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# Demise of a harbor: a geochemical chronicle from Ephesus

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## ABSTRACT

At the end of the first century BC, Ephesus became the Roman capital of Asia Minor and the most important commercial, religious, and cultural center of the region. In order to evaluate the status of anthropogenic fluxes in the port of Ephesus, a 12 m long sediment core drilled in the Roman basin was investigated to shed light on the paleo-environmental evolution of the harbor using grain size distribution analysis, $^{14}C$ ages, major and trace element geochemistry, and Pb isotope compositions. With the help of complementary sedimentological data and Principal Component Analysis, five distinct units were identified which, together, reflect the different stages of water history in the harbor. Among the major disruptive events affecting the port were earthquakes and military events, both of which were particularly effective at destroying the water distribution system.

Seasonal floods of the Cayster River (Küçük Menderes) were the major source of the silt that progressively infilled the harbor. Silting in was further enhanced by the westward migration of the river mouth. A single major disruptive event located at 550 cm core depth and heralding the development of anoxia in the harbor marks the end of the dynamic regime that otherwise controlled the harbor water throughout the Roman Empire period. This remarkable event may correspond to a major disruption of the aqueduct system or to a brutal avulsion of the Cayster River bed. It clearly represents a major disturbance in the history of life at Ephesus. It is poorly dated, but probably occurred during the reign of Augustus or shortly after. Lead isotope and trace metal evidence suggest that in the four bottom units pollution was subdued with respect to other Pb metal inputs, presumably those from aqueducts and natural karstic springs. Near the top of the core, which coincides with harbor abandonment and the more recent period, anthropogenic Pb contamination is clearly visible in both Pb abundances and isotopic compositions.

## 1. Introduction

Lead isotope studies have opened up a new, though somewhat controversial, perspective on the development of the manufacturing status of ancient cultures over the past several millennia (Hong et al., 1994). Isolated artifacts alone do not suffice to assess the broad and long-lasting aspects of antique trade routes. Lead isotopes constitute a complementary tool in that they play a critical role wherever their compositions can be ascribed to anthropogenic influence in the form of lead and heavy metal pollution of sediments accumulated in harbors, which are highly efficient traps for clays and suspensions. Anthropogenic impact using Pb isotopes as a tracer has so far been documented for the ancient harbors of Alexandria (Véron et al., 2006, 2013; Stanley et al., 2007), Sidon (Le Roux et al., 2003), Marseilles (Le Roux et al., 2005), and Rome (Delile et al., 2014a).

Applying similar methods to the Roman harbor of Ephesus is appealing because of the status of the Ephesus city port during Roman times as an exceptionally influential commercial and religious center of the ancient Mediterranean world. Ephesus was a major town of Asia Minor and has a long history that began in the 10th century BC. Its position at short distances from both the Dardanelles and the populated city states of southern Greece gave Ephesus a strategic role in all the wars affecting Asia Minor and the Aegean Sea since the Persian wars of the classical period. Its

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importance remained prominent during Hellenistic and Roman times and during the entire history of the Byzantine Empire, and only declined as a result of the Turkish conquest. Because sediments gradually filled in the inlet of the Cayster River (Küçük Menderes), the harbor of Ephesus repeatedly moved down river over the centuries (Kraft et al., 2000, 2011).

Here we use samples from a 12 m long sediment core taken in the Roman port of Ephesus to investigate the paleo-environmental and hydraulic evolution of the harbor using grain size distribution analysis, $^{14}$C ages, major and trace element geochemistry, and Pb isotope compositions. We focus in particular on the relative abundances of Pb and other chalcophile elements in the harbor sediments and discuss the respective status of the anthropogenic and natural metal fluxes and their origins as deduced from the Pb isotope record.

## 2. Historical background

Literature on the history of Ephesus is abundant because of the wealth of ruins left by its different inhabiting cultures and its role in the history of this part of the world first as a major religious center dedicated to Artemis and later as one of the leading churches of the Mediterranean world. For a detailed historical context of the present work, the reader is referred to the well-documented textbook by Foss (1979) and to Scherrer (1995). Here we provide only a brief overview.

Different sites were inhabited in the immediate vicinity of classical Ephesus since the Neolithic culture and during the Bronze Age. The historical city (close to the Artemision) was founded in the 10th century BC by Ionians and became part of the Ionian League. The classic site (at the base of the western side of the Panayırdağ) was occupied around 300 BC under Lysimachus, one of Alexander's generals, but quickly passed under Seleucid and then Ptolemaic rules. After the Battle of Magnesia in 190 BC, Ephesus came under the domination of Pergamon, and finally became part of the Roman Republic in 133 BC. After the Mithridatic wars (ending in 63 BC), Augustus made Ephesus the capital of Asia Minor. At that stage, the surface area of the city, enclosed by the walls of Lysimachus, is thought to have extended over more than 2 km$^2$ and its population to have reached 50,000 inhabitants.

The city and its temple were destroyed by the Goths in 262 AD. But Ephesus was rebuilt and enlarged by Constantine and soon recaptured most of the importance it had held since Hellenistic times. A burst of seismic activity between 358 and 365 AD repeatedly destroyed major cities around the Aegean (Guidoboni, 1994), including Ephesus. In the 7th century AD, several additional disasters struck Ephesus, notably the major earthquake of 614 AD, as well as the repeated sacks by Arab, Frankish, and Turkish raiders. Western Turkey is well known for being subjected to frequent earthquakes of large magnitude (e.g., Vannucci et al., 2004). Although some dates are not well established, particularly severe earthquakes persistently ravaged the city in AD 17, 23, 47, 178, 194, 262, 275, 337, 358 to 365, and 614 (Guidoboni, 1994; Foss, 1979). In AD 1304, what was by then left of Ephesus fell into the hands of the Turks, and its population was either deported or massacred. These adverse troubles combined with the final stages of insilting of the harbor basin, which had incessantly plagued harbor activity since its early Hellenistic days (Strabo, XIV.1.24), precipitated the demise of the harbor and the city it served.

## 3. The study area

Ephesus' harbor lies on the Aegean coast of Turkey at the western extremity of the Küçük Menderes graben (KMG) (Fig. 1). The KMG corresponds to the catchment area of the Küçük Menderes (Cayster) river, which is divided into five sub-basins delimited by pre-Miocene geology (Rojay et al., 2005). The surrounding hills are composed of crystalline marble or partially dolomitic breccias of Mesozoic age (Vetters, 1989; Çakmakoğlu, 2007). The hills over which Ephesus aqueducts run also include Paleozoic crystalline rocks such as granites, gneisses, and micaschists. Water was brought to the city by up to seven aqueducts built between Archaic times and the Roman Empire and repaired during different periods, notably after major earthquakes. This point is particularly important since all the waters from the aqueducts terminated in the harbor where they were susceptible to mixing with Cayster river water, marine water, and waste waters of public (baths, fountains) and domestic usage, as well as with water from local workshops (Ortloff and Crouch, 2001).

The variation of relative sea level and the westward migration of the shoreline since Antiquity have been studied by Brückner (2005) and Pavlopoulos et al. (2012). Comparison of the apparent sea level changes with the values predicted by the regional model of Lambeck and Purcell (2005) indicates that subsidence of the coastline next to Ephesus since the classical period was of the order of 3–7 m. According to coring evidence and with respect to sea level index points it seems that, in addition to eustatic sea level rise, there are max. 2 m of rise caused by subsidence.

Geoarcheological research has been carried out at the Ephesus site and in the delta of the Cayster river since the 1990s (Brückner, 1997, 2005; Kraft et al., 1999, 2000, 2001, 2011; Stock et al., 2013, 2014, unpublished data). Besides reconstruction of the successive paleo-environments and the coastline as it has existed since 6000–5000 BC (Fig. 1), this work also has shown that delta progradation led to multiple westward resettlements of the harbor. The ceaseless fight against silting to maintain the harbor of Ephesus as a functioning port during the Hellenistic period is first and foremost reflected in the displacement of the city to the western side of mount Pion (Panayırdağ) by Lysimachus in ~290 BC (Scherrer, 1995).

## 4. Analytical techniques

A sediment core about 12 m long (EPH 276) was drilled in the hexagonal Roman harbor basin of Ephesus (Fig. 1). We sampled the core at high resolution by taking a total of 111 samples (one sample every 10 cm). The samples were analyzed for grain size distributions (see Stock et al., 2013, for details), major and trace element concentrations (Table S1; see Delile et al., 2014b, for details), and Pb isotope compositions (Table S2; see here below and Delile et al., 2014a, for details). Lead isotope compositions were obtained not on the bulk sediment, but, in order to isolate potential anthropogenic components, on HBr leachates. The leaching procedure consisted in first treating the samples with chloroform to remove most of the organic fraction, then, after rinsing the residues with clean water, leaching them with dilute HBr including ultrasonicating and heating steps. As shown for Portus (Delile et al., 2014a), this technique enhances the contrast between Pb held in surface contamination-prone coatings and detrital silicates. Carbonates also dissolve during the leaching process, but Pb contents of detrital carbonates are naturally low. As for carbonates precipitated within the harbor, they are of biogenic origin (cf. discussion of series D and E below) likely meaning that isotope information obtained on carbonate-rich samples is consistent with that derived from the leachates of the rest of the sample series. The HBr leach fraction was recovered for Pb separation by anion-exchange chromatography using HBr as eluent of the sample matrix and HCl as eluent of the Pb. Lead was also separated from the residues of 16 of the 111 EPH 276 samples. The amounts of Pb extracted from all samples were large (>1 μg) and orders of magnitude above the total procedural blank of ~20 pg. The purified Pb was analyzed for its isotopic composition by multiple-collector inductively coupled plasma mass spectrometry