Harbouring Resilience:

Environmentally Resilient Construction and Engineering at Portus

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Introduction

Portus was constructed in the mid-first century AD to enhance a pre-existing network of harbours that facilitated the transshipment of goods into Rome's urban centre and to promote imperial participation in the ancient Mediterranean economy. Claudian-era engineers constructed the harbour's first phase at the mouth of the Tiber River, where local geomorphology and hydrodynamics had previously prevented large-scale natural mooring. In the Trajanic period, engineers expanded the existing facilities, remediated earlier structural deficiencies and counteracted sedimentary accumulation impacting the harbour's navigability. This study identifies the technologies and methodologies of Roman maritime engineering and imperial-era harbour construction through literary analysis, archaeological evidence, and review of modern scholarship. In doing so, it demonstrates the archaeological discipline's capacity to inform infrastructural responses to climatic and environmental volatility in modernity.

Environment

***The Tyrrhenian Sea**:* A young interarc basin in the western Mediterranean situated between the European-divergent and African-divergent branches of the Alpine orogenic belt. The seafloor, comprised of the Valviov and Marsili sub basins, is characterized by volcanic and non-volcanic seamounts. These features developed out of tectonic interactions and impact patterns of wave dispersion, which exacerbate patterns of erosion and sedimentation patterns along the Latium coast. The same tectonic interactions cause elevated volcanism and seismicity in surrounding landscapes.

The Tiber River: Flowing from the northern Apennine mountains, along the Italian Peninsula, past Rome, and towards the Latium coast, the Tiber River erodes lime, sandstone, shale, and clastic material from the land formations through which it runs. It carries these sediments to the coast, where they accumulate. Geological analysis of the site indicates that it experienced sedimentation at a rate greater than 1cm/year during its operable lifespan.

The Mediterranean Sea, Tyrrhenian Basin, and tectonic boundaries.

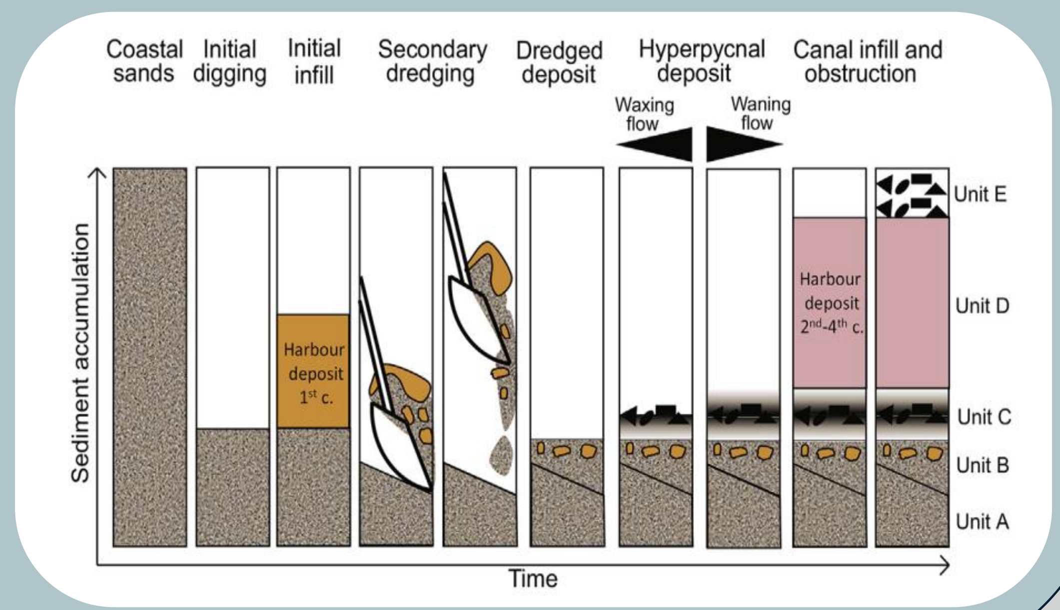
Environmental Management

Without intentional action to counteract volatile environmental forces, Portus and its associated canal systems and facilities would have become inoperable. Thus, counteracting environmental forces at the Tiber mouth was critical to extending the facility's lifespan.

Flood Canals: Low elevation, high seasonal rainfall and high soil-content of hydrophobic volcanic ash resulted in frequent and damaging flood events during the Roman period. Contemporary literature states that the canal system at Portus was introduced in the first phase of construction to allow floodwaters to exit the main basins, mitigating damage to the harbour, its surrounding infrastructure, and the boats were moored there.

Canal Gates: An inquiry into the sedimentary record at Portus discovered increased hydrodynamic energy and freshwater in the upper section of the harbour sequence. This increase in energy, alongside palynological and micropaleontological evidence is consistent with the hydrodynamics expected after the removal of canal gates in the *Canale Traverso.* The existence of a post-gate-controlled sedimentary deposit necessitates the existence of a gate-controlled period within the canal, thus preliminarily indicating the use of gate technologies within the canal system.

Dredging: Without the removal of sediment, Portus would have experienced issues of navigability immediately from the time of its construction. A 2011 multi-proxy sedimentary analysis undertaken with a stationary hydraulic piston system at Portus recovered undisturbed and continuous sediment sequences from the *Canale Traverso.* The analysis discovered that the canal's construction in the first century AD contradicts its sedimentary date, which reflects dredging activities between 120 and 186 AD. This period coincides with Trajan's refurbishment of the port in the second century A.D and is interpreted as large-scale efforts to clear the canal of sediment buildup to maintain its operability alongside new canal construction.



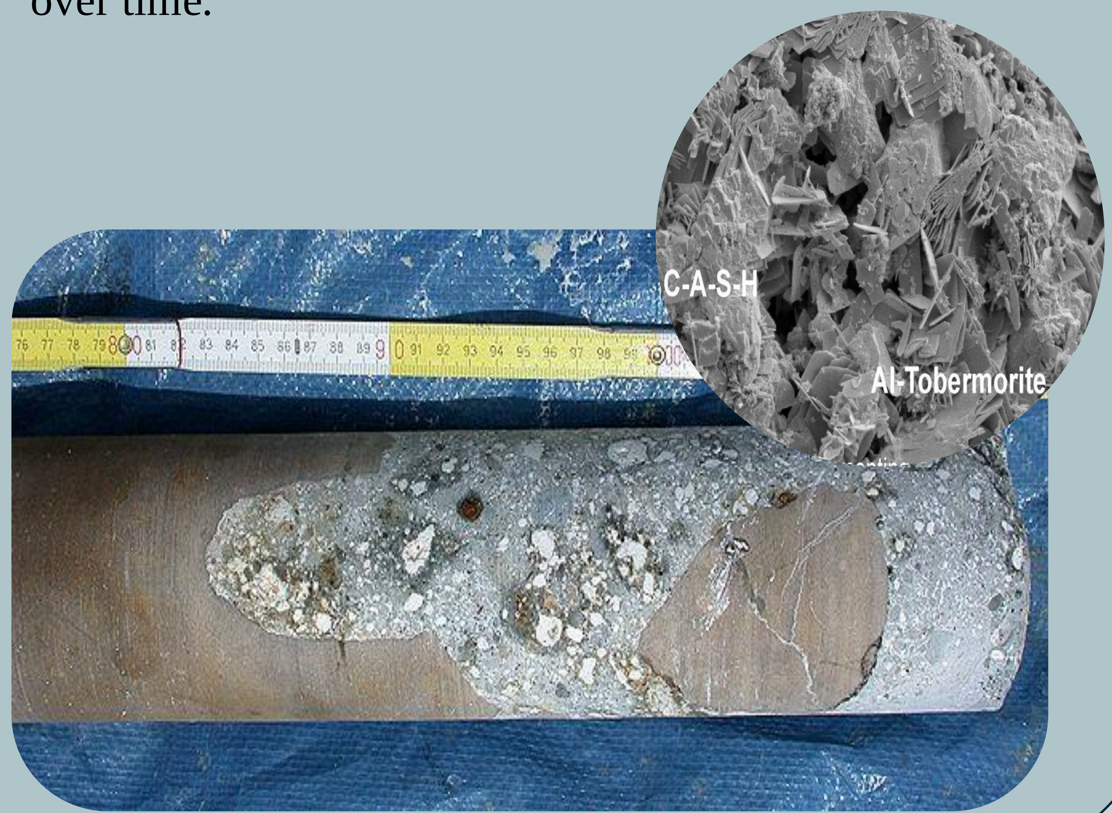
Sediment Record of Canale Traverso.

Material Resilience

Despite the methods of environmental management employed to maintain the harbour facilities, Portus' longevity is largely the result of the material resilience of its structures. Without resilient material construction, degradation of submerged materials would have occurred at unparalleled rates.

Concrete Formwork: The employment of Roman maritime concrete in the construction of Portus necessitated the use of a technology by which the cementitious materials could cure, taking on their desired shape and compressive resistance in submerged environments. Contemporary literary sources indicate that Roman labourers employed varying types of concrete forms to respond to diverse seafloor conditions, wave activity, and material availability, sometimes constructing forms directly onto the seafloor and other times constructing them on land and lifting them into the sea.

Roman Maritime Concrete: Roman maritime concrete is characterized by its ability to be poured and cured directly in seawater. Core drillings from Portus demonstrate adherence of concrete samples to contemporary recipes for creating hydraulic concretes. Both Roman Maritime Concrete and contemporary hydraulic concretes contained a total volume of 35% volcanic rock (*scoriae*), 5% volcanic crystals (leucite and clinopyroxene), 28% poorly crystalline calcium-aluminum-silicate-hydrate (C-A-S-H) binder, and 32% hydrated lime. Uniquely, Roman maritime concrete contained an additional crystallizing mineral, Al- Tobermorite ($[Ca_4(Si_{5.5}Al_{0.5}O_{17}H_2)]Ca_{0.2}\cdot Na_{0.1}\cdot 4H_20$).
Because submerged concrete at Portus contained this mineral, when seawater permeated fractures within the cement face, residual pumice glass and zeolite structures were dissolved and supersaturated in silicon, aluminum, sodium, and potassium, triggering renewed crystallization of Al-Tobermorite and zeolite mineral cement. For this reason, as Portus' submerged infrastructure experienced degradation it gained compressive strength, thus becoming more resilient over time.



Roman maritime concrete Core Sample and structure of cement crystal.

Conclusion

The construction and maintenance of Portus exemplifies the advanced methods of engineering and environmental management leveraged by the Romans during the imperial period. Flood canals were implemented to mitigate the impact of frequent inundations in the port and its hinterland. While canal gates may have reduced the transport of sediment throughout the canal system, dredging activities further contributed to maintaining the sustained navigability of the harbour and its canal systems. Furthermore, the use of Roman Maritime Concrete for the facility's submerged infrastructure provided resilience against structural degradation and extended the lifespan of the harbour despite seismic and fluvial volatility in its environment. This interdisciplinary study underscores the sophisticated engineering methodologies that extended Portus's operational lifespan and highlights the enduring relevance of archaeological insights in addressing contemporary infrastructure challenges posed by climatic and environmental volatility. The empirical data and historical analysis from Portus offer valuable guidance for modern sustainable engineering practices, demonstrating the timeless utility of historical knowledge in civil engineering.

Portus and its canal system.

This research was supported by the Jamie Cassels Undergraduate Research Awards, University of Victoria.

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Full text, references and images