

The drowning of ancient Limyra (southwestern Turkey) by rising groundwater during Late Antiquity to Byzantine times

Gerd RANTITSCH¹⁾, Walter PROCHASKA¹⁾, Martin SEYER²⁾, Helmut LOTZ³⁾ & Christian KURTZE²⁾

¹⁾ Chair of Geology and Economic Geology, Montanuniversität Leoben, Peter-Tunner Strasse 5, A-8700, Leoben, Austria;

²⁾ Austrian Archaeological Institute, Franz Klein-Gasse 1, A-1190 Vienna, Austria;

³⁾ Documenta Antiqua – History of Ancient Law, Institute for the Study of Ancient Culture, Austrian Academy of Sciences, Postgasse 7/4, A-1010 Vienna, Austria;

^{*)} Corresponding author: gerd.rantitsch@unileoben.ac.at

KEYWORDS Geoarcheology; SW Turkey; Lycia; Limyra; Hydrogeology

Abstract

From the 6th century BC to Byzantine times, the ancient city of Limyra was an important urban center of the Lycian territory at the southwestern coastal region of Asia Minor. Archaeological, geological, hydrochemical and surface elevation data, as well as ¹⁴C age dating constrain a paleo-hydrogeological model, explaining the submergence of the city foundation walls below the groundwater table. In this model, tectonically induced subsidence of the acropolis (Toçak Dağı) initiated a debris flow into the area of the lower city. Both, natural and anthropogenic gravel accumulation resulted in the formation of a new aquifer pathway redirecting formerly bypassing karst water into the city center. Consequently, the inhabitants of Limyra had to fight against the rising ground water table at least since the 6th to 10th centuries AD.

Die antike Stadt Limyra war vom 6. Jh. v.Chr. bis zu byzantinischer Zeit ein bedeutendes urbanes Zentrum in Lykien an der südwestlichen Küste von Kleinasien. Archäologische, geologische und hydrochemische Daten sowie ein Geländemodell und ein ¹⁴C Alter unterstützen ein paläo-hydrogeologisches Modell, welches das Absinken der Grundmauern der Stadt unter den Grundwasserspiegel erklärt. Das Modell beschreibt tektonisch induzierte Massenbewegungen vom Burgberg (Toçak Dağı) in die Unterstadt. Die natürliche und eine zusätzliche anthropogene Schuttanreicherung führten zu einer Umleitung des ursprünglich vorbeifließenden Grundwassers in das Stadtzentrum. Dies hatten die Bewohner von Limyra spätestens seit dem sechsten bis zehnten Jh. n. Chr. zu bewältigen.

1. Introduction

In southwestern Turkey, the archaeological study of ancient buildings revealed important information about land deformation processes due to historical earthquakes (e.g. Akyüz and Altunel, 2001; Karabacak, 2011; Karabacak et al., 2013; Özdaş and Kızıldağ, 2013; Passchier et al., 2013). Geomorphological studies additionally constrained the interaction of humans and landscape (Kraft et al., 2007, 2011; Brückner et al., 2013; Stock et al., 2013, 2014; Seeliger et al., 2014; Delile et al., 2015). Geoarchaeological work therefore contributes to a better understanding of ancient life in southwestern Asia Minor.

Water is an essential prerequisite for settlements. Although water scarcity was a major problem during ancient times (e.g. Rantitsch and Prochaska, 2011; Dermody et al., 2014), observations in the Lycian city of Limyra at the southwestern coastal region of Turkey (Figs. 1a, b) give the paradoxical view of an oversupply of water, because the ancient walls of Limyra had sunk below the ground water table (Fig. 1c). A settlement in Limyra existed at least since the 6th century BC and archaeological evidence suggests that the inhabitants of Limyra had to fight against the rising water since Late Antiquity to Byzantine times. From the geological point of view, this historical record indicates an important tectonic process at the southwestern coast of Turkey over the last 1400 years. Borchhardt (1993)

explained this by a regional subsidence of the coastal plain relative to the mountainous hinterland. However, recent geological, geophysical and archaeological data emphasize the importance of seismic deformation during historical times (Tan et al., 2008). Consequently, Özdaş and Kızıldağ (2013) explained the submergence of Kekova, an ancient harbor close to the study area (Fig. 1a), by both tectonic subsidence and eustatic sea-level rise since the late 6th century AD. As evidenced in the ancient city Kibyra (Fig. 1a), seismic deformation at that time had also affected the more interior parts of Asia Minor (Karabacak et al., 2013).

In this study, hydrogeological data (geological mapping data, water chemistry, surveying data) are used in combination with archaeological data and a ¹⁴C age estimate to explain the rise of the water table in the city of Limyra. The data give further insight into landscape evolution of southwestern Asia Minor during the past two centuries and illuminate the currently badly understood “Dark Ages” following Roman times.

2. History of ancient Limyra

Limyra is located ca. 5 km northeast of the modern small town of Finike at the foot of the Toçak Dağı (Fig. 1), a spur of the Bey Dağları. Scientific investigations in the city began as

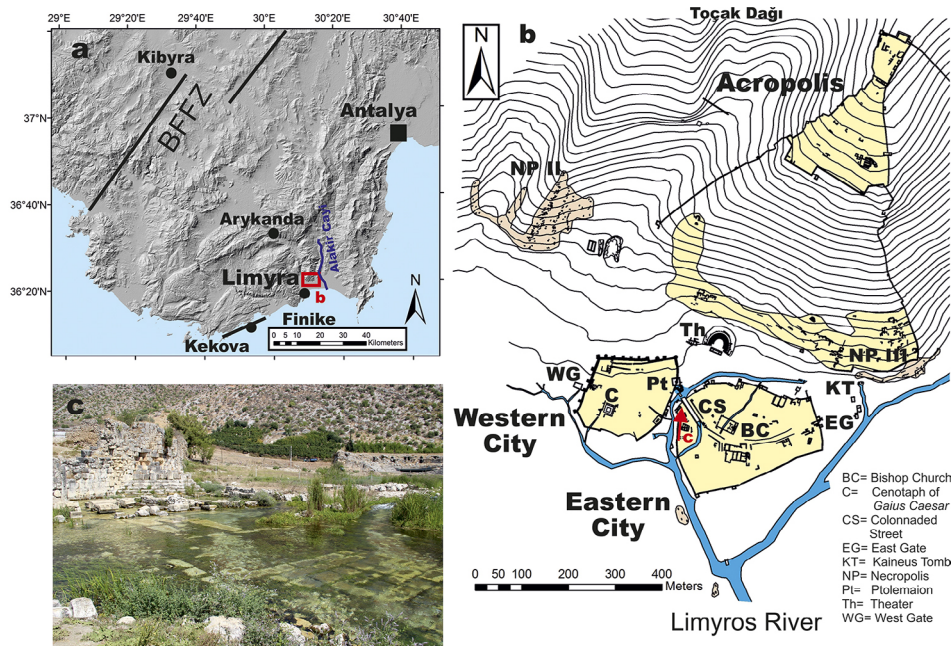


Figure 1: Ancient Limyra (a, b) with the drowned colonnaded street and Ptolemaion (c, photo direction indicated in b). The lines in (a) indicate seismic active faults (Karabacak et al. 2013; Özdaş & Kızıldağ 2013; Hall et al., 2014; BFFZ= Burdur-Fethiye Fault Zone). At the East Gate (EG in b) an ash layer was sampled for radiocarbon dating.

early as 1812, when C.R. Cockerell visited the ruins and discovered the sarcophagus of Siderija/Sidarios. Modern research started with the discovery of the so-called Heroon of the Lycian King Perikle, a temple-tomb dating to the 4th century BC, by the German archaeologist J. Borchhardt in 1966. Since 1969, when the excavations started, Limyra has become of interest from the archaeological point of view.

Although no secure information is known regarding the settlement of the city in the earliest period, Zemuri, the Lycian name of Limyra, can with great probability be traced back to the Hittite word zumarri found in texts dating to the 2nd millennium BC (Borchhardt, 1993). Apart from a few pottery fragments, which might date back to prehistoric times, the earliest finds belong to the early 7th century BC. A settlement existed in this area at the latest since the 6th century BC. However, due to the scant amount of the remains, its structure and extent have not yet been identified. Zemuri must have had an important position within the settlement hierarchy of Lycia already in the 5th century BC, but the first heyday the city experienced was in the 4th century BC, when it was developed into the residence city of an aspiring east Lycian dynasty. Beforehand, the dynast Perikle had succeeded to conquer Xanthos, the most important city of Lycia, and to extend his power over the complete region of Lycia and the neighboring areas in the north and east.

Under his reign, an extensive building program was developed in Limyra, during the course of which a massive ring of walls surrounded an area of ca. 25 ha, including a fortification at the summit (Marksteiner, 1997). Two prominent tower structures, probably designed to symbolize the power and importance of the ruler, dominated the fortifications.

The residential quarter was enlarged and included the lower slope of the acropolis hill with houses partially hewn out of the bedrock (Seyer, 1993). At this time, the monumental heroon of the dynasty was built on the acropolis (Borchhardt, 1976). This monument is a magnificent royal tomb, a counterpart to the famous Nereid Monument from Xanthos.

The five necropoleis of the classical period with roughly 400 tombs also came into being in the 4th century BC (see Seyer, 2011). Of these burial areas, Necropoleis II and III are assigned to the immediate city area (Fig. 1b), while the remaining burial areas are to be assigned to the periphery. If, however, one takes into account the necropoleis and individual

tombs of the village settlements in the hinterland, then the number of tombs increases considerably. Limyra has by far the largest number of tombs among the Lycian cities.

Few structures attest the Hellenistic and Early Imperial periods in Limyra. Nevertheless, due to their monumentality and the high quality of their architecture and sculptural decoration they are evidence of the importance of the settlement during these epochs. The so-called Ptolemaion (Fig. 1) of the first half of the 3rd century BC, located in the lower city not far from the Roman Theatre, belongs to this group of impressive structures (Stanzl, 2012). Due to its excellent craftsmanship it is regarded as one of the most outstanding monuments from this period in Asia Minor.

On his way back from a diplomatic mission to the east, Gaius Caesar, the heir presumptive, grandson and adopted son of Augustus, died in Limyra on 21 February 4 AD. A cenotaph was set up at the site of the prince's death (Ganzert, 1984; Borchhardt, 2002). The massive core of opus caementitium from this cenotaph is preserved in the western lower city of Limyra, rising up above a limestone foundation and socle of limestone ashlar blocks. Besides the theatre (Fig. 1), erected in the 2nd to 1st centuries BC and rebuilt after a devastating earthquake in 141 AD, also other buildings such as huge bathing complexes, broad colonnaded streets, bridges, i.e. illustrate the flourishing urban life of Limyra in the Roman Imperial period.

In the Late Antiquity to Byzantine periods, the city was an episcopal see. Between the 4th and the late 9th centuries AD, the names of six bishops are known, who, as with all bishops of Limyra, were subordinate to the Metropolitan of Myra. In the late 5th/early 6th century AD, the city was divided into two regions by means of two wall circuits, independent of each

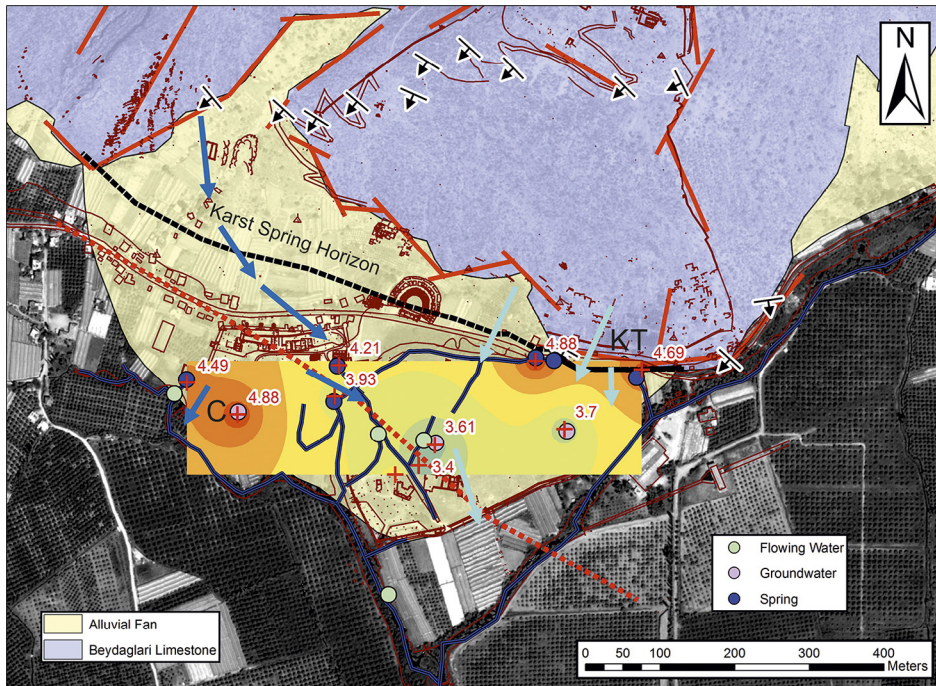


Figure 2: Hydrogeological map of Limyra (KT= karst spring in the Kaineus Tomb, C= Cenotaph). Limestones of the Beydaglari Formation dip below Quaternary sediments of the Finike coastal plain. At the northern margin of Limyra, a karst spring horizon crops out at the surface, feeding two water flow systems (indicated by arrows). The modeled ground water surface (colored raster overlay) is based on the altitude labeled surveying locations (cross symbols).

other (Fig. 1b). Amongst the monuments of the Byzantine period, the three church buildings are worth being mentioned. Excavations in the region of the Byzantine eastern city wall in 2012 discovered a building remarkable in many respects. According to various features, it certainly was a public building for Limyra's Jewish community, and it is probable that it was even the city's synagogue (Seyer and Lotz, 2014).

3. Hydrogeological setting

The study area is located within the Bey Dağları Block (Van Hinsbergen et al., 2010), bordered by the seismically active (Tan et al., 2008) Burdur-Fethiye Fault Zone (Hall et al., 2014) towards the west (Fig. 1). This region bears a lot of evidence that earthquakes damaged ancient settlements during historical times (Akyüz and Altunel, 2001; Tan et al., 2008; Karabacak, 2011; Karabacak et al., 2013). An important settlement of the Bey Dağları Region is Limyra, built at the southern toe of the Toçak Dağı, bordering the Finike coastal plain (Fig. 1). The Toçak Dağı is composed of Upper Cretaceous limestones of the Beydaglari Formation (Sari and Özer, 2001), forming the southern limb of the Finike Anticline (Hayward and Robertson, 1982). The limestones dip below Quaternary sediments of the Finike coastal plain (Öner, 1996, 2013), forming the uppermost sequence of the offshore Finike Basin, which was filled by sediments from Eocene times onwards (Aksu et al., 2014). Öner (1996, 2013) explored the subsurface of the Finike coastal plain by shallow drill cores. Accordingly, the basement of the city of Limyra was built over Quaternary silty strata of an alluvial flood plain and silts of a limnic environment at a depth

between ca. 7 and 22 m below the surface.

The strongly karstified (Bayari et al., 2011) Beydaglari limestone of the Toçak Dağı shows karst conduits along southwestern dipping bedding planes and along a related conjugated joint system. Steeply dipping faults dismember the southern slope of the mountain (Fig. 2). The mountain toe outlines a karst spring horizon, pouring water out from the Beydaglari limestones into the subsurface of Limyra. The water flows towards the south and is collected in a stream flowing in a western direction (Figs. 1, 2). Between the eastern and the western city, this stream bends towards the south and feeds the western spring branch of the south-flowing Limyros River, which is also fed by an eastern branch, coming from the

northeast (Figs. 1, 2). At the northern margin of the city, the karst spring horizon crops out at the surface, flooding the Kaineus rock-cut tomb (Figs. 1, 2) of the Classical period. Further to the west, it disappears below an alluvial fan, transporting gravel out of a fault-controlled valley (Fig. 2).

4. Methods

Elevation data along the ground water table were collected by differential GPS (DGPS) surveying, giving 3D-coordinates within the LRF08 (Limyra Reference Frame 2008) system of the Austrian Archaeological Institute (Vienna) with a precision of ca. 2 cm.

To determine the drainage area of the Limyra water, eleven water samples were taken in September 2013 and analyzed chemically by ion chromatography. The samples were filtered through a 0.2 µm nylon filter prior to analysis. The final filtrate was diluted and analyzed for cations and anions using two different sets of ion chromatography equipment. Anions were determined on a Dionex DX-3000 system with an external suppression. For standard runs, a 25 µl sample loop was used. At these conditions, detection limits for Cl, F and SO₄ were 10, 5 and 10 µg/l, respectively. All analyzed values were well above the detection limits. Cations were analyzed using a Dionex DX-120 system with electrochemical micro-membrane suppression and a 25 µl sample loop. Li (0.1), Na (5), K (5), Ca (10), and Mg (10) were analyzed as well [detection limits (µg/l) in the brackets]. Electrical conductivity of the samples were analyzed in the field by using a DiST 3 WP (Hanna Instruments) conductivity meter (accuracy of 2% expressed for 20°C).

The radiocarbon lab of the Physics Institute (Climate and

Environmental Physics) of the University of Bern (Switzerland) dated a charcoal sample by the ¹⁴C method, using the radio-carbon calibration of Reimer et al. (2009 and the “Calib” radio-carbon calibration software of Stuiver and Reimer (1993).

5. Results

5.1 Surveying

At the Cenotaph, ground water levels to the karst spring horizon (Fig. 2). This indicates that an aquifer exists within the alluvial sediments. The mapped elevation data depict an elongated depression of the groundwater table within the city (Fig. 2), southeastward deepening to a minimum of ca. 1.5 m below the shoulders of the graben at the center of the Eastern City. The depression collects the water and discharges it towards the south in the outlet channel of the Limyros River.

5.2 Hydrochemistry

The hydrochemical data analyzed for the sample sites within the city of Limyra reveal a homogeneous composition (Table 1). They are in accordance with the data of Bayari et al. (2011), representative for the Bey Dağları karst water. Deviating values characterize samples from the Alakır Cayı (Fig. 1) water (Table 1), sampling a watershed within a geologically different area (Antalya Nappes; Woodcock and Robertson, 1981). It is important to note that the Alakır Cayı feeds the groundwater of the Finike plain (Fig. 1). Therefore, the Alakır Cayı data characterize the chemical composition of the Finike plain groundwater.

Consequently, the chemical composition of water samples from the city indicates that the water originates from the Toçak

Dağı karst system (see also Demirel and Gunay, 2000; Bayari et al., 2011). The chemical data also show that the groundwater of the Finike plain, fed by the Alakır Cayı does not influence the groundwater system of Limyra. The karst water flows through the alluvial gravel and pours out in several springs within the excavated city (Fig. 2). At these locations, the observed stream directions indicate two major stream systems, one flowing from the limestones north of the city towards the south, and the other flowing through the gravels of the alluvial fan in a southeastern direction (Fig. 2). Obviously, the limestones outcropping west of the city (Fig. 2) fill the second aquifer.

5.3 Excavation and chronological aspects

In order to study the urban development of Limyra, the East Gate of the Byzantine Eastern City (Fig. 1b) was excavated (Seyer and Lotz, 2012 a, b; Seyer and Lotz, 2013 a, b). The road accessing the city from the east was excavated here for a length of 13.0 m inside and 6.5 m outside the gate (Fig. 3). The 4.3 m wide road was paved with mostly rectangular limestone slabs, lying between 0.6 m and 1.1 m below modern ground level. The road level in the excavated area inside the city wall is constant, while outside the gate it rises for about 0.3 m. Pottery fragments of the foundation layer show that the road was paved in the 6th century AD. Its course, however, seems to be older.

The archaeological stratigraphy above the road’s pavement is quite similar inside and outside the gate (Fig. 3 a): Below modern subsoil, there is a 0.8 m thick massive collapse layer of material from the adjacent buildings and the gate. This layer overlies a 0.2 m thick layer consisting of small tile fragments, sand and mortar, covering the road surface. A comparable pavement

		Alakır Cayı Samples		Limyra Samples								
		Roman Bridge	Reservoir Water	Western Wall	Western City	Cenotaph	Ptolemaion	Spring at the Karst Horizon	Kaineus Tomb	Eastern Gate	Bishop Church	Limyros River
Li ⁺	µg/l	0.5	0.4	1.0	1.6	1.8	2.0	2.0	2.0	2.0	2.0	1.8
Na ⁺	µg/l	4270.6	4344.9	11523.8	16190.9	17743.8	17887.0	16288.0	16689.3	15350.8	15615.5	16472.3
K ⁺	µg/l	383.4	370.8	329.3	395.0	437.4	433.0	431.1	422.6	409.2	415.6	408.6
Mg ²⁺	µg/l	8399.1	8866.7	8602.0	8152.6	8402.7	8678.6	8935.3	9022.7	9588.4	9096.6	8796.2
Ca ²⁺	µg/l	12565.2	16069.7	23184.2	20979.5	22205.8	19604.5	19325.3	20517.6	16593.8	20621.5	21290.2
F ⁻	µg/l	40.9	45.1	53.0	58.1	65.3	61.9	62.4	66.4	61.7	57.7	66.2
Cl ⁻	µg/l	2575.4	2650.8	18511.3	25908.7	27462.2	26423.5	22962.2	24393.1	19522.4	21248.2	24264.2
Br ⁻	µg/l	5.7	8.4	35.4	43.0	43.4	44.2	35.3	36.0	26.6	29.0	38.1
I ⁻	µg/l	< 0.1	< 0.1	0.3	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
SO ₄ ²⁻	µg/l	3784.0	3908.0	5191.0	5465.7	5473.6	5426.4	5171.5	5371.9	5077.2	4940.4	5278.4
NO ₃ ⁻	µg/l	24.7	64.0	2991.3	1699.0	1126.7	1028.7	623.7	643.8	n.a.	628.1	1008.1
Conductivity	µS/cm	310	320	505	520	510	500	490	490	485	520	502

Table 1: Conductivity (expressed at 20°C) and hydrochemical data of the Alakır Cayı and Limyra water samples. The data demonstrate significant differences between the Limyra water and the Alakır Cayı water, representing the Finike plain groundwater.

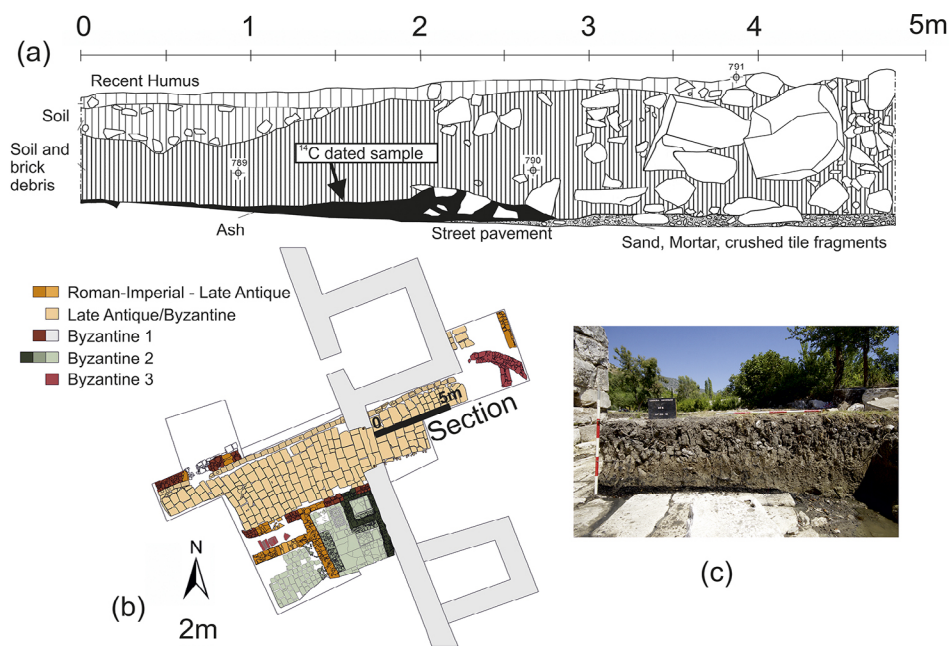


Figure 3: Excavation at the East Gate (EG in Figure 1) showing the location of the ¹⁴C-dated ash layer in section (a) and map (b) view. The photo in (c) shows the ash layer in a related section. The ash layer overlies a layer consisting of small tile fragments, sand and mortar (see Figure 3 a), applied to raise the road from the 6th century AD in reaction to the rising water level.

Laboratory code	Material	¹⁴ C age (BP, 1 σ)	Calendar age (2 σ)
B-10354	charcoal	1145 \pm 50	771-989 AD

Table 2: Radiocarbon results of the ash horizon next to the Eastern Gate of Limyra (see Figure 2) carried out at the Physics Institute of the University of Bern (Switzerland). Calibration according to Reimer et al. (2009) and “Calib” radiocarbon calibration software of Stuiver and Reimer (1993).

of the road is found at the NW corner of the southern baths (formerly so-called bishop’s palace) in the Eastern City (Pülz and Ruggendorfer, 2004). At the East Gate, this material covers the entire road and is heavily compressed. Outside the gate where the road level rises, it becomes thinner and finally disappears. Apparently, this layer was applied to raise the road level in reaction to the rising water level (Fig. 3 a).

The original paving of the road at the East Gate in the 6th century AD gives a terminus post quem, the destruction of the city gate a terminus ante quem for the water level rising above the original road pavement. Elements of the gate and the adjacent city wall have collapsed into the area around the door sill and between the two towers flanking the gate at its outer side. Outside the gate, they rest on a black layer of ash and burnt timber, measuring up to 0.2 m and covering the whole road as far as 6 m distant from the sill. Thus, the destruction of the gate was accompanied by heavy fire, which consumed wooden elements such as wings of the door or superstructures.

The ¹⁴C age of this ash layer dates therefore the time after the groundwater had risen to the former surface. Within the timeframe of 771 to 989 AD (Table 2), the gate seems to have been changed or renovated for a last time, before it was finally destroyed. After the collapse, the gate was not rebuilt and the material was left on the road. During that time at the

latest, the now blocked road went out of use in this area. From a distance of 6.5 m from the gate, the road pavement is lost. Instead, a semi-circular wall of broken stones closes the area between the two towers (Fig. 3). A similar structure is present in Arif, the Byzantine follow-up-settlement of Arykanda 30 km to the northwest of Limyra (Fig. 1a). In Limyra, a small doorway was left open adjacent to the northern tower. The foundation of this semi-circular wall reaches beyond the level of the road that was cut for its erection. The use of hydraulic mortar shows that also here the rising groundwater table was a concern. The construction data of this wall is hard to be determined, but it must have taken place after the road went out of use; possibly the semi-circular wall took over the defensive function of the now destroyed city gate.

The excavation at the East Gate demonstrates that in early

or middle Byzantine times (6th to 10th centuries AD) groundwater had reached the level of the road’s 6th century pavement. In reaction to this threat, a layer of crushed tiles mixed with sand and mortar was added. A similar situation is documented for the area around the so-called Ptolemaion church (Fig. 1c, Ruggendorfer, 1990).

6. Drowning of Limyra

Obviously, the present hydrogeological setting does not match the ancient setting. Archaeological evidences demonstrate that drowning of Limyra commenced during Byzantine times at the earliest (Table 3). The drowned colonnaded street (Fig. 1c) presumably dates to Late-Antiquity or Early-Byzantine times (Reiter, in Borchhardt, 1993), and the drowned Byzantine sacral buildings of the Eastern City are dated to the 5th/6th century AD (Borchhardt, 1993). In the late 5th to early 6th century AD, the city was divided into two fortified centers (Eastern and Western City, Fig. 1b) with a channel in-between. The bridge which crossed the channel is now flooded (Fig. 1c). The implementation of a new architectural city design during this time reflects most probably the fight against rising groundwater. The latest time marker is given by the ¹⁴C age of the ash horizon, evidencing a water rise to the surface before the late 8th to late 10th centuries AD.

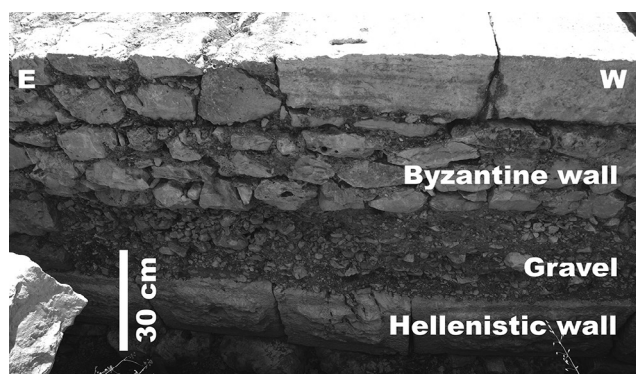


Figure 4: At the West Gate (WG in Figure 1), alluvial gravel overlies Hellenistic basement walls, and is itself overbuilt by a Byzantine wall (photo taken during September 2013).

Excluding a significant increase in precipitation since Roman times (Bakker et al., 2013), subsidence of the coastal plain would lower the karst spring horizon. However, the observation of water flowing through the chamber of the so-called Kaineus tomb, cut into the bedrock limestone, excludes downward karst progression and evidences that the bedrock at the toe of the mountain subsided relative to the karst spring horizon.

Hydrogeological and archaeological observations evidence that subsidence is not the only cause of drowning. About 3 m thick alluvial gravel overlies the former pavement level at the Cenotaph (Borchhardt, 1993). The finding of Byzantine remnants at the top of those sediments (Borchhardt, 1993) evidences a gravel filling after the time of building (1st century AD). At the West Gate (Fig. 1b), gravel overlies Hellenistic basement walls, and is itself overbuilt by a Byzantine wall (Fig. 4). Therefore, to reconstruct the pre-Byzantine landscape, the alluvial gravel deposited in the area of the western city (Fig.

2) has to be removed. In such a reconstruction, karst water of that time followed the direction of the eastern water flow system and brought the waters towards the south by passing the center of the Western City.

Since Late Antiquity, alluvium (gravel) has been deposited in this area (Fig. 2). The gravel constitutes the modern aquifer, filled up to the pressure level of the spring horizon. The gravel composition suggests that both man-made land filling and natural debris flow, transported from a tectonic graben (Fig. 2), diverted the karst waters into the city center.

The observation of a surface depression (Fig. 2), channelling the flowing waters towards the city center might indicate a structural basement depression, paralleling the limestone escarpment at the toe of Toçak Dağı. A suspected subsurface normal fault outlined by this depression accommodates the slip of the subsiding Finike plain. In this model, kinematically related fault activity in the valley behind the city produced the debris filling of the subsurface depression.

7. Conclusions

Both, natural and anthropogenic processes influenced the unforced water drainage at the mountainous margin of the Finike plain (Table 3). Archaeological and hydrogeological data at the ancient city of Limyra suggest subsidence of the southern segment of the Toçak Dağı, accommodated by normal faults, being active at least up to the late 8th to late 10th centuries AD. Most probably, such landscaping fault activity was associated with earthquakes of high magnitudes (e.g. Monaco and Tortorici, 2004; Karabacak et al., 2013). A major earthquake may have changed the karst hydrography dramatically with some springs closing, while others opened up. In agreement, a large earthquake supposedly destroyed the

Date	Event	Reference
Early 7th century BC	Earliest finds in Limyra	
Since the 6th century BC	Settlement in Limyra	
4th century BC	Limyra as a Lycian dynastic residence city	Borchhardt (1993)
3rd century BC	Erection of the Ptolemaion in Limyra	
1st century AD	Erection of the Cenotaph of Gaius Caesar in Limyra	
23 AD	Devastating earthquake in Kibyra	Bean (1978)
141 AD	Devastating earthquake in Limyra	Borchhardt (1993)
4th - late 9th centuries	Limyra as an episcopal see	
417 AD	Devastating earthquake in Kibyra	Akyüz & Altunel 2001
5th/6th century AD	Byzantine sacral buildings of the Eastern City	Borchhardt (1993)
Late 5th/early 6th century AD	City division in Limyra, Begin of submergence	this study
6th to late 10th centuries AD	Earthquake induced debris flows in Limyra	
6th century AD	Road paving at the Limyra East Gate	Seyer and Lotz (2012 a, b); Seyer and Lotz (2013 a, b)
Late 6th to early 7th centuries AD	Begin of submergence of coastal structures at Kibyra	Özdağ & Kızıldağ (2013)
Early 8th century AD	Earthquake supposedly destroying the Bishop Church of Limyra	Jacobek in Borchhardt (1993)
Late 8th to late 10th centuries AD	Fire at the Limyra East Gate	this study
10th to 11th centuries AD	Devastating earthquake in Kibyra	Karabacak et al. (2013)

Table 3: A brief history of Limyra, completed by the earthquake record of the Bey Dağları region.

Bishop Church of Limyra (Fig. 1b) in the early 8th century AD (Jacobek, in Borchhardt, 1993). For the study area there are only sparse historical accounts of that time concerning earthquake faulting (Tan et al., 2008, see Table 3). However, similar evidence from ancient cities adjacent to the study area (Karabacak et al., 2013; Özdaş and Kızıldağ, 2013) demonstrates the importance of seismo-tectonic faulting within the Bey Dağları region, influencing significantly ancient life at the southwestern coast of Asia Minor.

Limyra drowned under karst water level, channelled by alluvial gravel within the city center. As evidenced by the gravel composition, anthropogenic dumping since Roman times complemented the natural debris flow. In this way, human landscaping enhanced the effects of natural disasters. Both processes contributed to the demise of urban life in Limyra during the "Dark Ages" after the collapse of the Roman Empire.

Acknowledgments

The authors thank the General Directorate for Cultural Heritage and Museums, Ministry of Culture and Tourism of the Republic of Turkey for the annual granting of the excavation permit in Limyra. Comments and suggestions of Helmut Brückner, Michael Wagreich and an anonymous reviewer helped to improve the manuscript.

References

- Aksu, A.E., Hall, J., Yalıtırak, C., Çınar, E., Küçük, M. and Çifçi, G., 2014. Late Miocene–Recent evolution of the Finike Basin and its linkages with the Beydağları Complex and the Anaximander Mountains, eastern Mediterranean. *Tectonophysics*, 635, 59–79. <http://dx.doi.org/10.1016/j.tecto.2014.04.042>
- Akyüz, S.H. and Altunel, E. 2001. Geological and archaeological evidence for post-Roman earthquake surface faulting at Cibyra, SW Turkey. *Geodinamica Acta*, 14, 95–101.
- Bakker, J., Paulissen, E., Kaniewski, D., Poblome, J., Laet, V. de, Verstraeten, G. and Waelkens, M., 2013. Climate, people, fire and vegetation: new insights into vegetation dynamics in the Eastern Mediterranean since the 1st century AD. *Climate of the Past*, 9, 57–87. <http://dx.doi.org/10.5194/cp-9-57-2013>
- Bayari, C. S., Ozyurt, N. N., Oztan, M., Bastanlar, Y., Varinlioglu, G., Koyuncu, H., Ulkenli, H. and Hamarat, S., 2011. Submarine and coastal karstic groundwater discharges along the southwestern Mediterranean coast of Turkey. *Hydrogeology Journal*, 19, 399–414. <http://dx.doi.org/10.1007/s10040-010-0677-y>
- Bean, G.E., 1978. *Lycian Turkey: An archaeological guide*. London: Ernest Benn Publications. 197 pp.
- Borchhardt, J., 1976. *Die Bauskulptur des Heroons von Limyra*. Mann Verlag, 143 pp.
- Borchhardt, J., 1993. *Die Steine von Zemuri. Phoibos*, 160 pp.
- Borchhardt, J., 2002. *Der Fries vom Kenotaph für Gaius Caesar in Limyra. Phoibos*, 152 pp.
- Brückner, H., Urz, R. and Seeliger, M., 2013. Geomorphological and geoarchaeological evidence for considerable landscape changes at the coasts of western Turkey during the Holocene. *Geopedology and Landscape Development Research Series*, 1, 81–104.
- Delile, H., Blichert-Toft, J., Goiran, J.-P., Stock, F., Arnaud-Godet, F., Bravard, J.-P., Brückner, H. and Albarède, F., 2015. Demise of a harbor: a geochemical chronicle from Ephesus. *Journal of Archaeological Science*, 53, 202–213. <http://dx.doi.org/10.1016/j.jas.2014.10.002>
- Demirel, I. H., Gunay, Y., 2000. Tectonic and karstic effects on the Western Taurus Region, Southwestern Turkey: Relations to the present temperature gradients and total organic carbon content. *Energy Sources*, 22, 431–441.
- Dermody, B.J., van Beek, R.P.H., Meeks, E., Klein Goldewijk, K., Scheidel, W., van der Velde, Y., Bierkens, M.F.P., Wassen, M.J. and Dekker, S.C., 2014. A virtual water network of the Roman world. *Hydrology and Earth System Sciences*, 18, 5025–5040. <http://dx.doi.org/10.5194/hess-18-5025-2014>
- Ganzert, J., 1984. *Das Kenotaph für Gaius Caesar in Limyra*. Walter de Gruyter and Company, 195 pp.
- Hall, J., Aksu, A. E., Elitez, I., Yalıtırak, C. and Çifçi, G., 2014. The Fethiye–Burdur Fault Zone: A component of upper plate extension of the subduction transform edge propagator fault linking Hellenic and Cyprus Arcs, Eastern Mediterranean. *Tectonophysics*, 635, 80–99. <http://dx.doi.org/10.1016/j.tecto.2014.05.002>
- Hayward, A.D. and Robertson, A.H.F., 1982. Direction of ophiolite emplacement inferred from Cretaceous and Tertiary sediments of an adjacent autochthon, the Bey Dağları, southwest Turkey. *Geological Society of America Bulletin*, 93, 68–75.
- Karabacak, V., 2011. Geological, geomorphological and archaeological observations along the Cibyra Fault and their implications for the regional tectonics of SW Turkey. *Turkish Journal of Earth Sciences*, 20, 429–447.
- Karabacak, V., Yönlü, Ö., Dökü, E., Kiyak, N. G., Altunel, E., Özüdoğru, Ş., Yalçiner, C.Ç. and Akyüz, H.S., 2013. Analyses of seismic deformation at the Cibyra Roman stadium, Southwest Turkey. *Geoarchaeology*, 28, 531–543. <http://dx.doi.org/10.1002/gea.21456>
- Kraft, J.C., Brückner, H., Kayan, I. and Engelmann, H., 2007. The geographies of ancient Ephesus and the Artemision in Anatolia. *Geoarchaeology*, 22, 121–149. <http://dx.doi.org/10.1002/gea.20151>
- Kraft, J.C., Rapp, G., Brückner, H. and Kayan, I., 2011. Results of the struggle at ancient Ephesus: natural processes 1, human intervention 0. Geological Society, London, Special Publications, 352, 27–36.
- Marksteiner, T., 1997. *Die befestigte Siedlung von Limyra. Phoibos*, 202 pp.
- Monaco, C. and Tortorici, L., 2004. Faulting and effects of earthquakes on Minoan archaeological sites in Crete (Greece). *Tectonophysics*, 382, 103–116. <http://dx.doi.org/10.1016/j.tecto.2003.12.006>
- Öner, E., 1996. Finike ovasinin alüvyal jeomorfolojisi ve antik Limyra Kenti. *Ege Coğrafya Dergisi*, 9, 131–158.
- Öner, E., 2013. Likya'da Paleocoğrafya ve Jeoarkeoloji Araştır-

- malarý. Ege Üniversitesi, 478 pp.
- Özdaş, H. and Kızıldağ, N., 2013. Archaeological and geophysical investigation of submerged coastal structures in Kekova, southern coast of Turkey. *Geoarchaeology*, 28, 504–516. <http://dx.doi.org/10.1002/gea.21452>
- Passchier, C.W., Wiplinger, G., Güngör, T., Kessener, P. and Sürmelihindi, G., 2013. Normal fault displacement dislocating a Roman aqueduct of Ephesos, western Turkey. *Terra Nova*, 25, 292–297. <http://dx.doi.org/10.1111/ter.12035>
- Pülz, A. and Ruggendorfer, P., 2004. Kaiserzeitliche und frühbyzantinische Denkmäler in Limyra: Ergebnisse der Forschungen in der Oststadt und am Ptolemaion (1997–2001). *Mitteilungen zur Christlichen Archäologie* 10, 52–79.
- Rantitsch, G. and Prochaska, W., 2011. Die hydrogeologische Situation des Panayırdağ als Bewertungsgrundlage für die Wasserversorgung der vorlysimachischen Siedlung. *Jahreshefte des Österreichischen Archäologischen Institutes in Wien*, 80, 243–254.
- Reimer, P.J., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Ramsey, C.B., Buck, C.E., Burr, G.S., Edwards, R L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., McCormac, F.G., Manning, S.W., Reimer, R.W., Richards, D.A., Southon, J.R., Talamo, S., Turney, C.S.M., Van Der Plicht, J. and Weyhenmeyer, C.E., 2009. IntCal09 and Marine09 radiocarbon age calibration curves, 0–50,000 years CAL BP. *Radiocarbon*, 51/4, 1111–1150.
- Ruggendorfer P., 1990. Die Grabung im Osten des Ptolemaions – SO 14. *Kazi Sonuçları Toplantısı*, 12, 330–331.
- Sari, B. and Özer, S., 2001. Facies Characteristics of the Cenomanian–Maastrichtian Sequence of the Beydağları Carbonate Platform, Korkuteli Area, Western Taurides, Turkey. *International Geology Review*, 43, 830–839.
- Seeliger, M., Brill, D., Feuser, S., Bartz, M., Erkul, E., Kelterbaum, D., Vött, A., Klein, C., Pirson, F. and Brückner, H., 2014. The Purpose and age of underwater walls in the Bay of Elaia of Western Turkey: A multidisciplinary approach. *Geoarchaeology*, 29, 138–155. <http://dx.doi.org/10.1002/gea.21471>
- Seyer, M., 1993. Die Grabung in den Hanghäusern von Limyra. In: J. Borchhardt and G. Dobesch (Eds.), *Akten des II. Internationalen Lykien-Symposions Wien*, pp. 171–181.
- Seyer, M., 2011. Die intraurbanen Grabmäler der klassischen Periode in Limyra. *Actes des 2e Rencontres d'Archéologie*, 207–221.
- Seyer, M. and Lotz H., 2012 a. Limyra 2011, Grabung in der Oststadt. *Kazi Sonuçları Toplantısı*, 34, 221–234.
- Seyer, M. and Lotz, H., 2012 b. Limyra 2011, Excavation in the East City. *News of archaeology from Anatolia's Mediterranean areas*, 10, 59–64.
- Seyer M. and Lotz, H., 2013 a. Limyra 2012, Grabung in der Oststadt. *Kazi Sonuçları Toplantısı*, 35, 404–406.
- Seyer, M. and Lotz, H., 2013 b. Limyra 2012, Doğu Kapı Kazısı – East Gate Excavation, *News of archaeology from Anatolia's Mediterranean Areas*, 11, 83–85.
- Seyer, M. and Lotz, H., 2014. A building with jewish elements in Limyra/Turkey – A synagogue. *Journal of Ancient Judaism*, 5, 142–152.
- Stanzl, G., 2012. Zur Neuaufnahme der Arbeiten am Ptolemaion in Limyra. In: M. Seyer (Ed.), *40 Jahre Grabung Limyra. Akten des internationalen Symposions Wien*, pp. 327–342.
- Stock, F., Kerschner, M., Kraft, J.C., Pint, A., Frenzel, P. and Brückner, H., 2014. The palaeogeographies of Ephesos (Turkey), its harbours, and the Artemision – a geoarchaeological reconstruction for the timespan 1500 – 300 BC. *Geomorphologie*, 58, Suppl. 2, 33–66. <http://dx.doi.org/10.1127/0372-8854/2014/S-00166>
- Stock, F., Pint, A., Horejs, B., Ladstätter, S. and Brückner, H., 2013. In search of the harbours: New evidence of Late Roman and Byzantine harbours of Ephesus. *Quaternary International*, 312, 57–69. <http://dx.doi.org/10.1016/j.quaint.2013.03.002>
- Stuiver, M. and Reimer, P.J., 1993. Extended ¹⁴C data base and revised CALIB 3.0 ¹⁴C age calibration program. *Radiocarbon*, 35, 215–230.
- Tan, O., Tapırdamaz, C. and Yörük, A., 2008. The earthquake catalogues for Turkey. *Turkish Journal of Earth Sciences*, 17, 405–418.
- Van Hinsbergen, D. J. J., Dekkers, M. J. and Koc, A., 2010. Testing Miocene remagnetization of Bey Dağları: timing and amount of Neogene rotations in SW Turkey. *Turkish Journal of Earth Sciences*, 19, 125–156. <http://dx.doi.org/10.3906/yer-0904-1>
- Woodcock, N.H. and Robertson, A.H.F., 1981. Wrench related thrusting along a Mesozoic-Cenozoic continental margin: Antalya Complex, SW Turkey. *Geological Society, London, Special Publications*. 9, 359–362.

Received: 21 May 2015

Accepted: 11 December 2015

Gerd RANTITSCH^{1*)}, Walter PROCHASKA¹⁾, Martin SEYER²⁾, Helmut LOTZ³⁾ & Christian KURTZE²⁾

¹⁾ Chair of Geology and Economic Geology, Montanuniversität Leoben, Peter-Tunner Strasse 5, A-8700, Leoben, Austria;

²⁾ Austrian Archaeological Institute, Franz Klein-Gasse 1, A-1190 Vienna, Austria;

³⁾ Documenta Antiqua – History of Ancient Law, Institute for the Study of Ancient Culture, Austrian Academy of Sciences, Postgasse 7/4, A-1010 Vienna, Austria;

^{*)} Corresponding author: gerd.rantitsch@unileoben.ac.at