kayaçların jeolojik öneminin yanı sıra korunarak gelecek kuşaklara aktarılması hususundaki jeolojik miras potansiyeline de dikkat çekmektedir.*

Anahtar Kelimeler: *Depolanma sistemi, Doğu Anadolu, Erzincan, Gürlevik akarsu tufaları, litofasiyes.*

[*] Yazışma / *Correspondence:* egulbas@pau.edu.tr

http://tjb.jmo.org.tr
http://dergipark.gov.tr/tjb

Introduction

Calcareous tufa, or tufa, are terrestrial carbonate deposits deposited by calcium bicarbonate-rich, ambient temperature waters with low depositional rates, soft, porous calcareous rock and abundant mosses forming in springs, waterfalls and lakes in limestone areas (Pentecost, 1981; Ford and Pedley, 1996; Capezzuoli et al., 2014). The development of tufa is strongly related to the location of deposition, underlying topography, abundance of flora, colonisation by blue-green algae (cyanobacteria) and water flow regime (Villes and Gaudie, 1990). These rocks are sensitive to climatic changes and commonly form in semi-arid to temperate climate conditions from saturated waters because of degassing carbon dioxide (Pentecost, 1981) and microbial activity (Arenas-Abad et al., 2010; Capezzuoli et al., 2014). Many calcareous tufa deposits are found in karstic topography (Ford and Pedley, 1996; Özkul et al., 2010).

The present study focuses on tufa formation in a cascade at the southeast margin of the pull-apart Erzincan Basin, in eastern Anatolia. This tectonically active area is home to a monumentally impressive tufa waterfall/cascade formation. Furthermore, this tufa formation, known as Gürlevik or Çağlayan ("waterfall" in Turkish) tufa, is well-exposed and exhibits both vertical and lateral facies distribution. Gürlevik Waterfall is an important geosite due to being one of the tallest waterfalls in Türkiye and the presence of significant tufa terraces. Moreover, active tufa occurrences continue to exhibit ongoing growth (aggradation and progradation) in the investigated area. Gürlevik tufa has unfortunately not received much attention to date, except for a few studies published in recent years (Uysal, 2024; Uysal and Sunkar, 2024). Uysal and Sunkar (2024) mentioned Gürlevik waterfall and its value in detail although they identified these terrestrial carbonate deposits as "travertine" instead of "tufa". We present preliminary data and observations about Gürlevik fluvial tufa cascades in terms of their facies properties and distribution. This present work also aimed to clarify the debate about the terminological definition of terrestrial carbonate sediments, which has caused confusion. Moreover, we propose initiatives for Gürlevik calcareous tufa cascades and other key point natural resources in this region aimed at guiding further research about the geoheritage potential and geotourism in this region.

GEOLOGICAL SETTING

The Erzincan Basin is the largest sedimentary basin and is a strike-slip basin which formed along the North Anatolian Fault Zone (NAFZ) (Aktimur et al., 1995; Aydın et al., 2019; Figure 1a). The Erzincan Basin (N 39°36' 20"; E39°41'45"), in which the study area is located, developed near the boundary of the suture between the Pontides and Anatolides (Okay and Tüysüz, 1999). It is a region with active tectonic activity from past to present due to the influence of two important fault systems, the North Anatolian Fault Zone (NAFZ) and the East Anatolian Fault Zone (EAF), and therefore has geologically complex features (Bozkurt, 2001; Akpınar et al., 2016) (Figure 1b). Tectonic models proposed to explain the basin range from simple rhomboidal pull-apart to complex multi-phase evolution. The elevation of basin is 1218 m and length of basin is up to 40 km.

The Erzincan basin has different lithologic and stratigraphic characteristics. The basement of the study area consists of Palaeozoic rocks, which are overlain by the relatively thick Triassic-Cretaceous Munzur limestone composed of neritic limestones, conglomerate, sandstone-shale, and melange (Tüysüz, 1992; Gedik, 2008; Figure 1c). This unit is tectonically overlain by a Cretaceous ophiolitic complex. Ophiolites are represented by serpentinite, serpentinised peridotite, and rarely mafic rocks (Koçyiğit, 1990; Tüysüz, 1990; Aktimur et al., 1995; Gedik 2008). These units are unconformably overlain by Palaeogene-Neogene clastic and carbonaceous deposits of the Gülandere formation (Gedik, 2008).

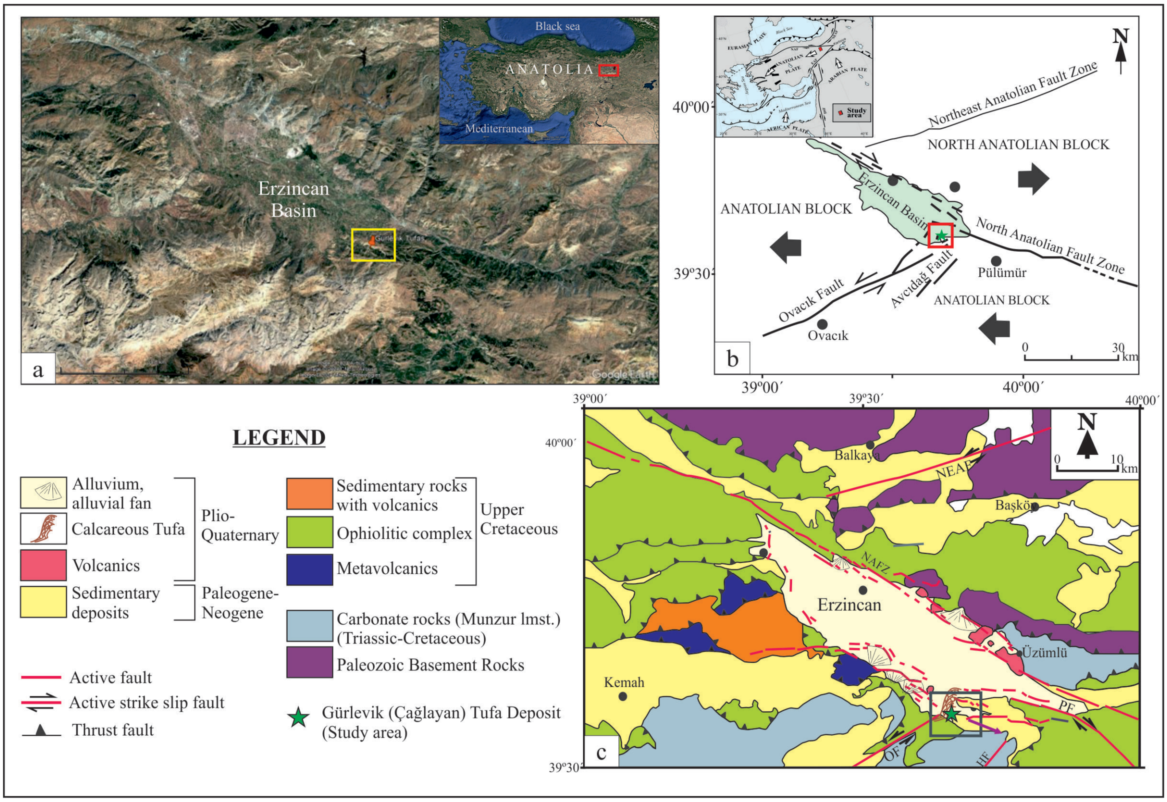

Figure 1. **a)** Satellite image of East Anatolia and the pull-apart Erzincan Basin. The yellow rectangle indicates the study area and Gürlevik tufa; **b)** Tectonic structures of the Erzincan Basin and surrounding area (simplified from Barka and Gülen, 1989; Kaypak and Eyidoğan, 2005, Tatar et al., 2013; Aydın et al., 2019); **c)** Geological units of Gürlevik and surroundings (modified from Emre et al., 2012; Akpınar, et al., 2016; Aydın et al., 2019). HF: Heltepe Fault, NAFZ: North Anatolian Fault Zone, NEAFZ: North East Anatolian Fault Zone, OF: Ovacık Fault, PF: Pülümür Fault.

***Şekil 1**. **a)** Doğu Anadolu ve Erzincan çek-ayır Havzası'nın uydu görüntüsü. Sarı dikdörtgen araştırma alanını, Gürlevik tufalarını göstermektedir; **b)** Erzincan Havzası ve çevresindeki tektonik yapılar (Barka ve Gülen, 1989; Kaypak ve Eyidoğan, 2005, Tatar vd., 2013; Aydın vd., 2019'dan basitleştirilmiştir). **c)** Gürlevik ve çevresindeki jeolojik birimler (Emre vd., 2012; Akpınar, vd. 2016; Aydın vd., 2019'dan değiştirilmiştir). HF: Heltepe Fayı, NAFZ: Kuzey Anadolu Fay Zonu, NEAFZ: Kuzey Doğu Anadolu Fay Zonu, OF: Ovacık Fayı, PF: Pülümür Fayı.*

The youngest rock units in the study area are represented by volcanics composed of dacite, andesite, rhyolite, basalts and pyroclastics, and fluvial sediments characterised by calcareous tufa and clastics within the Erzincan basin (Figure 1c).

The Gürlevik calcareous tufa deposits are porous terrestrial carbonates formed along river channels by interactions between ambient precipitation of calcium carbonate ($CaCO_3$) and organisms along Kalecik stream valley. Gürlevik tufa formed as a cascade tufa deposit with a thickness of up to 45 m. All the formations are unconformably covered by alluvium of Quaternary age (Figure 1c). Coarse–grained alluvial fans are observed along the northern and southern borders of the Erzincan Basin.

MATERIALS and METHODS

The research was performed during autumn 2024 through field work and suitable sample selection. The fieldwork included sedimentary logging (lithofacies description and interpretation, sedimentary structures), sampling for petrographic analysis (thin section) and also photographing the study area with a drone (Figure 2).

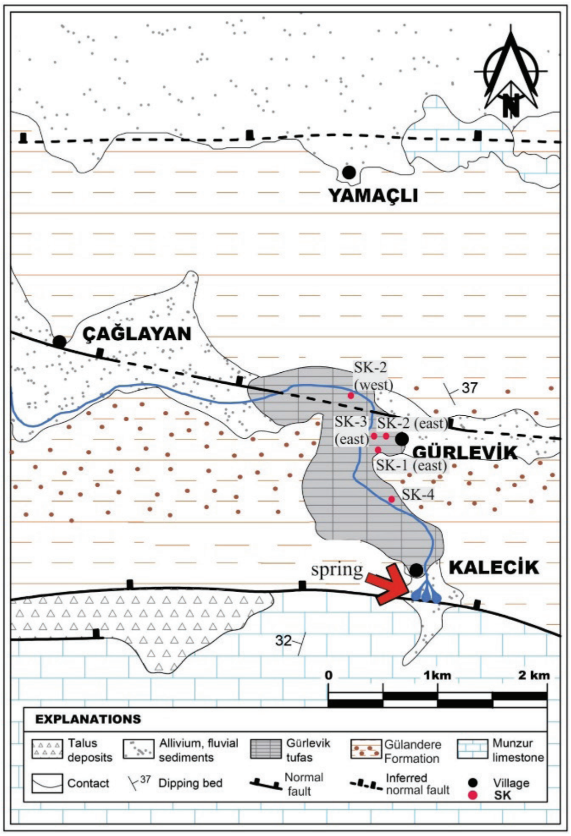

Figure 2. Geological units of Gürlevik and surroundings (modified from Akpınar et al., 2016). SK: Measured sedimentary log

Şekil 2*. Gürlevik ve çevresinin jeolojik birimleri (Akpınar vd., 2016'dan değiştirilmiştir). SK: Ölçülü sedimanter kesit.*

Gürlevik tufa outcrops formed in three different steps depending on different levels of spring water. For that reason, these tufa deposits were investigated separately as east and west sites. In total, seven measured sedimentary logs were taken, all facies were described and interpreted based on their morphological properties, and some characteristic structures such as presence of stromatolites, bryophytes, vertical stems etc. were noted. Identification of lithofacies was based on the descriptions of terrestrial carbonates by Ford and Pedley (1996) and Arenas-Abad et al. (2010). Tufa samples were collected for thin sections and prepared at İstanbul University-Cerrahpaşa, Geological Engineering Department and Pamukkale University, Geological Engineering Department, Denizli. In order to conduct the analyses, a polarised light microscope was used. Carbonate textural characteristics were determined according to the Dunham (1962) classification. Moreover, Folk's classification was used for the classification of carbonate rocks (Folk, 1959, 1962).

RESULTS

Gürlevik Tufa Facies

The Gürlevik tufa deposits consist of active and fossil precipitation due to changes in the direction of water flow from the Quaternary to the present. The tufa cascades have variable thickness, ranging from 5 to 22 m (Figure 3a, c). Approximately twenty metres above the present-day spring orifice, perched carbonate tufa cascade deposits formed at the southeastern margin part of the Erzincan Basin representing a perched springline tufa (Pedley, 1990; Pedley et al., 2003) or cascade/waterfall (Arenas-Abad et al., 2010). According to field work and detailed sedimentological observations, six different tufa and accompanying clastic facies were described and interpreted from the perched springline/fluvial cascade model (Figure 4). These facies are named in six different groups as follows; (1) moss tufa facies (Lmo); (2) stromatolitic tufa facies (Lst); (3) phytoclastic tufa facies (Lph); (4) tufa speleothem (Lsp); (5) extra-formational conglomerate facies (Lec); and (6) silt-clay clastics (Lsc).

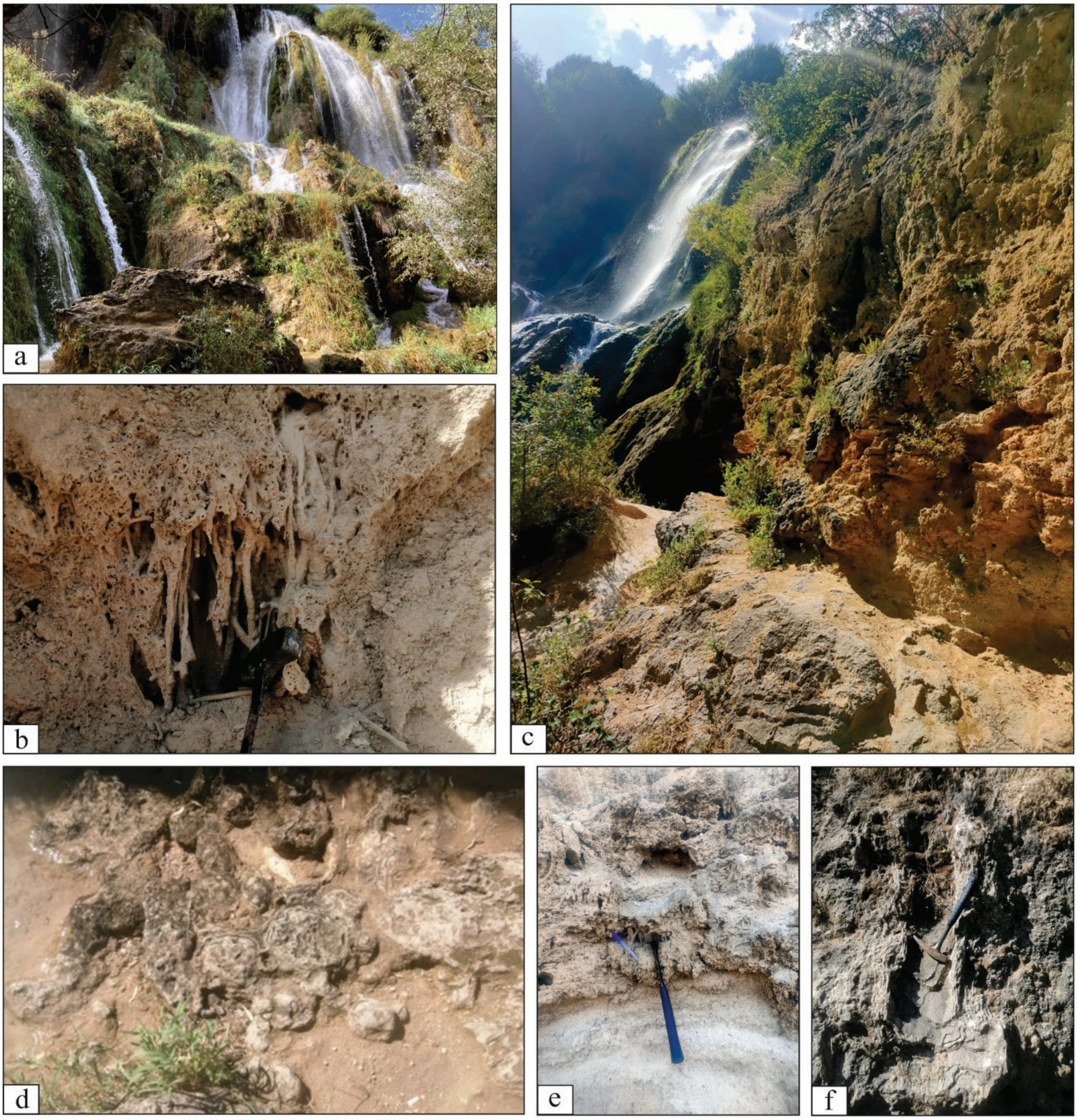

Figure 3. Field views of the Gürlevik tufa deposit. **a, c)** Monumental multi-step waterfall and fossil and active tufa precipitations; **b)** closer view of vertical plant stems coated by calcium carbonate; **d)** tufa speleothem (Lsp) located at the entrance of the cave; **e)** chaotic phytoclast facies (Lph) and fine grained clastics (silt and clay, Lsc) below; **f)** tufa channel for water flow in fluvial system.

***Şekil 3**. Gürlevik tufa çökellerinin arazi görünümleri. **a, c)** Anıtsal çok basamaklı şelale ve fosil ve aktif tufa oluşumları; **b)** kalsiyum karbonatla kaplı dikey bitki gövdelerinin daha yakından görünümü; **d)** mağaranın girişinde bulunan tufa speleotemi (Lsp); **e)** kaotik fitoklast fasiyesi (Lph) ve altında ince taneli kırıntılar (silt ve kil, Lsc); **f)** akarsu sisteminde akan suyun oluşturduğu tufa kanalı.*

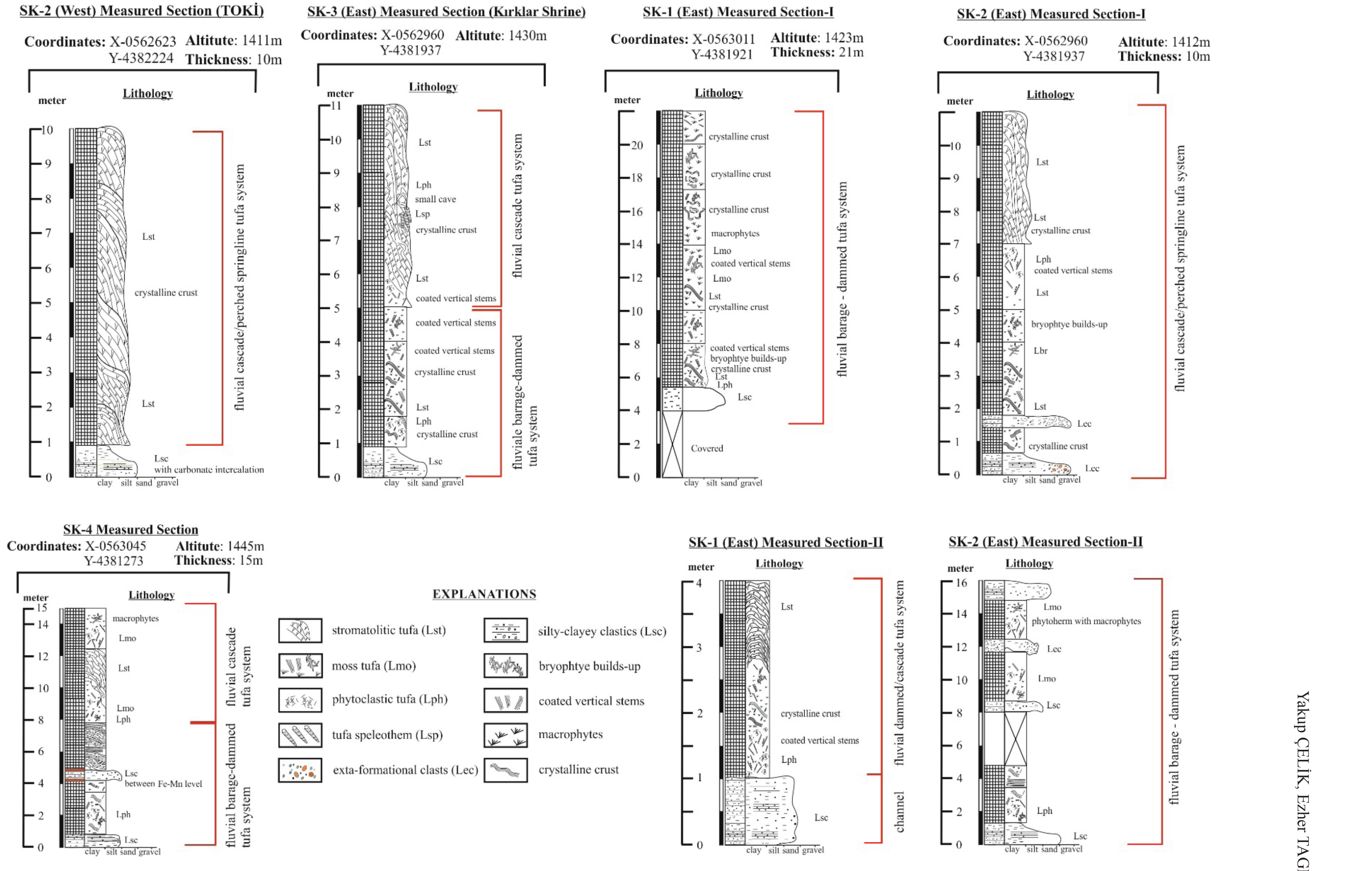

Figure 4. Measured sedimentary logs of Gürlevik tufa deposits with facies descriptions and depositional systems (for locations of measured sections see Figure 2).

***Şekil 4**. Gürlevik tufa çökellerinin ölçülü sedimanter kesitleri, fasiyes tanımları ve çökelme sistemleri (ölçülü kesitlerin yerleri için Şekil 2'ye bakınız).*

Figure 5. Some of the facies identified in the fossil Gürlevik tufas. **a)** Image of the progradation of tufa deposits from inner to outer areas, bryophytic layers are observed significantly; **b)** closer view of the cluster of bryophytes; **c)** appearance of the fossil barrage/dam tufa deposits in the field; **d)** close-up view of "c", undulated stromatolitic (Lst) structures and phytoclasts (Lph); **e)** undulated fine laminated crystalline crust on the inner wall of the small cavity; **f)** cauliflower-shaped knobs where globular crusts developed within a small cave below a tufa barrage rim; **g)** well-rounded extra-clast deposits at the bottom of the tufa formation; **h)** overturned fractured stromatolite tufa formation; **i)** silty-clay clastic (Lsc) layer between phytoclastic tufas (Lph); **j)** carbonate curtain of the tufa cascade face; and **k)** micritic laminae crust on the speleothem tufa (j and k photos are taken from SK-3 Kırklar shrine section).

Şekil 5. *Gürlevik fosil tufalarının tanımlanmış bazı fasiyesleri.* ***a)*** *tufa çökellerinin içten dışa doğru ilerlemesinin görüntüsü. Briyofitik seviyeler belirgin bir şekilde gözlenmektedir;* ***b)*** *bryofit kümesinin daha yakın görünümü;* ***c)*** *fosil baraj/set tufa çökellerinin arazideki görünümü;* ***d)*** *"c", dalgalı stromatolitik (Lst) yapılar ve fitoklastların (Lph) yakından görünümü;* ***e)*** *küçük mağara içi duvarındaki dalgalı ince laminalı kristalin kabuk;* ***f)*** *tufa set kenarının altındaki küçük bir mağarada küresel kabukların geliştiği karnabahar biçimli yumrular;* ***g)*** *tufa oluşumunun tabanındaki iyi yuvarlaklaşmış havza dışından taşınan konglomera;* ***h)*** *devrilmiş parçalanmış stromatolit tufa bloğu;* ***i)*** *fitoklastik tufalar (Lph) arasındaki siltli-kil kırıntılı (Lsc) seviye;* ***j)*** *tufa şelale yüzeyinde gelişen karbonat perdesi;* ***k)*** *tufa speleotemlerin dış çeperindeki mikritik laminalı krsital kabuk (j ve k, SK-3 Kırklar türbesi kesitinden alınmıştır).*

Moss Tufa Facies (Lmo)

Description: This facies is a common lithofacies in the investigated fluvial tufa deposits and is mainly composed of macrophtyes, coated vertical stems, twigs, bryophytes, and unidentifiable bushes (Figure 5a, b). The mold tubes of stems are filled with calcite spar and their orientation is parallel to other stems with horizontal/subhorizontal features (Figure 3b). The coated stems grow downward *in situ*. The thickness of this facies ranges from cm to a couple of metres. The geometry of this facies is lenticular and tabular in shape (Table 1). This facies consists of phytoherm framestone and is generally associated with phytoclastic tufa (Lph) and stromatolitic tufa (Lst). Bryophyte build-ups that consist of stacked layers centimetres thick are observed in progradation of tufa rims (boundstone of bryophytes; Figure 5a). Detrital clastics (Lsc) are also observed together in the depositional system.

Interpretation: The moss facies can be observed in almost all tufa occurrences and mostly represents fluvial and palustrine environments (Arenas et al., 2000; Arenas-Abad et al., 2010; Toker, 2017). In this case, Gürlevik moss tufa facies represents fluvial setting such as barrage-dammed and cascade/perched springline environments. The coated mosses which formed from perpendicular to oblique reflect current direction in some cases. These mosses were precipitated closer to the spring on the down slope.

Stromatolitic Tufa Facies (Lst)

Description: This facies consists of stromatolite-like, domal, parallel lamination bodies with slightly upward convex tops (from 1 cm to 1.5 m thick). Stromatolitic bodies are generally formed by lighter and darker micritic laminae. Stromatolites have various orientations and in some cases, they are slightly undulating (Figure 5d). This facies consists of phytoherm boundstone and is associated with phytoclastic tufa (Lph) and moss tufa (Lmo) facies (Table 1).

Interpretation: Stromatolites are the most common facies observed in calcareous tufa deposits. Tufa stromatolites might occur biotically (by cyanobacteria and algae) and abiotically (carbonate mineral nucleation) or both (Pentecost and Whitton, 2000; Shiraishi et al., 2008; Pedley, 2009; Gradziñski, 2010; Toker, 2017). Stromatolites can formed in both stagnant and fast-flowing water conditions (Gradziñski et al., 2013). In this case, stromatolites in cascade and slope areas indicate a fast-flowing aqueous setting.

Phytoclastic Tufa Facies (Lph)

Description: This facies is composed of branch fragments and clasts consisting of phytoherms (Figure 3e). The geometry of phytoclastic tufa is tabular and lenticular, thickness is up to several metres and phytoclasts are encrusted by carbonate coatings. This facies consists of phytoherm framestone and is mostly associated with stromatolitic tufa (Lst) and extra-formational clast (Lec) (Table 1).

Interpretation: The phytoclastic tufa facies represents shallow braided rivers and barrage systems after a high energy event and it constitutes barrage/waterfall deposits (Arenas-Abad et al., 2010).

Tufa Speleothem (Lsp)

Description: Speleothem facies includes stalactite and stalagmite occurrences developing in caverns and caves (Arenas-Abad et al., 2010). Stalagmites are observed with concentric laminated crust (Figure 3d). The thickness of laminae reaches up to 2 millimetres, with micrite and spar calcite cement. The facies is characterised by alternating dark and light laminae and consists of phytoherm boundstone. The calcite-coated vertical stems are lithotypes commonly associated with the facies (Table 1).

Table 1: Principal facies of Gürlevik tufa deposits and associated carbonate systems.

Çizelge 1*. Gürlevik tufa çökellerinin başlıca fasiyes özellikleri ve ilişkili karbonat sistemleri.*

Facies Type	Geometry of tufa deposits	Sedimentary structures	Biological contents	Associated facies	Sedimentary Processes
Moss tufa facies (Lmo): *Macrophytes* *Coated vertical stems* *Bryophyte builds-up*	Tabular, lenticular Asymmetrical mounds and thickness up to couple of metres	Unlaminated Moss vertical stems aligned parallel to the direction of water flow Stacked parallel laminae	Subaquatic plants, reeds Perpendicular stems Thin stalks of mosses	Phytoclastic tufa (Lph) Stromatolitic tufa (Lst)	Medium flowing, barrage-dammed system and cascade perched springline, Vertical direction stems under turbulent water Waterfalls as dominant system in braided fluvial environment, barrage and cascades
Stromatolitic tufa facies (Lst)	Dense, domal laminae, crystalline crust, gentle stepped, hemidomic deposits, dm to cm thickness	Horizontal and undulating laminations Micritic laminae	Bryophytes and coated vertical stems	Phytoclastic tufa (Lph)	Fast flowing water, slope zones and cascades
Phytoclastic tufa facies (Lph)	Tabular and lenticular, thickness is up to several metres	Not organised, no stratification	Fragments of stems	Coated vertical stems	Slow-flowing barrage dammed areas
Tufa Speleothem (Lsp)	Variable shape	Cavities with stalactites, laminated crystalline crust	Coated vertical hanging stems	Stromatolitic tufa (Lst)	Caves and small cavities associated with cascades and perched spring line, fast flowing, turbulent water
Extra-formational tufa facies (Lec)	Lenticular, channel-shaped	Dominantly clast supported, structureless	Allochthonous benthic fossil fragments	Phytoclastic tufa (Lph)	Fast flowing fluvial system with clastic inputs high-energy events could be associated with incision periods of the fluvial systems
Silt-clay clastics (Lsc)	Tabular cm to m thickness	Massive, structureless	Snail shells	Phytoclastic tufa (Lph)	Fine grained siliciclastic in channelised fluvial system

Interpretation: Speleothems developed in unlit and poorly lit cavities and inter-particle sites, from ambient temperature waters dripping from cavity walls and seepage through tufa (Ford and Pedley, 1996). The stalactites and laminar crystalline crusts form in a cave setting with abiogenic precipitation from thin films of supersaturated water (Figures 3d, 5e). Tufa speleothems can be observed at the base of the active tufa cascade and entrance of the cave. Caves and small cavities are associated with cascades and perched springline and fast flowing, turbulent water (Arenas-Abad et al., 2010).

Extra-formational Conglomerate Facies (Lec)

Description: Extra-formational clasts consist of conglomerates and sand size clastics. Dark greenish grey, greyish blue, beige coloured, rounded to well-rounded polymictic conglomerates are mostly derived from limestone, dolomitic limestone and ophiolitic pebbles (Figure 5g). The maximum pebble size is up to 15 cm, and the conglomerates are clast-supported with sandy matrix and cemented by carbonate. The clasts are poorly sorted and are observed at the base of the tufa formation (Figure 4; SK-2). The conglomeratic clasts mainly consist of fossils of *Nummulites* sp., *Discocyclina* sp., algae and undefined benthic foraminifers (Figure 6h-k). Pebble-cobble clasts probably derived from the Eocene Gülandere formation. This facies is mostly associated with phytoclastic tufa (Lph) (Table 1).

Interpretation: Extra-formational clasts are interpreted as products of weathering and erosion of the basement, including carbonate rocks, ophiolites and metavolcanics from the surrounding area. These poorly sorted and well-rounded pebbles were deposited in channelised fluvial settings (Arenas-Abad et al., 2010). Clasts found in the tufa formation are intercalated, derived from basement rock (Munzur limestone) and transported by streams. The clasts were transported along a braided fluvial system into the tufa formation with moderate to high clastic input.

Silt-clay clastics (Lsc)

Description: The facies mainly consists of finer grained sediments (silt, marl) and occurs between phytoclastic tufa deposits (Figures 3e and 5i). This facies has beige and whitish grey coloured clay and silt with tufa fragments. The massive silt-clay bed has a thickness of about 20 cm (Figure 4). These finer sediments include land snail shells in some places.

Interpretation: The presence of these finer sediments is strongly related to low energy. In some tufa fluvial systems, fine siliciclastic sedimentation representing floodplain conditions may be preserved at the top of channel deposits (Arenas-Abad et al., 2010).

Petrographic Results

Microscopic examinations were carried out on selected tufa samples representing tufa lithofacies from field observations. According to textural classification of carbonates, the tufa microfacies consists of micrite with less than 10% grains and represents mudstone character (Figure 6a-b). Phytoherm boundstone is observed to be whitish and dark, with planar or wavy laminated, and dense structure (Figure 6d-f), while phytoherm framestone is characterised by stems, trunk and branches of plants (Figure 6h-i). Moreover, distinct microstructures such as porous, filamentous algae, planar/wavy laminations and mosses were also detected.

Porous textures are generally observed in almost all tufa deposits and different types of porosity can assist in understanding the structure of tufa formation (Arenas-Abad et al., 2010). The intergranular, framework, moldic, dissolution and fenestral voids are some porosity types (Arenas-Abad et al., 2010). The moldic and fenestral pores are common porous types in the Gürlevik tufa deposits in the moss tufa facies derived from barrage-dammed and cascade flows.

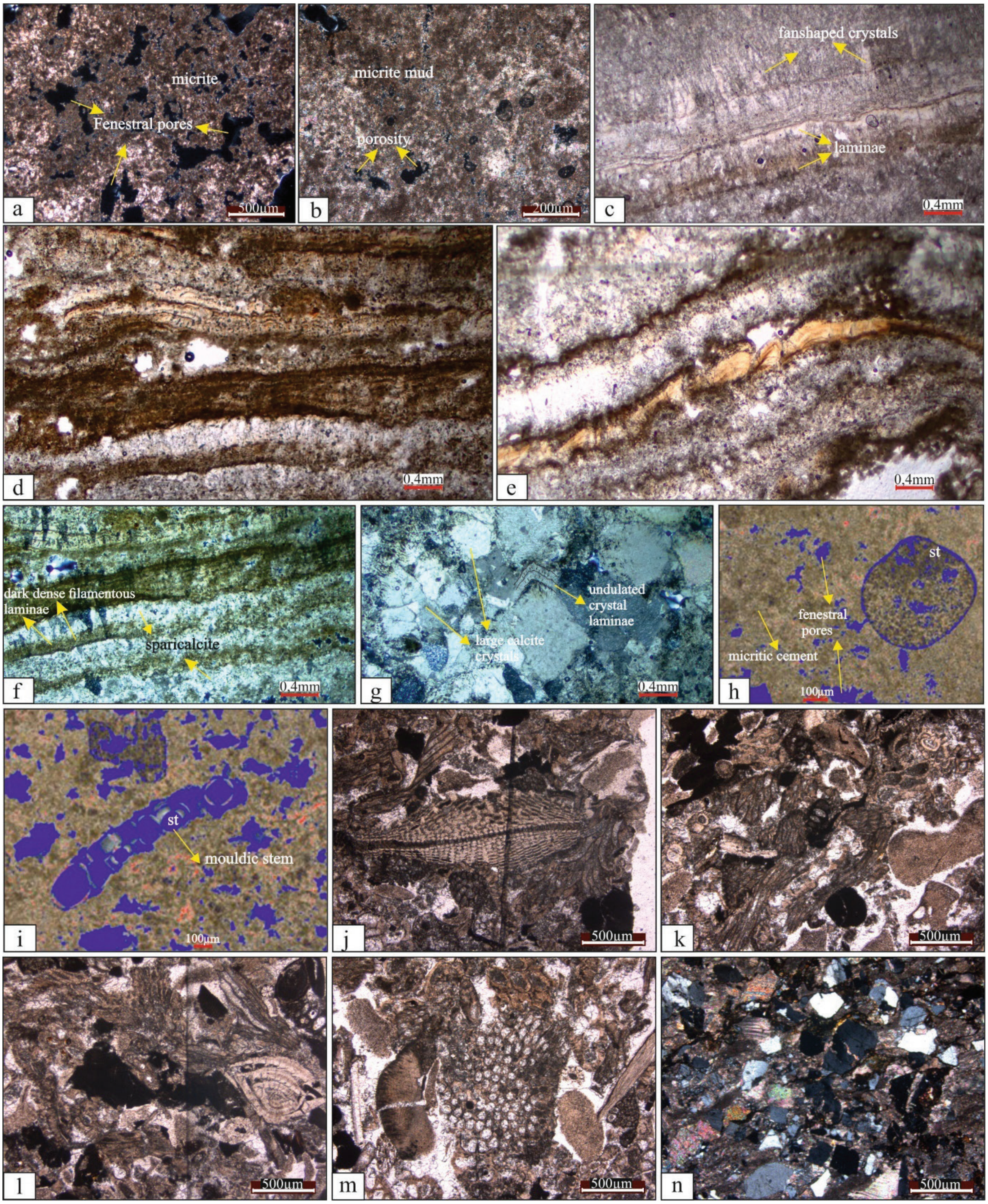

Figure 6. Images of thin sections collected from the Gürlevik fossil tufa and associated facies. **a-b)** Photomicrographs showing micritic phytoherm boundstone (dark areas denote fenestral porosity; under crossed nicols); **c)** fan-shaped crystals alternating with dense planar and wavy laminae in the stromatolitic tufa facies (sample no; SK-1/4) obtained

from the east part of the first tufa terrace (under plane polarised light); **d, e)** stromatolitic fabric which comprises alternating thin laminae composed of thrombolitic and massive micrite (obtained from SK-3/1 Kırklar Shrine wall) (under plane polarised light); **f)** dense and loose filamentous laminae with micrite and sparry calcite fillings formed in fast flowing conditions (under crossed nicols); **g)** large minerals with broken undulated calcite crystal laminae from SK-3/1 Kırklar shrine section (under crossed nicols); **h-i)** transversal cut of a plant stem (st; blue circle line) filled by micritic cement and moldic pores visible in the coated stem (st; blue longitudinal line) (under plane polarised light); **j-n)** microscope images of conglomerate clasts (section SK-2/2) derived from fossiliferous shallow marine Eocene limestone: **j-l)** transported benthic fossil fragments with sparry calcite in allochthonous limestone (m) (unsorted biosparite; under plane polarised light); **n)** sand-sized quartz grains in clastic limestone with carbonate mud (under crossed nicols).

Şekil 6. *Gürlevik fosil tufalarından ve ilişkili fasiyeslerden toplanan ince kesit görüntüleri.* ***a-b)*** *Mikritik fitoherm bağlamtaşı gösteren mikroskop görüntüsü (koyu alanlar fenestral gözenekliliği göstermektedir; çift nikol);* ***c)*** *Birinci tufa terasının doğu kısmından elde edilen stromatolitik tuf fasiyesindeki yoğun düzlemsel ve dalgalı laminalarla dönüşümlü yelpaze biçimli kristaller (numune no; SK-1/4) (tek nikol);* ***d, e)*** *Trombolitik ve masif mikritik çamurdan oluşan ardalanmalı ince laminalanmalı stromatolitik doku (SK-3/1 Kırklar Türbesi'nden) (tek nikol);* ***f)*** *Hızlı akış koşullarında oluşan mikrit ve spari kalsit dolgulu yoğun ve gevşek filamentli laminalar (çift nikol);* ***g)*** *SK-3/1 Kırklar Türbesi kesitinden alınan kırılmış kristalin kabuk parçası içeren büyük kalsit mineralleri (çift nikol);* ***h-i)*** *Mikritik çimento ile doldurulmuş bir bitki sapının enine kesiti (st; mavi daire çizgisi) ve kaplanmış gövdedeki kalıp şeklindeki gözenekler (st; mavi uzunlamasına çizgi) (tek nikol);* ***j-n)*** *Fosil içeren sığ denizel Eosen kireçtaşından türemiş konglomeratik çakılların (SK-2/2) mikroskop görüntüleri:****(j-l)*** *allokton kireçtaşında spari kalsitli taşınmış bentik fosil parçaları; (m) (boylanmamış biyosparit; tek nikol);* ***n)*** *karbonat çamurlu kırıntılı kireçtaşında kum büyüklüğünde kuvars taneleri (çift nikol).*

Filamentous algae structures are mainly found in stromatolites, as mats in mosses and coating stems (Arenas-Abad et al., 2010). Petrographic examinations of collected tufa samples show that filamentous laminae were present in SK-3 cascade tufa deposits (Figure 6f). These structures represent fast flowing conditions.

Planar and wavy laminations are characteristic structures in the stromatolite tufa facies and are commonly observed microfacies in the Gürlevik tufa formation (Figure 6d-e). The stromatolitic laminations are entirely composed of micritic to sparry calcite and no detrital grains. Internal structures comprise thick and continuous wavy to planar laminae (Figure 6c-e).

Mosses are the most abundant deposits in fluvial tufa systems (Arenas-Abad et al., 2010). The moss layers with irregular porosity can be clearly observed and are mostly covered with micritic cement (Figure 6a-b). Mosses formed in the Gürlevik fluvial cascade and barrage-dammed tufa system.

Moreover, extra-formational clasts were collected from the SK-2 sedimentary log (Figure 4) for petrographic investigations. In thin section studies, these pebble-cobble clasts clearly have grainstone features. The rock is grain-supported with spar cement (Dunham, 1962). The grains are bioclasts, mainly benthic fossil fragments (*Nummulites* sp., *Discocyclina* sp., algae and undefined benthic foraminifers). According to carbonate textural classification, extra-formational clasts transported into tufa deposit consist of biosparite microfacies (Folk, 1959, 1962) (Figure 6j-l). These sediments were transported by streams into the tufa depositional environment from the basement rock (Gülandere Formation) where Nummulites and other benthic fossils are abundant in shallow marine sediments.

DISCUSSION

Depositional System of Gürlevik Tufa

Gürlevik tufa are characterised by both active and fossil tufa deposits based on direction changes of the water flow. Tufa deposits are actively forming throughout the entire stream, including barrage and cascade settings in fluvial environments. Gürlevik tufa precipitation consists of two main depositional systems. These are the; (1) perched springline/cascade tufa system, and (2) barrage-dammed tufa system. These depositional systems are described briefly below.

Perched springline/cascade tufa system

This depositional system formed both aggradation and progradation growths (Arenas-Abad et al., 2010). The Gürlevik tufa deposits typically correspond to the 'perched springline system' identified by Pedley (1990), the 'slope system' named by Violante et al. (1994), the 'fluvial with waterfalls/barrage-cascade' system defined as vertical sequences of facies by Arenas-Abad et al. (2010), and the 'high-gradient and stepped fluvial conditions' termed as sedimentary facies model by Arenas-Abad et al. (2010)

The Gürlevik perched springline tufa site comprises lobe-top terrace and waterfall/cascade areas (Figure 7). The lobe-top terrace zone is a cultivated area which used by local people. The waterfall/cascade area is located at the upper part of the tufa system and waterfall, emerging from Kalecik karst spring and flowing down from a height of 53 m. The waterfall is composed of three tufa terraces and these three different levels of tufa terraces continued to develop until the distal part of the creek (Figure 8).

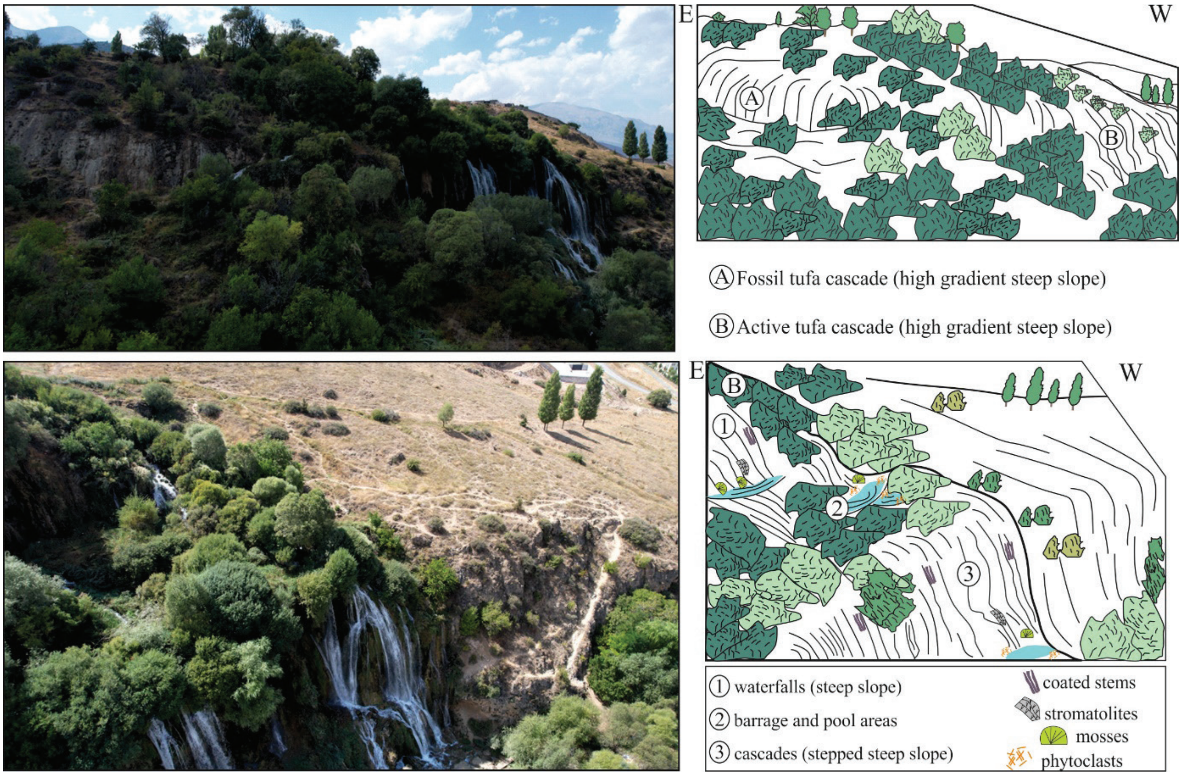

Figure 7. Drone photos and sketches showing high gradient slope area including the main depositional systems of the Gürlevik tufa (In the sketch, fossil tufa deposits shown as (A) and active tufa deposits shown as (B) in steep slope areas).

Şekil 7. *Gürlevik tufalarının başlıca depolanma sistemlerini drone fotoğraflarıyla birlikte yüksek eğimli yamaç alanını gösteren diyagram; (A) Fosil tufa çökelleri ve (B) Dik yamaç alanlarındaki aktif tufa çökelleri.*

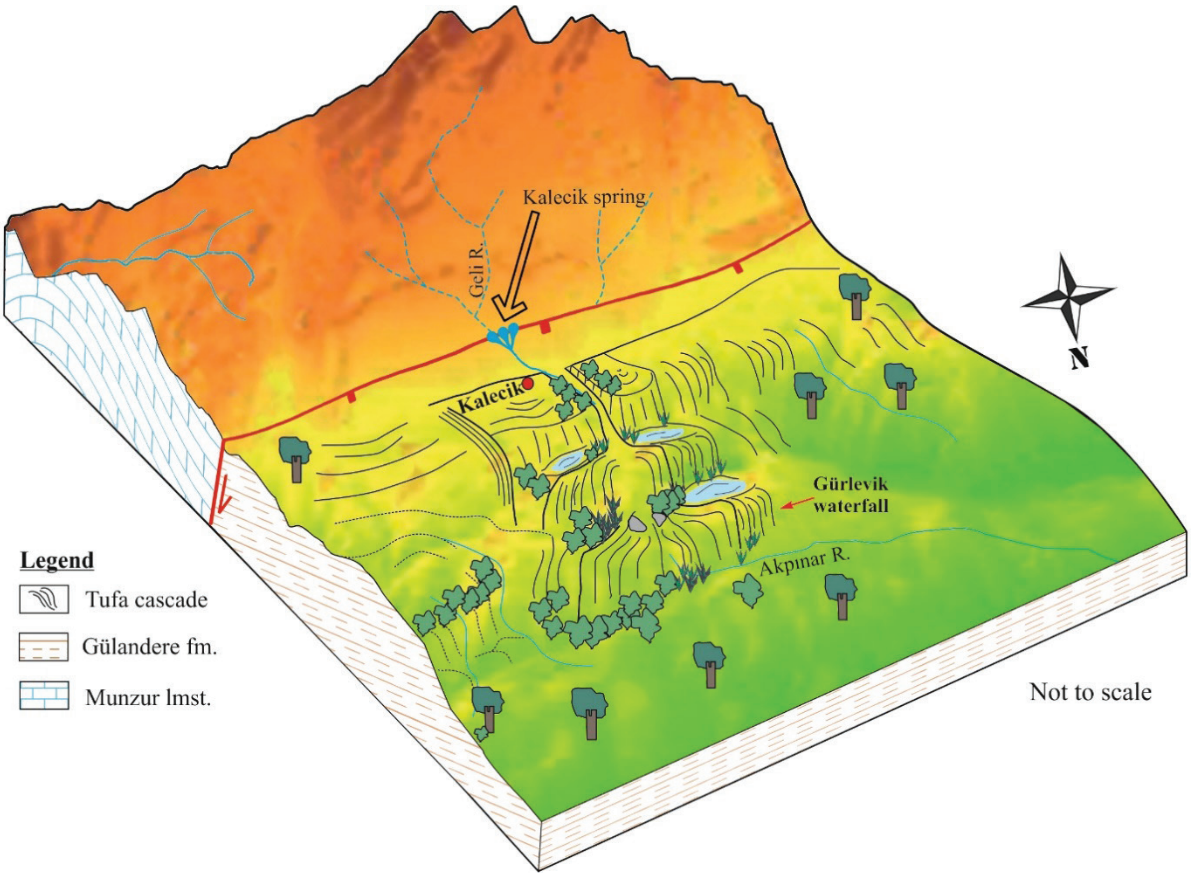

Figure 8. Block diagram of the Gürlevik tufa waterfall deposits and surrounding area.
***Şekil 8**. Gürlevik tufa şelalesi çökelleri ve çevresinin blok diyagramı.*

The increases and decreases of the water source flow rate as a result of climate fluctuations during the Quaternary period are assumed to have been effective in the development of these terraces (Uysal, 2024). The face of the waterfall is up to 20 m high and is mostly covered by stacked moss layers, hanging vertical stems, and upgrowing vertical stems. The internal structure of the tufa is nearly horizontal at the crest of the waterfall and dips sharply in the most distal area. Phytoclasts are associated with these moss layers (vertical stems). Caves (speleothem tufa) are observed behind the overhangs and dammed areas (Figures 3a, 4 and Table 1). Consequently, this type of tufa system generally develops in slope areas, and steeper faces experience the fastest tufa growth (Ford and Pedley, 1996).

Similar spectacular perched springline tufa or waterfall/cascade tufa systems can be observed in various parts of Anatolia. Some spectacular examples include the Antalya tufa in southern Anatolia (Glover and Robertson, 2003; Koşun et al., 2005; Dipova and Doyuran, 2006); Güney Waterfall in Denizli province in SW Anatolia (Özkul et al., 2010); Sarıkavak paleocascade tufa system in Afyon province, SW Anatolia (Toker, 2017; Tagliasacchi and Kayseri-Özer, 2020); and Gürleyik creek tufa forms located in Eskişehir province, Central Anatolia (Uzun et al., 2023).

In addition, there are several magnificent tufa occurrences in the world. Some of the best examples are the Plitvice system, "Mali prštavac" and Skradinski Buk tufa waterfalls, Croatia (Horvatinčić et al., 2000; Golubić et al., 2008); and tufa cascades at the Monasterio de Piedra Natural Park, Iberian Range, NE Spain (Vázquez-Urbez et al., 2011).

Barrage-dammed tufa system

The barrage-dammed tufa system is also clearly observed in the Gürlevik gentle slope fluvial environment (Figure 3). Dammed areas are generally shallow sites with sedimentation of fine-grained carbonate sediments and phytoclasts forming upstream of the barrage (Arenas-Abad et al., 2010). Pedley (1990, 2009) identified the barrage tufa model with mosses and undefined plants. Barrages initially form on phytoclast precipitations and then grow upwards due to plant colonisation (Arenas-Abad et al., 2010). Small ponds develop behind the barrage, which are characterised by stromatolitic facies on their vertical upstream edges (Figures 7 and 8). Lateral development of the stromatolite towards the ponds leads to their colonisation by plants (Figure 6).

High gradient tufa systems have developed in different parts of Anatolia. For instance, the Antalya tufa (Koşun et al., 2005) and Sarıkavak barrage-dam tufa system in Afyon, SW Anatolia (Toker, 2017; Tagliasacchi and Kayseri-Özer, 2020). Furthermore, tufa in Plitvice Natural Park in Croatia (Horvatinčić et al., 2000); the Piedra, Mesa and Añamaza Rivers in NE Spain (Vázquez-Urbez et al., 2011) and Ruidera Lakes Natural Park in central Spain (Ordóñez et al., 2005) are the best examples of barrage-dammed tufa systems in Europe.

Geological Heritage and Geotourism Potential of Gürlevik Tufa Waterfall

The concept of geological heritage is defined as "a natural heritage that preserves evidence of a specific section of the Earth's surface, holds scientific value, and whose destruction would result in the irreversible loss of information and documentation regarding its geological formation" (Wimbledon, 1996; Kazancı, 2010; Çiftçi and Güngör, 2016). This natural heritage can include a vast canyon, a fossil deposit, a glacial lake, a mineral formation, a karst cave, a fold or a waterfall. A geosite refers to a locality where a geological or geomorphological formation is best represented among multiple geological heritage elements (ProGeo Group, 1998; Çiftçi and Güngör, 2016; Güngör and Angı, 2021). Particularly after the emergence of geoparks and their increasing global recognition, geological tours initially started within geoparks and have gradually expanded to larger areas in recent years. These tours are collectively termed geotourism.

Geotourism encompasses a broad range of geological and geomorphological phenomena, including rocks, fossils, minerals, volcanoes, glaciers, glacial lakes, mountains, erosion patterns, and natural hazards such as earthquakes, floods, and landslides. It also includes structural formations, deserts, lakes, caves, rivers, waterfalls, and mines, where the interaction between human activity and geological processes is prominently observed. Additionally, geotourism can extend to cultural elements associated with geological heritage. As these sites are prepared for visitors, protective measures are implemented to prevent potential damage and serve the function of geoconservation. Thus, the protection of geological heritage is inherently linked to geotourism activities. Consequently, geotourism is a form of tourism that fosters interest in knowledge-based, geoscientific elements (Güngör and Angı, 2021).

In light of the terminological information briefly summarised above, waterfalls formed by tufa deposits are widespread fluvial landforms that were nominated as World Heritage Properties (Goudie, 2020). Based on this concept, the Gürlevik Waterfall, designated as a Natural Protected Area in 1990 and placed under qualified natural protection, stands out for its aesthetic appeal as well as its geological and geomorphological significance. However, these attributes must be effectively communicated to visitors through informational signage. These signs will educate visitors about the geoscientific processes underlying the formation of Gürlevik Falls, fostering an unconscious yet impactful nature education experience. This educational approach is expected to enhance visitor awareness regarding the conservation of tufa formations within the area. In this context, safeguarding the tufa deposits of Gürlevik Waterfall and integrating them into geotourism initiatives has critical importance.

In recent years, climate change-induced reductions in precipitation have led to a noticeable decline in the streamflow feeding the waterfall. Consequently, the volume of water cascading from Gürlevik Waterfall has significantly decreased. Today, the development of tufa terraces has slowed, and tufa blocks have begun to collapse into the valley. This alarming deterioration of the waterfall's natural beauty should prompt geoscientists to adopt a more proactive and vigilant approach. A robust geoconservation strategy is imperative for the sustainable development of geotourism. Such a strategy will ensure that geological heritage sites contribute economically to the region in a long-term and sustainable manner. Moreover, an effective geoconservation framework can pave the way for a sustainable development model. This is because geotourism is not merely a short-term touristic activity; rather, it constitutes a sustainable development model that safeguards geological heritage and facilitates its long-term contribution to regional economies (Güngör, 2021).

Within this framework, Gürlevik Waterfall qualifies as a geological heritage site, a geosite, and a significant geotourism destination due to its distinctive tufa formations, palaeoenvironmental characteristics, tectonic structures, and exceptional visual appeal. According to the classification system of ProGeo (ProGeo, 1998), Gürlevik Waterfall corresponds to categories B, E, and F within the 10 geosite groups (Table 2).

Table 2. Geosite classification of ProGeo Group-98 (www.progeo.com).

Çizelge 2*. ProGeo Group-98'in jeosit sınıflandırması (www.progeo.com).*

Geo-Code	Geosite Class (GC)
(A)	Stratigraphic
(B)	Palaeoenvironmental & palaeontological
(C)	Igneous, metamorphic and sedimentary petrology, textures and structures, events and provinces
(D)	Mineralogical, economic
(E)	Structural
(F)	Geomorphological features, erosional and depositional processes, landforms and landscape
(G)	Astroblemes
(H)	Continental or oceanic-scale geological features, relationships of tectonic plates and terrain
(I)	Submarine
(J)	Historic for development of geological sciences

In many countries, including Türkiye, where the principles of sustainable tourism have not been fully embraced, natural resources in potential geotourism sites are often exploited indiscriminately in pursuit of economic benefits. However, geotourism represents a crucial form of ecotourism that can generate economic value without compromising the natural and cultural environment. Given that Türkiye has traditionally focused on mass tourism, the shift towards diversified tourism strategies, including geotourism, presents an opportunity to expand the national tourism economy in new directions. The rich geomorphology and natural scenic appeal of Gürlevik Waterfall provide a unique potential for various geotourism activities. However, as geotourism initiatives develop, it is essential to ensure that natural monuments of significant scientific and aesthetic value, such as Gürlevik Waterfall, are rigorously protected through close collaboration with local communities.

CONCLUSIONS

The Gürlevik (Çağlayan) tufa site is a spectacular representative of the perched springline tufa or high gradient waterfall/cascade model in Eastern Anatolia. This study is one of the first investigations involving detailed sedimentological fieldwork (facies descriptions) and petrographic analysis of the Gürlevik tufa deposit. The main conclusions of this research are:

1. Six tufa facies were identified and interpreted. These are: (i) moss tufa facies (macrophytes, coated vertical stems, bryophyte builds-up); (ii) stromatolitic tufa facies; (iii) phytoclastic tufa facies; (iv) tufa speleothem; (v) extra-formational conglomerate facies; and (vi) silt-clay clastics.
2. In the investigated area, the Gürlevik tufa developed in barrage and cascade systems within fluvial environments. Two depositional systems are distinguished based on the lithofacies analysis: (i) perched springline/barrage-cascade tufa system composed of lobe-top terrace and waterfall/cascade areas; and (ii) barrage-dammed tufa system.
3. The well-exposed cascade/waterfall and barrage-dammed tufa systems are consequences of tectonic (faulted) effects and climatic factors in the region.
4. Detailed multidisciplinary research should be carried out to determine the activation of faults controlling tufa development in this region and to obtain more data about past climatic changes.
5. Gürlevik Waterfall, which fascinates those who see it with its natural beauty, was declared a natural protected area and taken under protection. It is of great importance that these tufa deposits with such spectacular natural beauty be preserved and promoted for geotourism.

GENİŞLETİLMİŞ ÖZET

Gürlevik (Çağlayan) tufalarının oluştuğu alan, Erzincan çek-ayır havzasının güneydoğusunda yer alan yaklaşık 50 metre yükseklikten akan şelale yapısıyla dikkat çekici özelliğe sahip karasal karbonat çökelleridir. Gürlevik Şelalesi'nin güneyinde bulunan Kalecik karstik kaynağından çıkan sulara bağlı olarak gelişen bu tufa çökelleri, farklı genişlik ve yükseklikte 3 basamaktan oluşmaktadır. Bu çalışmada, tektonik olarak aktif bir havzada gelişen Gürlevik tufa çökelleri, ilk kez ayrıntılı olarak çalışılmıştır. Bu çalışmayla ilk defa, Gürlevik tufalarını oluşturan karasal karbonat çökellerinin ayrıntılı sedimantolojik incelemeleri (litofasiyeslerinin belirlenmesi ve tanımlanması) ve petrografik analizleri gerçekleştirilmiştir. Bu amaçla, tufa çökellerinin en iyi gözlemlendiği farklı seviyelerdeki tufa teraslarından toplam yedi adet ölçülü sedimantolojik kesit alınmış ve ince kesit çalışmaları için örneklemeler yapılmıştır. Yapılan arazi çalışmaları sonucunda başlıca altı adet tufa litofasiyesi belirlenmiş ve özellikleri ayrıntılı olarak açıklanmıştır. Bunlar; yosun tufa fasiyesi (makrofitler, karbonatlaşmış bitki sapları ve briyofitler gibi), stromatolitik tufa fasiyesi, fitoklastik tufa fasiyesi, tufa speleotem, havza-dışı konglomera fasiyesi, silt-kil kırıntılı fasiyesidir. Gürlevik tufaları, akarsu tufa çökeli olup, baraj-set ve şelale tipi depolanma sistemlerinde oluşmuştur. Bu karasal karbonatların gelişiminde bölgenin aktif tektoniği ve iklimi oldukça önemlidir.

Tufaların bulunduğu alanın kuzeyinde sağ yanal doğrultu atımlı Kuzey Anadolu Fayı ve şelalenin bulunduğu alanın güneybatı *devamında sol yanal doğrultu atımlı Ovacık Fayı bulunmaktadır. Tufa şelalesini oluşturan Kalecik kaynağı da Kuzey Anadolu Fayı'nın Erzincan Havzası'nın güneyindeki kollarından olan Kalecik-Tatlısu Fayı üzerinde yer almaktadır. Munzur Kireçtaşları ile Gülandere Formasyonu birimlerinin dokanağını oluşturan fay hattı boyunca Kalecik kaynağından yüzeye çıkan soğuk ve bikarbonatça zengin sular, Gürlevik tufa çökellerini oluşturmuşlardır.*

Bölgede tufa gelişimini kontrol eden fayların aktivasyonunun belirlenmesi ve geçmiş iklim değişiklikleri hakkında daha fazla veri elde edilebilmesi için daha detaylı ve multidisipliner araştırmaların yapılması oldukça faydalı olacaktır.

Doğal güzelliğiyle görenleri büyüleyen ve Anadolu'nun en yüksek şelalelerinden biri olan Gürlevik Şelalesi, doğal sit alanı ilan edilerek koruma altına alınmıştır. Bu kadar muhteşem doğal güzelliğe sahip olan bu tufa çökellerinin, korunarak jeoturizm için tanıtılması; büyük önem taşımaktadır.

ORCID

Yakup Çelik https://orcid.org/0000-0002-2150-852X
Ezher Tagliasacchi https://orcid.org/0000-0002-1774-5012

REFERENCES

Akpınar, Z., Gürsoy, H., Tatar, O., Büyüksaraç, A., Koçbulut, F. & Piper. J. D. A. (2016). Geophysical analysis of fault geometry and volcanic activity in the Erzincan Basin, Central Turkey: Complex evolution of a mature pull-apart basin. *Journal of Asian Earth Sciences, 116*, 97–114. https://doi.org/10.1016/j.jseaes.2015.11.005

Aktimur, H. T., Sarıarslan, M., Keçer, M., Turşucu, A., Örçen, S., Yurdakul, M. E., Mutlu, G., Aktimur, S. ve Yıldırım, T. (1995). Erzincan dolayının jeolojisi (Report no: 9792 (unpublished)). MTA, Ankara.

Arenas, C., Gutiérrez, F., Osácar, C. & Sancho, C. (2000). Sedimentology and geochemistry of fluvio-lacustrine tufa deposits controlled by evaporite solution subsidence in the central Ebro Depression, NE Spain. *Sedimentology, 47*, 883-909.

Arenas-Abad, C., Vázquez-Urbez, M., Pardo-Tirapu, G. & Sancho-Marcén, C. (2010). Fluvial and associated carbonate deposits. In Alonso-Zarza, A. M., Tanner, L. H. (Eds.), *Carbonates in Continental Settings. Facies, Environments and Processes, Developments in Sedimentology* (pp. 133-175), vol. 61. Elsevier, Amsterdam. https://doi.org/10.1016/S0070-4571(09)06103-2

Aydın, O. L., Bektaş, O., Büyüksaraç, A. & Yılmaz, H. (2019). 3D Modelling and Tectonic Interpretation of the Erzincan Basin (Turkey) using Potential Field Data. *Earth Sciences Research Journal, 23*(1), 57-66. https://doi.org/10.15446/esrj.v23n1.71090

Barka A. & Gülen L. (1989). Complex evolution of the Erzincan basin (Western Turkey). *Journal of Structural Geology, 11*(3), 275-283.

Bozkurt, E. (2001). Neotectonics of Turkey - a synthesis. *Geodinamica Acta, 14*, 3–30, https://doi.org/10.1016/S0985-3111(01)01066-X

Capezzuoli, E., Gandin, A. & Pedley, M. (2014). Decoding tufa and travertine (freshwater carbonates) in the sedimentary record: the state of the art. *Sedimentology, 61*(1), 1–21. https://doi.org/10.1111/sed.12075

Çiftçi, Y. & Güngör, Y. (2016). Proposals for the Standard Presentation of Elements of Natural and Cultural Heritage within the Scope of Geopark Projects. *MTA Dergisi, 153*, 223-238.

Çiftçi, Y. & Güngör, Y. (2021). Jeolojik Miras Envanter Çalışmaları: Yeni Yaklaşımlar. S. Er (Ed.), *Jeolojik Miras: Kavramlar, Mevzuat ve Uygulama Örnekleri* (ss. 62-104). Pınar Yayınevi-Jeoloji Mühendisleri Odası, İstanbul.

Dipova, N. & Doyuran, V. (2006). Characterization of the Antalya (Turkey) tufa deposits. Carbonates and Evaporites, 21, 144–160. https://doi.org/10.1007/BF03175664

Dunham, R. J. (1962). Classification of carbonate rocks according to depositional texture. In W. E. Ham (Editor), *Classification of Carbonate Rocks (pp.: 108-121)*. Mem. Am. Assoc. Petrol. Geol., 1.

Emre, O., Duman, T.Y., Kondo, H. Olgun, S., Özalp, S., Elmacı, H. (2012). *1:1250.000 Scale Active Fault Map Series of Turkey, Erzincan (NJ 37-3) Quadrangle. Serial Number: 44*. General Directorate of Mineral Research and Exploration (MTA), Ankara-Turkey.

Folk, R. L. (1959). Practical petrographic classification of limestones. *American Association of Petroleum Geologists Bulletin, 43*, 1-38.

Folk, R. L. (1962). Spectral subdivision of limestone types. In Ham,W.E. (Ed.), *Classification of carbonate rocks* (pp. 62–84). American Association of Petroleum Geologist Memoirs 1, Tulsa.

Ford, T.D. & Pedley, H.M. (1996). A review of tufa and travertine deposits of the world. *Earth-Science Reviews, 41*(3-4), 117-175. https://doi.org/10.1016/S0012-8252(96)00030-X

Gedik, A. (2008). Kemah-Erzincan Çayırlı yöresi Tersiyer Birimlerinin Jeolojisi ve Petrol Kaynak Kaya Özellikleri. *MTA Dergisi, 137*, 1-26 (in Turkish).

Glover, C. & Robertson, A. H. (2003). Origin of tufa (cool-water carbonate) and related terraces in the Antalya areas, SW Turkey. *Geological Journal, 38*, 1-30.

Golubić, S., Violante, C., Plenković-Moraj, A. & Grgasović, T. (2008). Travertines and calcareous tufa deposits: an insight into diagenesis. *Geologia Croatica, 61*(2-3), 363-378.

Goudie, A. S. (2020). Waterfalls: Forms, Distribution, Processes and Rates of Recession. *Quaestiones Geographicae, 39*(1), 59–77. https://doi.org/10.2478/quageo-2020-0005

Gradziñski, M. (2010). Factors controlling growth of modern tufa: results of a field experiment. *Geological Society Special Publications, 336*, 143–191. https://doi.org/10.1144/SP336.8

Gradziñski, M., Hercman, H., Jaoekiewicz, M. & Szczurek, S. (2013). Holocene tufa in the Slovak Karst: facies, sedimentary environments and depositional history. *Geological Quaterly, 57*(4), 769-788. https://doi.org/10.7306/gq.1131

Güngör, Y. (2021). Jeoloji ve Sürdürülebilir Kalkınma. *MTA Doğal Kaynaklar Ekonomi Bülteni, 31*, 53-59.

Güngör, Y. ve Angı, O. S. (2021). Kültürel Jeoloji ve Jeoturizm içerisinde jeolojik mirasın yeri I. S. Er (Ed.), *Jeolojik Miras: Kavramlar, Mevzuat ve Uygulama Örnekleri* (ss. 105-112). Pınar Yayınevi-Jeoloji Mühendisleri Odası, İstanbul.

Horvatinčić, N., Čalić, R. & Geyh, M. A. (2000). Interglacial growth of tufa in Croatia. *Quaternary Research, 53*, 185-195.

Kaypak, B. & Eyidoğan, H. (2005). One-dimensional crustal structure of the Erzincan basin, Eastern Turkey and relocations of the 1992 Erzincan earthquake (Ms=6.8) aftershock sequence. *Physics of the Earth and Planetary Interiors, 151*(1–2), 1-20.

Kazancı, N. (2010*). Dünyada ve Türkiye'de Jeosit-Jeopark-Jeomiras Olgusuna Yaklaşımlar. Kızılcahamam Çamlıdere Jeopark ve Jeoturizm Projesi Raporu*, 76, Ankara.

Koçyiğit, A. (1990). Üç Kenet Kuşağının Erzincan Batısındaki (KD Türkiye) Yapısal ilişkileri: Karakaya, İç Toros ve Erzincan Kenetleri. *Türkiye 8. Petrol Kongresi Bildiriler Kitabı*, 152-160.

Koşun, E., Sarıgül, A. ve Varol, B. (2005). Antalya Tufalarının litofasiyes özellikleri. *MTA Dergisi, 130*, 57-70.

Okay, A. I. & Tüysüz, O. (1999). Tethyan Sutures of Northern Turkey. In Durand B., Jolivet G., Horvoth F., Serrane M (Eds.), *The Mediterranean Basins: Tertiary Extension Within the Alpine Orogen*, *Geological Society, London, Special Publications., 156*, 475-515. https://doi.org/10.1144/GSL.SP.1999.156.01.22

Ordóñez, S., González Martín, J.A., García del Cura, M.A. & Pedley, H.M. (2005). Temperate and semi-arid tufas in Pleistocene to Recent fluvial barrage system in the Mediterranean area: the Ruidera Lakes Natural Park (Central Spain). *Geomorphology, 69*, 332-350.

Özkul, M., Gökgöz, A. & Horvatinčić, N. (2010). Depositional properties and geochemistry of Holocene perched springline tufa deposits and associated spring waters: a case study from the Denizli province, Western Turkey. In Pedley, H.M. (Ed.), *Tufas and Speleothems: Unravelling the Microbial and Physical Controls: the Geological Society, London. Special Publications, 336*, 245-262. https://doi.org/10.1144/SP336.13

Pedley, H. M. (1990). Classification and Environmental Models of Cool Freshwater Tufas. *Sedimentary Geology, 68*, 143-154.

Pedley, M., González Martín, J.A., Ordóñez, S. & García del Cura, M.A. (2003). Sedimentology of Quaternary perched springline and paludal tufas: criteria for recognition, with examples from Guadalajara Province, Spain. *Sedimentology, 50*, 23-44.

Pedley, H. M. (2009). Tufas and travertines of the Mediterranean region: a testing ground for freshwater carbonate concepts and developments. *Sedimentology Special Volume 56*, 221-246.

Pentecost, A. (1981). The tufa deposits of the Malham district, North Yorkshire. *Field Studies 5*, 365–387.

Pentecost, A. & Whitton, B. A. (2000). Limestones. In B.A. Whitton & M. Potts (Eds.), *The Ecology of Cyanobacteria* (pp.: 257–279). Kluwer, Amsterdam.

ProGeo Group (1998). A first attempt at a geosites framework for Europe - an IUGS initiative to support recognition of World Heritage and European geodiversity. *Geologica Balcanica, 28*, p.: 532.

Shiraishi, F., Reimer, A., Bissett, A., Beer, D. de & Arp, G. (2008). Microbial effects on biofilm calcification, ambient water chemistry and stable isotope records in a highly super saturated set ting (Westerhöfer Bach, Germany). *Palaeogeography, Palaeoclimatology, Palaeoecology, 262*, 91–106.

Tagliasacchi, E. & Kayseri-Özer, M.S. (2020). Multidisciplinary approach for palaeoclimatic signals of the non-marine carbonates: The case of the Sarıkavak tufa deposits (Afyon, SW-Turkey). *Quaternary International, 544*, 41-56. https://doi.org/10.1016/j.quaint.2019.12.016

Tatar, O., Akpınar, Z., Gürsoy, H., Piper, J. D. A., Koçbulut, F., Mesci, B. L., Polat, A. & Roberts, A. P. (2013). Palaeomagnetic evidence for the Neotectonic evolution of the Erzincan Basin, North Anatolian Fault Zone, Turkey. Journal of Geodynamics, 65, 244– 258. https://doi.org/10.1016/j.jog.2012.03.009

Toker, E. (2017). Quaternary fluvial tufas of Sarıkavak area, southwestern Turkey: Facies and depositional systems. *Quaternary International*, *437*, (Part A), 37-50. https://doi.org/10.1016/j.quaint.2016.06.034

Tüysüz, O. (1990). Tectonic evolution of a part of the Tethyside orogenic collage: the Kargı Massif, northern Turkey. *Tectonics, 9*(1), 141-160. https://doi.org/10.1029/TC009i001p00141

Tüysüz, O. (1992). Erzincan Çevresinin Jeolojisi, (Yerbilimci Gözüyle Erzincan Depremi, Dünü-Bugünü-Yarını ve Türkiye Deprem Sorunu, (Derleyen; Ahmet Ercan). *İ.T.Ü. Maden Fak. Jeofizik Bölümü ve Jeoloji Müh. Böl. Ortak Oturum Bildirileri*, İ.T.Ü. İstanbul.

Uysal, A. (2024). *Erzincan Ovası ve Çevresinin Morfotektonik Özellikleri ve Deprem Analizi*. [Yayımlanmamış Doktora Tezi]. Elazığ, Fırat Üniversitesi, Sosyal Bilimler Enstitüsü.

Uysal, A., Sunkar, M. (2024). Girlevik Şelalesi ve Traverten Taraçasının Oluşumu (Erzincan). Kıranşan, K. (Ed.), *Fiziki coğrafya alanında uluslararası araştırmalar-II* (s: 117-145). Eğitim Yayınevi.

Uzun, A., Bahadır, M., Karaer, F., Gürgöze, S. & Vural, B. (2023). Gürleyik Creek Tufa Forms, Eskişehir/Türkiye. *The most Recent Studies in science and art* (s.: 1-9). Gece Publishing.

Vázquez-Urbez, M., Pardo, G., Arenas, C. & Sancho, C. (2011). Fluvial diffluence episodes reflected in the Pleistocene tufa deposits of the River Piedra (Iberian Range, NE Spain). *Geomorphology, 125*, 1-10. https://doi.org/10.1016/j.geomorph.2010.07.022

Villes, H.A. & Goudie, A. S. (1990). Tufas, travertine and allied carbonate deposits. *Progress in Physical Geography Earth and Environment. 14*(1), 19-41. https://doi.org/10.1177/030913339001400102

Violante, C., Ferreri, V., D'Argenio, B.& Golubic, S. (1994). Quaternary travertines at Rochetta a Volturno (Isernia, Central Italy). Facies analysis and sedimentary model of an organogenic carbonate system. In *PreMeeting Fieldtrip Guidebook, A1, International Association of Sedimentologists, Ischia'94, 15th Regional Meeting* (pp.: 3223), Italy.

Wimbledon, W. A. P. (1996). National site election, a stop on the road to a European GeositeList. *Geologica Balcanica, 26*, 15–27.