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Natural Risks and Water Management in Delphi

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Abstract: The archaeological site of Delphi is subject to several natural hazards including earthquakes, gravity gliding, and slope instabilities. The architectural remains at the site bear the marks of the disasters that occurred in antiquity but also show how ingeniously the ancient Greeks dealt with risks and major events. The greatest danger seems to be landslides and rock falls, which are caused by surface and underground water runoff. The period of reconstruction that followed the collapse of the Temple of Apollo in the 4th century BC seems to mark an important turning point in how ancient designers considered and responded to water-related risks. Water is appropriately channelled and later exploited for thermal baths.

Keywords: earthquakes, rockfall, underground waters, architecture, thermal baths

Introduction

Delphi, one of the historically most relevant sites of antiquity, is located in central Greece, on the slope of Mount Parnassus, at the foot of the Phaedriades cliffs (called Phlemboukos, to the east of Kastalia Spring, and Rhodini, to the west of it) (Figure 1), about 600 m a.s.l. and 10 km inland from the northern coast of the Gulf of Corinth (Figure 2). The topographical positioning of the ancient site of Delphi is indeed exceptionally scenographic and suggestive. Gustave Flaubert wrote that the oracular Sanctuary of Apollo was located in a ‘landscape of religious terror’ and that to have put Pythia there was ‘genius’.¹

The Sanctuary of Apollo, which housed the famous oracle and was in function between the 8th century BC and the 4th century AD, was located in the heart of the ancient city of Delphi. The city of Late Antiquity developed until the last quarter of the 6th century, when the site was abandoned, which is generally attributed to the wave of Slavic invasions that occurred c. 580–590 AD. The sanctuary was mainly excavated from 1892 to 1903 by French archaeologists. In addition to the monuments of Apollo’s sanctuary and the districts of the city, the remains include the Sanctuary of Athena Pronaia, necropolises, the Castalian Fountain, the gymnasium and the stadium.

From a geological point of view, the site lies on the downthrown block of one of the major seismic faults that form the northern margin of the Corinth Rift: the Delphi Fault, which runs from Arachova to Amphissa at the foot of the southern slope of the limestone massif of

Mount Parnassus. Because of its position and of the local conditions of this geologically active environment, whose processes have shaped the landscape, the archaeological site is subject to several natural hazards, the most relevant ones linked to seismicity and to the action of water, and archaeological traces of past catastrophes are preserved in the monuments. It seems that from the earliest period, already in the Mycenaean period, various strategies have been implemented, more or less successfully, to manage these risks.

In this contribution we offer a first joint analysis of the geological context and the archaeological remains in order to measure in particular the risks related to water and the relevance of the technical responses implemented to cope with them.

Geological setting

The geodynamic history of the Mediterranean region has been dominated by the convergence of Africa and Eurasia, starting since the Jurassic (200–150 Ma), inducing subduction, collision, and obduction processes, but also back-arc extension such as in the Aegean and Thyrenian zones.² The 2,457-meter-high Mount Parnassus that towers above Delphi formed during the Alpine-Hellenic orogeny, which has affected the Mesozoic limestone platforms of the Thetys margin from the Late Cretaceous–Eocene (100–30 Ma).³

Due to the clockwise rotation of the region between 15 and 8 Ma,⁴ the Hellenic orogenic belt is now

¹ G. Flaubert, *Lettres de Grèce* (ed. 1948): 52–53, quoted in Hellmann 1992: 47.

² Dercourt *et al.* 1986; Menant *et al.* 2016; Ricou *et al.* 1986; Ricou 1994; Şengör and Yilmaz 1981.

³ E.g. Nirta *et al.* 2015; Nirta *et al.* 2018, and references therein.

⁴ Brun and Sokoutis 2007; Jolivet *et al.* 2015.



Figure 1: Panorama of Delphi archaeological area and the Phedriades cliffs (called Phlemboukos, to the east of the Kastalia Spring, and Rhodini, to the west of it).

oriented nearly north–south. In reaction to the south Mediterranean subduction, back-arc extension took place from the Oligocene in the Aegean Sea, and the slab quickly migrated to the south, and the trench is now located south of Crete. Since the Late Miocene, the Hellenides have been affected by N–S extension localised in the active rift zones of Corinth, Evia, and within the Central Hellenic Shear Zone.⁵ The relative roles of the southward migration of the subduction-related extension and of the westward propagation of the North Anatolian fault⁶ remain open to discussion.

The Corinth Rift, the tectonic depression that hosts the Gulf of Corinth (Figure 2), is characterised today by particularly high rates of deformation, which are among the highest in the Mediterranean area (c. 1.5 cm/year).⁷ The extension started at the end of the Miocene⁸ and the current phase of extension began c. 1 Ma ago,⁹ and has

an average rate of about 10 mm/yr.¹⁰ The downthrow of the central portion is realised by slip on faults on its sides, dipping toward the axis of the depression (Figure 2 section). On the basis of geologic data and uplifted topography, vertical slip rates of the main faults, which are currently along the southern Gulf margin, appear to range between 6–7 and 11 mm/yr at Xilocastró¹¹ and between 3 and 8 mm/yr at Helice.¹² Paleoseismological trenching indicated a slip rate between 0.7 and 2.5 mm/yr for the Skinós fault alone (Figure 2).¹³

The evolution of the rift is well constrained into three phases:¹⁴ (1) an initiation phase dominated by small-extension continental and lacustrine sedimentation; (2) an increase of the fault activity associated with a connection of the basins, leading from a deep-water lacustrine to marine environment; and (3) the uplift of the Peloponnese since 1 Ma, with the exhumation

⁵ Armijo *et al.* 1996; Moretti *et al.* 2003; Papanikolaou and Royden 2007.

⁶ Sakellariou *et al.* 2017, and references therein.

⁷ Moretti *et al.* 2003, and references therein.

⁸ E.g. Rohais and Moretti 2017, and references therein.

⁹ Armijo *et al.* 1996; Jackson *et al.* 1982; Lyon-Caen *et al.* 1988; Mouyaris

et al. 1992; Ori 1989.

¹⁰ Ambraseys and Jackson 1990; Billiris *et al.* 1991.

¹¹ Armijo *et al.* 1996.

¹² Armijo *et al.* 1996; Mouyaris *et al.* 1992.

¹³ Collier *et al.* 1998.

¹⁴ Gawthorpe *et al.* 2018; Ori 1989; Rohais and Moretti 2017.

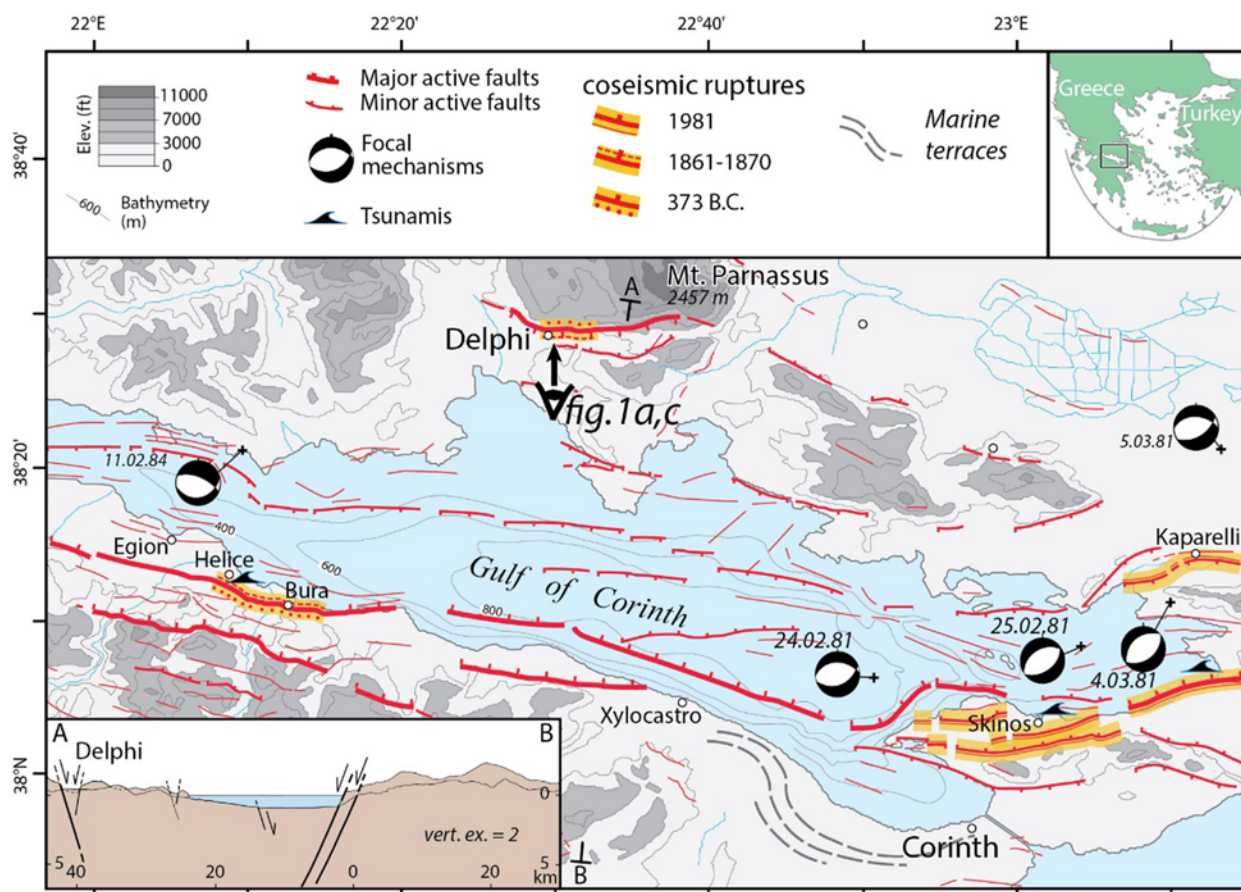


Figure 2: Map of active faults of the Delphi region (modified from Piccardi 2008 and Moretti *et al.* 2003). Dashed lines west of Corinth show the edge of marine terraces that registered the Peloponnese uplift.

of the syn-rift deposits on the southern shore and the shifting deltaic systems northward. Marine terraces of Upper Pleistocene age (c. 350 ka) have been exposed especially around the towns of ancient and modern Corinth. Due to hot fluid circulations, travertines are present along some major faults, such as the Xylocastro fault, as well as, at places, quaternary stromatolites all along the faults that border the Perachora peninsula.¹⁵ On the northern shore of the gulf, Oligo-Miocene sediments are mainly absent and Quaternary slope breccias lie unconformably on top of the Cretaceous limestones and Paleogene flysch across most of the region.¹⁶

The seismicity of the Corinth Gulf represents a major hazard for the inhabitants, with maximum earthquake magnitudes (M) exceeding 6.¹⁷ The occurrence of coseismic surface faulting is a well-known phenomenon in the Gulf of Corinth, and extensional coseismic surface faulting has also been documented by palaeoseismological trenching along the southern

margin. Fault rupture at surface has been observed during the 1981 ($M = 6.7$ and $M = 6.4$) Corinth seismic sequence, coherent with measured geophysical stress orientation, on conjugate faults at the eastern end of the Corinth Rift.¹⁸ In that sequence, the earthquakes of February 24 and 25, 1981 originated fault ruptures on the south side of the rift, while the shock of March 4, 1981 ($M_s = 6.4$) ruptured the antithetic fault on the north side of the graben. A rupture (c. 13 km long) was described along the Helice active fault in the 1861 Aigion earthquake,¹⁹ and rather similarly the appearance of a large 'chasm' is historically reported for the same fault in the Helice earthquake of 373 BC.

Delphi is located of the northernmost south dipping fault that borders the Corinth Rift (Figures 2, 3). The site of Delphi lies mainly in slope breccias and flysch but Mesozoic carbonate rocks also outcrop and the blocks of this basement cut by the major faults shape the landscape (Figure 3). Three main tectonic units are present in the area of Delphi: 1) the Parnassus Nappe which overlaps 2) the Pindos Nappe to the west and

¹⁵ E.g. Armijo *et al.* 1996; Hayward 2003; Kreshaw and Guo 2006.

¹⁶ Solakius *et al.* 1998.

¹⁷ Ambraseys 1996; Ambraseys and Jackson 1990; Mariolakos *et al.* 1989.

¹⁸ Jackson *et al.* 1982.

¹⁹ Mouyaris *et al.* 1992; Schmidt 1881.



Figure 3: View towards the north of Delphi and the southern slope of Mt Parnassus. White triangles indicate the trace of the active fault.

which is overthrust by (3) the Pelagonian Nappe of the Internal Hellenides eastward.²⁰ The Parnassus Nappe itself is composed of i) Triassic to Upper Cretaceous neritic limestones, ii) Campanian to Maastrichtian pelagic limestones, iii) red Paleocene pelitic rocks and Eocene flysch. The thrusting of the Pindos Nappe toward the west is dated from about 50 myr (Eocene).

North of the sanctuary outcrops the Jurassic limestone of Parnassus (Figure 2) and below the sanctuary, in the hanging wall of the fault, the youngest series are present, dated from the Upper Cretaceous (Maastrichtian, as in the St Elli quarry) to the Eocene. The slope breccia and debris flows, not specifically dated but clearly the product of the activity of the Delphi Fault, and the high of the cliff, largely covers this basement. Another large normal fault, dipping northward, borders the Pleistocene Valley, south of Delphi.²¹

The Delphi active fault

Ancient Delphi lies above a seismically active structure, the Delphi Fault, which has been active from at least 1 myr based on calcite cement dating²² and maybe during the full quaternary as the onshore south dipping faults near Galixidi that affect the full rift sequence based on marine seismic data.²³ The Delphi Fault is a fault system made of parallel slip planes, which bounds the calcareous massif of Mt Parnassus on the

south, extending for a distance of c. 28 km from east to west (Figures 2, 3). It is an east/west-trending fault, downthrowing the southern block and with minor right-lateral component of movement, as indicated by the geometry of the fault and slip-parallel lineation on the main fault plane (east of Delphi, the fault plane has an average strike of 260°N, dips 60–65° and is linedated by corrugations and striations with a pitch of about 70°W). For the most part, the main fault plane affects the Mesozoic limestone and Paleogene flysch of the bedrock. Würmian (< c. 18 ka) slope debris and Holocene (< 10 ka) debris cones are faulted as well. Delphi is positioned at a bend of the fault.

Slip is distributed at the surface on a few parallel subsidiary faults, within a fault-zone several tens of meters wide.²⁴ Intra-fault hanging wall collapse has created a stepped morphology. This is particularly visible to the east of the Kastalia Spring, east of the Apollo Sanctuary and north of that of Athena Pronaia, where subsidiary faults offset the paleosurface of the Quaternary slope-deposits. Slip during historical times on one of these splay faults may be deduced by archaeological evidence. In the shrine of Athena, for example, one of the segments of the fault cuts and displaces the main temple and altar, built near the end of 6th century BC. An offset of about 30 cm, still evident in the main altar's west wall, caused the break, and tilt, of the basement of the temple.²⁵

The Delphi Fault being large, earthquakes generated by its slip can be major, with a magnitude (M) up to

²⁰ Doutsos *et al.* 2006; Jolivet and Brun 2010; Royden and Papanikolaou 2011; Menant *et al.* 2016; Nirta *et al.* 2018.

²¹ Pécoux 1977; Piccardi 2000; Piccardi *et al.* 2008; Valkaniotis *et al.* 2011.

²² Causse *et al.* 2003; Pécoux 1977.

²³ Rohais and Moretti 2017.

²⁴ Pécoux 1977.

²⁵ Piccardi 2000.

7. The fault is known to have ruptured a few times in the past: in 373 BC,²⁶ in AD 551 with an estimated magnitude of $M = 7.2$,²⁷ and more recently in the $M_s = 6.7$ earthquake of August 1, 1870.²⁸ The epicentre of the last event was located at Kastri, the village that stood at that time on the main archaeological site of Delphi. The main shock occurred a little to the east, and the two major aftershocks ($5.4 < M < 6.3$) occurred west of it.²⁹ The ejection of sand and water (typically reddish because of the bauxite content of the limestone) from some spring observed after the 1870 earthquake³⁰ recalls the blood breathed forth by the Homeric dragoness after her death.³¹ Other significant earthquakes in the area, although not precisely documented, are indicated in 278 BC (Valkaniotis *et al.* 2011), AD 326 (Marinos and Rondoyanni 2005), in 354–346 and 279 BC, at Galaxidi at the turn of the 11th century (in 976–1025), and in 1580, and at Aigion (1402, 1938, 1965, 1970).

The most famous historical earthquake in this sector of the Corinthian Gulf is that of 373 BC, which destroyed two cities on the southern border of the Gulf. Bura is said to have ‘disappeared in a chasm of the Earth’ (Strabo, 1.3.18), while Helice was wiped out by ‘tidal waves which engulfed the open country and cities’ and remained submerged (Diodorus 15.1–4). Mouyaris *et al.* 1992 proposed that the rupture of the Helice Fault, with associated surface faulting, is the most probable source. That earthquake caused massive destruction at Delphi too, although far away from the main-shock epicentre. From archaeological data, Bousquet and Péchoux 1977 attributed a macroseismic intensity of IX MCS to this shock at Delphi, and the ‘Catalogue of Strong Earthquakes in the Mediterranean’ estimate a M_e of 6.4.³² Integrating tectonic, archaeological and historical data, Piccardi 2000 suggested that during the earthquake of 373 BC, not only was the Helice Fault ruptured on the southern border of the graben, but also the corresponding south dipping fault at Delphi. If this is the case, the seismotectonic mechanism of that earthquake would appear to be the same as that of the 1981 Corinth earthquake.

The description of the geomorphic effects of the $M = 6.7$, 1870 Kastri earthquake can provide a realistic idea about the coseismic phenomena and about the possible scenario which started the myth of a supernatural chasm in the earth at Delphi.³³ The earthquake caused

significant damage to the monuments at Delphi as well as in the nearby towns of Chrisso, Itea, and Arachova. A series of ground ruptures occurred along the trace of the Delphi seismic fault, at the base of the cliff, along a distance of c. 18–20 km from east to west, with maximum vertical displacement of 1 m.³⁴ Just north of the archaeological site: ‘... large cracks developed at the foot of the cliffs above the village [Kastri] leading in a north-westerly direction’, and near Chryso below, ‘ground cracks more than one metre wide and 5 metres deep were formed running along the mountain side for a short distance’.³⁵ Landslides and rock-falls were triggered in many places, being particularly intense in the area of the archaeological site.

Because of the different lithologies on the two sides of the fault, the fault zone determines a threshold for emergence of water circulating in the Parnassus limestone, so that many springs are located in correspondence of this structure, Kerna and Kastalia springs being ones of these. A few instances of gas emissions also have been described by Joseph Fontenrose (1981) and some inhabitants of Delphi, but we did not find traces of such seepages at present. The lack of any geochemical ‘anomalies’ in springs, soil gases, travertine deposits and local spring-waters, however, indicates that, today, i.e. during the current quiescence period, the Delphi active fault system is not a preferential circulation route for deep fluids, and that the shallow, karstic, hydrological system is isolated from any system at greater depth. The origin of the travertine deposits, covering archaeological relics in places, is definitely related to the superficial circulation of meteoric water within in the Parnassus limestone.³⁶

Falling rock

Rockfalls are generated on the steep slope located on the northern side of the archaeological site, the Parnassian Phaedriades (Figures 2, 5a). These almost vertical limestone rock cliffs, rise more than 500 m above the archaeological site (Figure 5a), and consist of limestone that has been intensively fractured into blocks of various dimensions. Rockfalls associated with widespread erosion and detritic slips occur along the borders of the calcareous wall. These phenomena produce toppling and rolling of calcareous blocks as well as recurrent debris flow, and are mainly triggered by seismic phenomena or intense rainfalls and storms,³⁷ such as recently occurred in September 2009, activated after prolonged rainfall,³⁸ and as reported at many places during the earthquake of 1870.³⁹

²⁶ Piccardi 2000.

²⁷ Ambraseys and Jackson 1998, Marinos and Rondoyanni 2005; Papazachos and Papazachou 2003.

²⁸ Ambraseys 1996; Ambraseys and Jackson 1998; Papazachos and Papazachou 2003; Pavlides and Caputo 2004.

²⁹ Ambraseys and Pantelopoulos 1989.

³⁰ Ambraseys and Pantelopoulos 1989.

³¹ Piccardi 2000.

³² CFTI5Med, <http://storing.ingv.it/cfti/cfti5/>; Guidoboni *et al.* 2019.

³³ E.g. Ambraseys and Pantelopoulos 1989 and 1992; Pavlides and Caputo 2004; Marinos and Rondoyanni 2005; Schmidt 1879.

³⁴ Pavlides and Caputo 2004.

³⁵ Schmidt 1879, reported by Ambraseys and Pantelopoulos 1989.

³⁶ Piccardi *et al.* 2008.

³⁷ Lazzari and Lazzari 2012.

³⁸ Christaras and Vouvalidis 2010.

³⁹ See Ambraseys and Pantelopoulos 1989.



Figure 4: View towards the south of the main Temple of Athena Pronaia (end of 6th c. BC), with one of the blocks that fell on it in 1905 (photo 2005, since the block has been removed). The figure to the left of the block provides the scale.

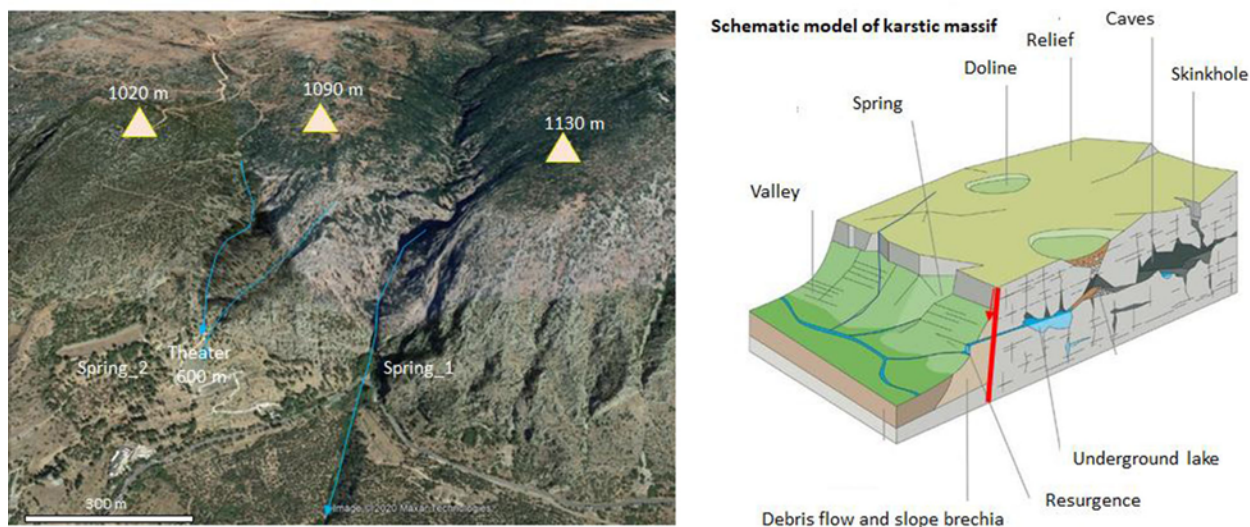
Rockfalls are mainly due to the release of blocks individuated by fractures of the rock mass and bedding planes, and the falling blocks vary greatly in size and weight. Fractures which cut the rock mass, limit the falling blocks and contribute to rainwater infiltration. The seepage of groundwater at the interface between the overlying thrust limestone and the underlying impermeable flysch, softens the flysch, inducing tensile forces from below, enhancing the fracture of the overhanging limestone and rockfall phenomena. The release of ‘keyblocks’, i.e. blocks which are determinant in the overall equilibrium of other blocks in an intensely fractured area, can sometimes precipitate rockfalls of significant size or, in extreme cases, large-scale slope failures.

The archaeological site of Delphi is so situated in an active scree deposition area. Rockfalls represent the main threat in the area, and have been reported on numerous occasions at or in the vicinity of Delphi, imposing the temporary closing of relevant parts of the

archaeological site (e.g. the Stadium, Kastalia Spring, and the Gymnasium). At the western part of the site, major rockfalls occurred repeatedly at the stadium also in recent times, and barrier have been set up for protection. Everywhere in the archaeological site, foundations of several ancient structures have been constructed on large fallen blocks of rock, given the abundance of such blocks in the scree material. Many large boulders have fallen after the excavations of the site, and in 1905 a rockfall destroyed a temple in the Sanctuary of Athena, which had remained relatively well preserved until then (fifteen columns were still standing before the rockfall). One of the blocks remained on the temple basement until removed a few years ago (Figure 4).

Other natural risks: waterflow and karstic environment

The Parnassus limestones that form the cliff north of the Sanctuary are subject to dissolution, water



Figures 5a and 5b: Left – 3D view of the reliefs north from Delphi showing some of the seasonal torrent beds as well as the resurgences (springs 1 and 2). Right – schematic behaviours of a karstic relief.

infiltration, development of karstic conditions and resurgence, potentially drastic. Also if limestone may have some primary porosity, circulation of water within these rocks mostly occurs through fractures, and karstification process involves the solution of carbonate minerals (calcite and/or dolomite) due to the acidity of water, enlarging the water conduits. Karstification is driven by climatic conditions because dissolved CO_2 concentrations are controlled by temperature and atmospheric CO_2 partial pressure. If these conditions change, carbonate can be deposited instead of being dissolved: as mentioned above, at Delphi some carbonate, dissolved by meteoric water and circulating within the limestone massif, precipitate creating travertine deposits when emerging. Karst systems are numerous in Greece, and many of them have been extensively studied, especially in central Greece and Crete,⁴⁰ but these phenomena have not been studied so far in the area of Delphi and Parnassus. Figures 5a and 5b show the relief around Delphi and propose the presence of a karstic system; since it has not been completely documented, the presented behaviour is generic. The resurgence of water that accumulated in the Parnassus karstic massif leads to torrents of mud and landslides. Historical events are known, and even today, mudslides are still frequent, and rushing waters have often dug natural trenches on the periphery of the archaeological site. In December 1935 one particularly disastrous flood completely buried the site (Figure 6). On a larger scale, the landscape around Delphi allows us to observe slope breccia deposits caused by gravity gliding and, in the Gulf of Corinth itself, seismic data likewise indicate this kind debris flow related to fault activity.⁴¹

All these natural phenomena, earthquakes, rockfalls, landslides, debris flows and overflowing waters on the surface or in karstic subsurface channels, have affected the area of Delphi and its inhabitants since the first settlement of the region. In the following sections we will study the archaeological traces of these more or less catastrophic events and consider how the ancient Greeks protected themselves.

Traces of natural disasters on the monuments in Delphi

The history of the Sanctuary of Apollo in Delphi could be written as a succession of destructions and reconstructions in the light of the natural disasters it has experienced. In spite of the lack of a stratigraphic record for the Sanctuary of Apollo due to the nature of the 19th-century excavations at the site, part of the chronology of the disasters can be discerned thanks to more recent surveys associated with both the testimony of literary sources and the analysis of monuments and traces of ancient repairs.⁴² The oldest examples date back to the Mycenaean and Geometric periods, as detailed below.

The 1938–1939 excavations on Foundations VIII,⁴³ also known as the Potidaeen Treasury, and IX⁴⁴ (Figure 7) revealed, under the Geometric layer, a 2-m-thick layer of debris showing that this area had been devastated by a torrent that would have destroyed a modest domestic building from the Late Mycenaean period (1100 BC).⁴⁵ In the 1990s, excavations of the Geometric habitation

⁴⁰ Kazakis *et al.* 2018.

⁴¹ Moretti *et al.* 2004.

⁴² Perrier 2021.

⁴³ Bommelaer and Laroche 2015: n° 227.

⁴⁴ Bommelaer and Laroche 2015: n° 228.

⁴⁵ Amandry 1940–1: 258–259.



Figure 6: December, 1935. Deposits left by the catastrophic flood event over the Sanctuary of Apollo (French School at Athens).

area located in the eastern part of the sanctuary (Figure 7) showed that the circulation of underground water was a major risk with which the excavators associated the continual rising of the ground due to flooding and colluvium. The destruction of at least one house (B046) can be explained by the phenomenon of solifluction,⁴⁶ in a landslide that separated the soil from the retaining wall. In fact, there are archaeological traces of several landslides at the same place:⁴⁷ the wall of this house (B046) shows at least three states of repair. In the 8th century, the village of Delphi was laid out in a multitude of micro-terraces. Houses tended to be built up against retaining walls, which also explains their peculiar plans. According to J.-M. Luce, the laying out of the sanctuary and the first *peribola* in the 6th century BC (c. 585–575) modified the appearance of the site, with the micro-terraces grouped together to form deeper ones,

allowing the emergence of new architectural units.⁴⁸ This excavation has clearly shown that the steep natural gradient of the site, combined with significant water circulation, constitutes in itself a major risk for the construction and preservation of the monuments.

The first major natural disaster in Greece for which we have relatively detailed testimonies is the devastating earthquake that struck Sparta c. 464 BC, but it did not affect Phokis.⁴⁹ The episode that undoubtedly made the biggest impression on ancient authors, in terms of the extent of the destruction and the political and religious importance of the destroyed sites, was the earthquake, or series of them, dated to 373 BC, as previously mentioned, that affected several sites, including Helice, Bura, Olympia,⁵⁰ and Delphi. At Delphi, it also had a significant impact, destroying the Temple of Apollo,

⁴⁶ Luce 2008: 31.

⁴⁷ Luce 2008: 54.

⁴⁸ Luce 2008: 94.

⁴⁹ Thély 2016: 25.

⁵⁰ Partida 2016.

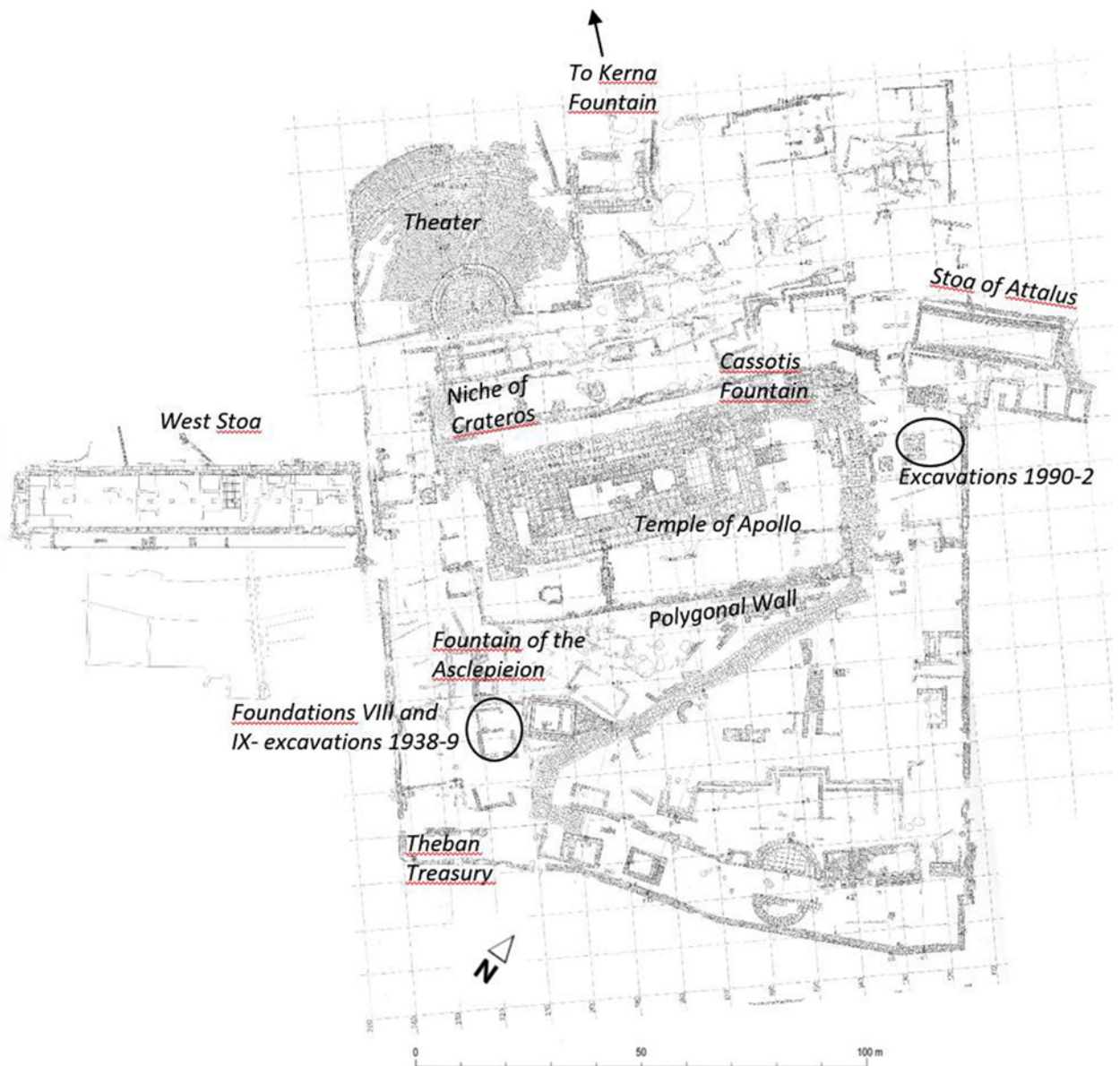


Figure 7: Map of the Sanctuary of Apollo (after Algreen-Ussing and Hansen 1975 and Perrier and Malmay 2013).

and initiating in effect an early ‘fundraising campaign’ throughout the Greek world for the reconstruction of the temple.⁵¹

Other rock- and mud-slides occurred from time to time at Delphi, destroying monuments and uncovering ravines. The remains bear witness to several catastrophic episodes that occurred throughout antiquity. The recent survey of the ancient city identified collapses of walls all over the site due to the action of water.⁵² The damage caused by the torrents and runoff seem to have

been taken very seriously by the ancient caretakers of the site, and several solutions were implemented, especially after the destruction of the temple in the 4th century. The temple terrace was particularly exposed to the effects of water, as the natural pathways of water ran on both the eastern and western sides of the temple.⁵³

The construction programme that followed the great catastrophe of 373 BC at Delphi deserves a longer reference, not only because it is very well documented through construction accounts,⁵⁴ but because it

⁵¹ Herodotus 2.180; Aristotle, *Athenian Constitution*, 19.4; Xenophon, *Hellenica*, 6.4.2; and see Amandry and Hansen 2010.

⁵² Luce 2012: 782–783.

⁵³ Amandry and Hansen 2010: 150, fig. 1.5; 152, fig. 1.7; 153, fig. 1.8.

⁵⁴ Bousquet 1988 and 1989.



Figure 8: Temple of Apollo. Distortion of the *euthynteria*.

seems to mark a turning point, from which we see architectural responses to the specific risks at the site. Analysis of the deformation of the present remains has revealed that the 4th-century temple was destroyed, as was probably its predecessor, by a violent landslide due to the underground circulation of water, probably combined with a seismic event. Danish architect Erik Hansen measured a difference in level of more than 53 cm between the northwest and southeast corners of the temple's outer *euthynteria* and a southward shift of 85 cm on the east side to the south.⁵⁵ The *euthynteria* on the north side (Figure 8) shows a very pronounced curvature, due to the soil pressure that was partially compensated for, from Antiquity, by the abundant use of cramps of which only the lead gangue gave way. According to this analysis, the deformation of the present ruin is essentially due to a violent episode that took place in Late Antiquity, and not to progressive pressure.⁵⁶

Two elements suggest that the Late Antique event, causing the eastern part to subside and the western part to twist, was the same type of landslide that destroyed the 6th-century temple in 373 BC. On the one hand, the foundations of that temple show at the southwest

corner that they suffered a similar collapse and that the courses had to be straightened to accommodate the foundations of the new temple. On the other hand, the measures taken to ensure architectural security and cohesion in the construction of the 4th-century temple let us understand what happened during the destruction of the previous temple. Indeed, the very important reinforcement of the foundations at the external and internal south-western corners suggests that the south-western corner had become dissociated from the north-western one, causing cracks and opening joints. The plan of the current remains shows the effectiveness of the measures implemented during the reconstruction. During the destruction of the 4th-century temple in Late Antiquity, the southwest corner did not move: the rupture occurred a little further east.

The southwest angle had been reinforced, in particular, because this part of the temple is located in a sensitive corridor that experienced major landslides, as shown by the stratigraphy and the remains of other affected structures (Figure 9),⁵⁷ such as the Archaic Treasury n° 227 (foundations VIII), whose visible south-eastern corner has moved 130 cm southwards, or the wall of the southern *peribola*, in which blocks from the 6th-century temple were reused in repairs.

⁵⁵ Amandry and Hansen 2010: 145.

⁵⁶ Amandry and Hansen 2010: 147, fig. 1.3–4; 149; 150, fig. 1.5.

⁵⁷ Amandry and Hansen 2010: 152, fig. 1.7.

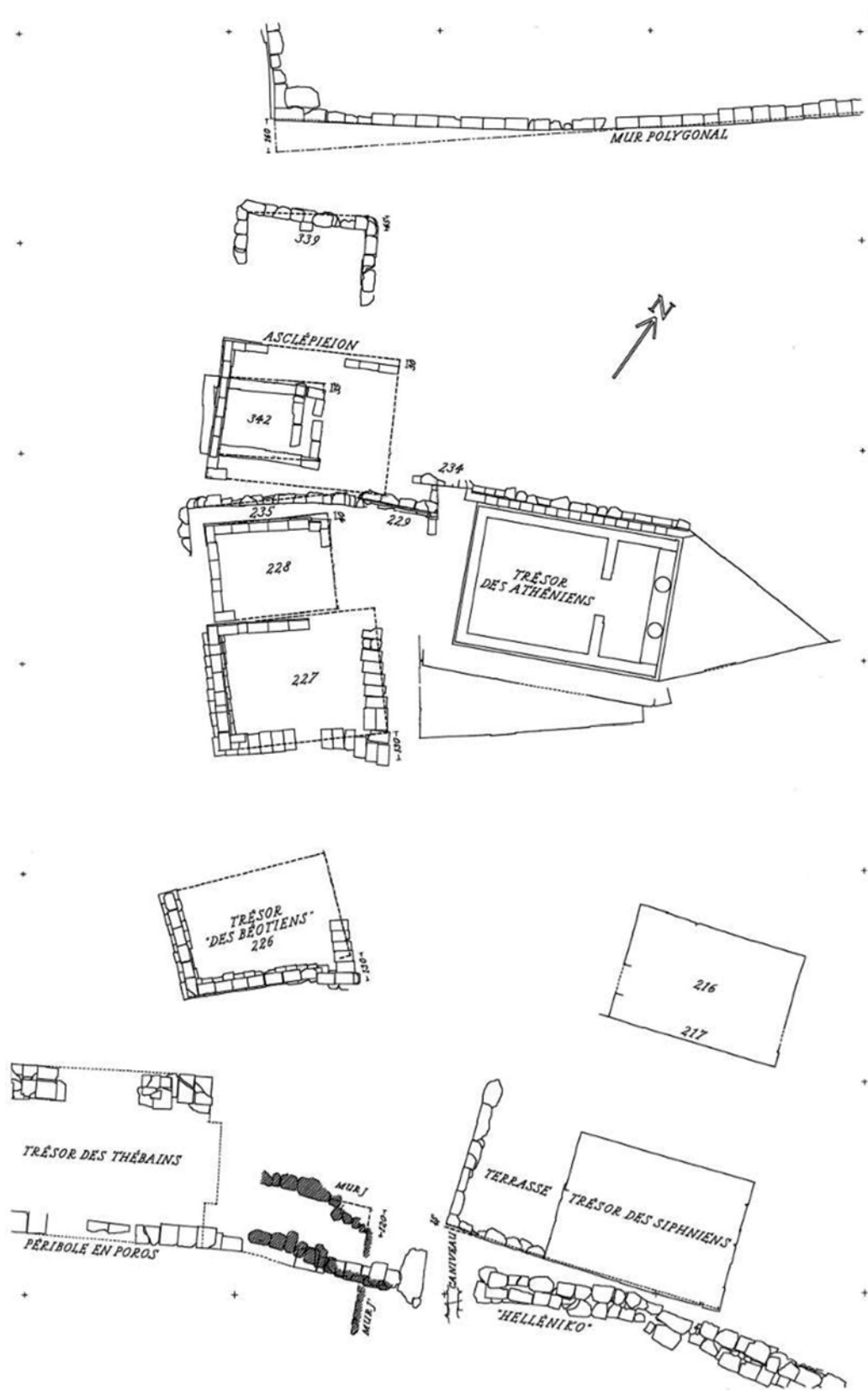


Figure 9: Monuments affected by landslides (after Amandry and Hansen 2010: 152, fig 1.7).

Generally, many retaining walls show deformation due to the effect of soil pressure. Examples include the wall of the Crateros Monument, a prominent 4th-century BC statue niche just above the temple (Figure 7), the wall of the *xystos*, located in the gymnasium near the sanctuary of Athena, on the axis of a fault, and where the same type of deformation related to a catastrophic event can also be seen in the stylobate of the outer colonnade, as well as the retaining wall of the lower terrace of the gymnasium.

Risk prevention and solutions for water management

Preventive measures were implemented as early as the Mycenaean period. These measures are generally of three types: (1) the construction of dams; (2) the creation of a network of hydraulic monuments across the site; and (3) the reinforcement of foundations.

Evidence of the building of dams above the sanctuary spans its entire history. Monumental blocks from the Mycenaean period have been found north of the sanctuary at the site of later dams built in antiquity up to the beginning of the 19th-century excavations.⁵⁸ They have been interpreted as the remains of a dam. The remains of a monumental wall from the Mycenaean period found under the Temple of Apollo may have served a similar purpose.⁵⁹ This suggests that people from the earliest development of the site may have tried to protect constructions at the site from flash floods from above.

The site of Delphi, especially the Sanctuary of Apollo, has many springs and fountains, whose role exceeded the water needs of the cult and the pilgrims.⁶⁰ Hydraulic monuments were constructed on different terraces and operated in part as a network. Water management in Delphi includes fountains, wells, basins, a swimming pool, large cisterns, thermal baths, and an impressive network of underground pipelines. The 4th-century Kassotis Fountain,⁶¹ located in the northeast corner of the temple terrace, was originally probably intended to receive the waters of Kerna,⁶² an abundant spring north of the sanctuary, and to channel the waters threatening the temple terrace to the southern perimeter. The dangers of infiltration and solifluction may explain the organisation of an hydraulic network linking several fountains. One of the roles of the Fountain of the Asklepieion (Figure 7) was to drain water from an underground resurgence west of the *opisthodomos* of the temple.⁶³ Additionally, a fountain located right underneath the temple probably allowed for the

drainage of natural springs. From the reconstruction of the temple during the 4th century BC, perhaps already before, the fountains helped divert the overflow of water, if not from the entire sanctuary, then at least from the temple terrace, but they were insufficient to fulfil this role.

Several solutions were adopted to protect certain monuments from the effects of water, in particular by strengthening the masonry of the foundations and the terrace walls, as shown by these few examples. The foundation mass was largely reinforced at the southwest corner of the Temple of Apollo as seen above.⁶⁴ The Theban Treasury (Figure 7), built on one of the exposed axes after 371 BC, and thus after the catastrophe of the 4th century, was also later affected by a landslide. Preventive measures had been implemented as early as the construction of the monument – its foundation was reinforced by a wooden frame.⁶⁵ The southeast corner of the foundations of the West Stoa, built c. 330 BC, were even sealed and separated from the adjacent gutter with lead.⁶⁶ This device has not yet been observed in other foundations in Delphi, but the slabs of the northern gutter are themselves well sealed by thick vertical lead joints (Figure 10), a feature little known in Greece but also found in Delphi at the Archaic Fountain of Castalia.⁶⁷

The architectural effort begun in the 4th century to preserve the Sanctuary of Apollo and to protect the temple terrace, in particular, continued with the construction of the theatre, beginning in the middle of the 3rd, or beginning of the 2nd century BC.⁶⁸ The monument, located at the northwest corner of the sanctuary, above the temple and south of the Kerna fountains and ancient dams, served as a funnel to collect and channel surface and underground runoff through a system of drains that were built under the steps and the orchestra. The water was collected both in a fountain built on the back wall of the theatre and along the steps. It was then channelled through an hydraulic network organised within the sanctuary, and, at least in the west, evacuated out of the sanctuary by two main conduits through the theatre and into the large western gutter of the West Stoa, and by the channel going from the orchestra to the west of the Crateros Monument.

The majority of the terrace walls in Delphi, up to the Classical period, were built to resist seismic shocks, as well as to the pushing force of earth swollen by water, as shown by the various polygonal masonry methods

⁵⁸ Homolle 1897: 259.

⁵⁹ Darcque 1991: 689.

⁶⁰ Perrier 2019.

⁶¹ Bommelaer and Laroche 2015: 222–223, 248.

⁶² Bommelaer and Laroche 2015: 259.

⁶³ Amandry 1942–1943: 342.

⁶⁴ Amandry and Hansen 2010: plate XXII (study of deformations on the west side); study of foundation restoration: 161 ff. and conclusions: 467–468.

⁶⁵ Michaud and Blécon 1973: 24–25, 93.

⁶⁶ Perrier and Malmay 2013: 52–53.

⁶⁷ Amandry 1977: 201–203.

⁶⁸ Bommelaer 1992: 298–299.



Figure 10: West Stoa: detail of the north gutter sealed with lead; east part of the north gutter.

used for these walls, such as the polygonal masonry with curved joints, known as Lesbian masonry. But after the catastrophe of the 4th century, terrace walls built during the next century have large buttresses, especially the inner buttresses of the two large walls on either side of the temple terrace, outside of the *peribola* (the West Stoa and the 9-E wall located east of the stoa of Attalos).⁶⁹

The multiple architectural solutions implemented over the centuries in Delphi, and in particular from the 4th century BC onwards, reveal an awareness of the natural risks and a technical ingenuity, no doubt progressive and intimately linked to each catastrophic episode.

Evolution of water resources management

From the Archaic to the Protobyzantine period, the approaches to water management in the sanctuary and in the city seem to have evolved, moving from simple risk management, certainly in a religious context where water played a special role, to a real valorisation of the water resource. This phenomenon began as early as the 4th century BC with the development of the swimming pool and basins in the gymnasium,⁷⁰ but this is a special case. Except for a few examples, such as the remains of an Hellenistic bath in the northeast of the sanctuary,⁷¹ it was not until Late Antiquity that large-scale water exploitation began to take place.

In fact, from the 3rd century AD onwards, the city of Delphi was transformed with a number of construction projects: i.e. the large villas with baths, such as the Late Antique Southeast Villa;⁷² the building of public and private baths and associated reservoirs, with examples known east, south, and west of the sanctuary, especially the East Thermae; and even the adaptation of certain Classical or Hellenistic monuments into baths or cisterns, such as the Stoa of Attalos I (Figure 11), east of the temple terrace, which has been completely enclosed by brick walls and transformed into a huge reservoir (Figure 12), due to the construction of a villa and of the eastern thermal baths. To the west, a large cistern was built with a south wall reinforced with buttresses and a ceiling supported by arches (Figure 13).⁷³ It is now completely filled with earth and slope debris and has never been excavated. Even inside the heart of the sanctuary, domestic baths have been installed in the Crateros Monument.⁷⁴ This transformation can be related to the development of the Protobyzantine city, increasing the water needs, as shown especially by the construction of the large cistern in the new west district,⁷⁵ and the end of the distinction between sacred and secular spaces.

The location of these hydraulic installations seems to confirm our preliminary functional analysis of the monuments within the general economy of the site, since some of them are located around the terrace of the temple, as, for example, the Crateros Monument,

⁶⁹ See Trouki 1993.

⁷⁰ Homolle 1899: 581–583; Jannoray 1953.

⁷¹ Ginouvès 1952.

⁷² Déroche, Petridis and Badie 2014: 18–20.

⁷³ Amandry 1981: 733.

⁷⁴ Amandry 1981: 736; on baths in Delphi, see Ginouvès 1955.

⁷⁵ Petridis 2010: 21.



Figure 11: Main hydraulic structures during Late Antiquity in the area of the Sanctuary of Apollo (from Google Earth 2021).



Figure 12: Eastern cistern in the Stoa of Attalos I.



Figure 13: West cistern.

located exactly between the theatre and the temple, just above the *opisthodomos* square, or the cistern in the Stoa of Attalos I, northeast to the temple (Figure 11).

The observable conduits were reworked in Roman and Protobyzantine times. The network of drains and gutters allowing the circulation of water was adapted and increased. For example, a late 4th-century gutter found during the 2018 excavations to the west of the West Stoa was reworked in Roman times and connected to newly built baths to the west.⁷⁶ The so-called Roman Agora, dating to Late Antiquity, is equipped with important underground gutters, which not only drain the waters of the square but also collect the water from the upper terraces, since they are connected to the gutters of the thermal baths and cistern east of the main sanctuary.

An initial assessment of these remains reveals that by then water was no longer considered so much as a danger but as a resource, and one that was particularly abundant in Delphi, which undoubtedly contributed to the success of the site until Late Antiquity. These installations not only promoted new practices but adequately captured and therefore controlled rainwater on the site. It seems that the city, between

the 4th and 6th centuries AD, was particularly dynamic and experienced its greatest expansion – as shown, for example, by the number of craft workshops and the construction of luxurious villas.⁷⁷

Conclusion

The impressive landscape of Delphi is strongly marked by rocky escarpments and faults. Although earthquakes and rockfalls are frequent, it seems that the most devastating natural disasters are due to landslides, debris flow, gravity gliding and slope instabilities, from Antiquity to the present day. The remains clearly show that the ancient residents sought solutions and occasionally implemented building strategies to counter the disastrous effects of the passage of water, particularly in the Sanctuary of Apollo. As far as we know, the 4th century BC marked a turning point in the awareness of the risks associated with water, and the large construction site of the temple and its surroundings were redesigned to protect the heart of the sanctuary from this kind of danger. If the Greeks of the Classical period tried to protect themselves from the excess of water, from the Roman period onwards, they took it as an advantage. Water was exploited throughout the Roman Imperial period into Late

⁷⁶ Perrier et al. forthcoming.

⁷⁷ Petridis 2010: 142.

Antiquity as a resource in the service of a way of life that transformed the city of Delphi and its sanctuary.

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*From Hydrology to Hydroarchaeology in the Ancient Mediterranean: An interdisciplinary approach is devoted to the study of water management in ancient cities. It compares the approaches and methods adopted by researchers from different disciplinary sectors to identify the water conditions of past societies and to highlight the measures they have taken to adapt to their water resources. Deriving from an interdisciplinary meeting held in Aix-en-Provence (Mediterranean House of Human Sciences) in 2019, it brings together seven articles that present the innovative results of collaborations between archaeologists and environmental scientists, geologists, geomorphologists, and climatologists in particular. After an introduction that situates the discussions conducted in Aix-en-Provence within the framework of the Watertraces project, funded by the A*Midex foundation (Aix-Marseille University), most of the articles focus on the Sicilian situation. An initial synthesis covers all aspects of the question, followed by four case studies ranging from the 4th century BC to the 1st century AD. Case studies on Agrigento, Termini Imerese/Thermai Himerenses, Alesa/Halaesa, Solunte and Tyndaris are presented. The focus then moves to southern Italy (the Terme di Baia), and to Aegean Greece (the sanctuary at Delphi).*

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