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# **The Role of Plate Tectonics in Ancient Rome**

Katie Burdett

Student Number: 2206644

Dissertation submitted to the University of Wales Trinity Saint David for the degree of MA  
in Latin

06/09/2026 of September 2026

## **Abstract**

This dissertation examines the role of plate tectonics in the development and character of ancient Rome, challenging approaches that treat the Roman environment as merely a passive backdrop to human history. Situated within the complex tectonic setting of the Italian peninsula, Rome and its wider territories were shaped by geological processes that produced earthquakes, volcanism, distinctive landscapes, and abundant mineral and stone resources. This study investigates how these geological conditions influenced Roman settlement, construction, economic activity, religious practices, and cultural understandings of the natural world.

The role of plate tectonic theory is considered against the theories of Environmental Determinism, the Human Approach and the More-than-Human approach to explore the reciprocal relationship between Roman society and geological processes. In the past research has mainly kept physical and human processes separate however this dissertation addresses this historiographical gap by placing geological processes within a broader analysis of Roman society and its interaction with the physical environment.

Literary evidence from authors including Pliny the Elder, Seneca, Strabo, Lucretius, and Pliny the Younger is examined alongside archaeological and geological evidence to assess Roman knowledge and experience of tectonics. Roman religious responses are also considered, demonstrating how tectonic phenomena could simultaneously be understood as physical processes, divine manifestations, and sources of social and political meaning.

Consideration is given to volcanic materials such as pozzolana and tufa, the availability and transportation of stone and marble, and the development of construction practices capable of responding to the physical characteristics of the Roman environment. The study also examines earthquakes and volcanic activity as active forces that affected Roman communities and generated attempts to explain, interpret, and manage geological phenomena. By placing geological forces alongside human agency, the study offers a more integrated understanding of the relationship between Rome and its dynamic physical environment.

### Master's Degrees by Examination and Dissertation

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Name: Katie Burdett

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2. This dissertation is being submitted in partial fulfilment of the requirements for the degree of: Latin MA

Name: Katie Burdett

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3. This dissertation is the result of my own independent work/investigation, except where otherwise stated.

Other sources are acknowledged by footnotes giving explicit references.

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I am satisfied that this work is the result of the student's own efforts.

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## **Acknowledgements**

I would first like to thank my daughter Beth, for being my ‘study buddy’ during this process and my husband Mike, for his unwavering support and the many cups of tea.

Also, huge thanks must go to Matthew Cobb for his insightful suggestions and positive comments.

Lastly, this piece of work would not have been possible without the curiosity of the ancient writers, whose observations about tectonic events piqued my interest and started this whole investigation.

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## **Chapter 1 Introduction and Theoretical Discourse**

### **Outline of the Nature and Goals of the Dissertation**

This dissertation explores the role of plate tectonics in shaping the environmental, infrastructural and societal dynamics of ancient Rome, offering an interdisciplinary analysis that bridges geology and classical history. Traditional studies tend to be anthropocentric, treating the physical environment as merely a backdrop to Rome's rise, rather than playing a dynamic and influential role in the development of Roman civilisation. Tectonics, driven by the dynamic processes within the Earth's lithosphere, have left an indelible mark on the landscapes, climates, and socio-cultural characteristics of ancient societies. The research details the understanding of ancient Romans such as Pliny and Seneca and integrates geological, archaeological and historical perspectives to explore the multitude of ways in which tectonic activities have shaped the course of human history, with a focus on Ancient Rome and uses the portrayal and comprehension of tectonic forces in ancient literature as a conduit for understanding the profound impact of geological processes on human societies. Literature, as a reflection of cultural perceptions and societal consciousness, serves as a unique lens through which the intricate relationship between ancient civilizations and tectonics is explored.

Plate tectonics creates geomorphological hazards including volcanoes and earthquakes and is instrumental in the formation of mountain ranges. The Italian Peninsula is an ideal case study to explore the impacts of these processes as it sits at a complex and active tectonic boundary, making it prone to frequent earthquakes and volcanic activity. This dissertation analyses how

Rome's location within this geologically active zone affected the empire's urban development and infrastructure. It also considers the influence of tectonic activity on the distribution of igneous and metamorphic rocks and how they were utilised by the Romans.

This dissertation highlights Roman exploitation of geological features such as the catacombs for burials and geothermal features such as hot springs and fumaroles, for bathing, culture and religious rituals. The Romans' sophisticated water management systems, including aqueducts and cisterns also reveal an advanced awareness of the landscape's geological realities.<sup>1</sup> Tectonic processes offered valuable resources such as the use of pozzolanic concrete, a material resistant to seismic stress and derived from volcanic ash.<sup>2</sup> [discussed in chapter 4]

Additionally, this dissertation considers Roman understanding, through religious, scientific and philosophical interpretations of earthquakes and volcanic eruptions and how this influenced public policy and personal behaviour. Natural disasters were often viewed as omens or divine punishment, which in turn influenced political decision-making, urban reconstruction efforts and the literary narratives of authors such as both Pliny the Elder, Pliny the Younger and Seneca.<sup>3</sup> The research continues with an exploration of ancient texts, ranging from epics and myths to philosophical treatises and poetry, to identify recurrent themes and motifs related to tectonic phenomena such as Vergil's 'Aetna' and Pliny the Elder's 'Naturae Historiarum.' Through a comparative analysis of literary representations, the study explores the symbolic meanings ascribed to earthquakes, volcanic eruptions, and other geological events. [discussed in chapters 2 and 3]

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<sup>1</sup> Lancaster, 2005, p.22

<sup>2</sup> Jackson, M.D., et al., 2014, pp.18484–18489.

<sup>3</sup> Sen. *Q Nat* VI; Plin. *Ep* 6.16 and 6.20.

By examining descriptions of landscapes, cityscapes, and the portrayal of natural disasters, the research discerns how authors navigated and articulated the challenges posed by tectonic forces in the fabric of their societies. Additionally, the dissertation demonstrates how ancient texts functioned as repositories of empirical observations and cultural wisdom regarding the unpredictable forces of the Earth, thus linking with modern models and theoretical frameworks such as: the Human approach, where human factors are considered to be the determining elements of a society's success or failure <sup>4</sup> ; Environmental Determinism, which looks at the influence of physical factors on human development <sup>5</sup> ; and the 'More-ThanHuman' approach which examines the dynamic interactions between humans and the physical environment. <sup>6</sup> The aim of this research is to extend beyond the boundaries of geological studies, providing insights into the resilience and adaptability of ancient societies, specifically Rome, in the face of the Earth's dynamic processes.

The following section examines some of the highlighted themes in more detail, outlining the key technical, theoretical and methodological approaches that underpin my research.

Alongside Plate Tectonic Theory and Palaeoseismology, which are crucial when examining how the physical environment impacts the human environment, I also considered dendrochronology. However, this theory was more relevant to linking super eruptions to climate change and therefore was slightly outside the scope of this dissertation. My theoretical approaches began with environmental determinism, but I realised that I needed contrast to be able to reach valid conclusions, so I investigated the Human approach and this

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<sup>4</sup> Beard, 2015, p.220

<sup>5</sup> Huntington, 1915, p.2

<sup>6</sup> Abram, 1996, p.7

led to discovering the More-Than-Human approach. These three approaches have enabled me to cover a variety of modern scholars and reach valid, considered conclusions.

## Theories

**Plate tectonic theory**, has revolutionized the study of how tectonic forces shaped the physical landscape and influenced the development of ancient civilizations. This discussion examines the interplay between tectonic forces and human history, how geological processes influenced settlement patterns, resource distribution, and societal resilience in the ancient world. Plate tectonic theory examines the dynamic movements of Earth's lithospheric Plates and how they influence the creation of geological features such as mountains, valleys, and coastlines.

Ancient civilizations often emerged in regions shaped by tectonic activity, capitalizing on the geographical advantages provided by these features. Plate tectonic theory allows us to understand seismic hazards such as earthquakes and volcanic activity, which have played a pivotal role in shaping the dynamics of ancient civilizations. Regions near plate boundaries are often prone to such hazards, and the response of societies to these challenges reflects their adaptability and resilience. The ancient city of Pompeii, situated near the volcanic Mount Vesuvius, faced destruction in 79 AD. The archaeological evidence provides valuable insights into how societies coped with and adapted to tectonic hazards.<sup>7</sup>

Plate tectonic theory enhances our comprehension of how geological features, shaped by tectonic forces, held cultural and religious significance for ancient civilizations. Mountains, caves, and other formations became sacred landscapes, intertwined with the spiritual beliefs of these societies. In ancient Greece, the location of the Delphic oracle exemplifies the

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<sup>7</sup> Harries, 1996, p.2

cultural significance of geological features. The recognition of its tectonic origin deepens our understanding of the symbolic connection between ancient Greeks and their geological environment,<sup>8</sup> which later influenced ancient Romans.

**Palaeoseismology**, the study of past seismic activity through geological evidence, serves as a critical tool for understanding the influence of tectonic forces on the development and evolution of ancient civilizations. The theory enables the identification and dating of ancient earthquakes by examining geological indicators such as fault ruptures and ground displacements. These markers provide a chronological record of seismic events that affected specific regions, allowing researchers to reconstruct the seismic history of tectonically active areas.<sup>9</sup>

By mapping the distribution of seismic events over time, researchers can identify patterns of vulnerability and resilience. The ancient city of Pompeii lying at the base of the slope of Mount Vesuvius, prone to both seismic and volcanic activity, exemplifies how civilizations adapted to the challenges posed by tectonic forces. From assessing seismic vulnerability and urban planning to deciphering the collapse of civilizations, palaeoseismology enriches our understanding of the dynamic interplay between Earth's forces and human history.

## **Theoretical Approaches**

### **The Human Approach**

There are several theoretical approaches that can be useful when considering the factors that lead to the rise of Ancient Rome. Traditional historiography takes a human approach, attributing Rome's success to their military superiority through disciplined legions and

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<sup>8</sup> De Boer and Hale, 2000, pp. 399-412.

<sup>9</sup> Reicherter et al., 2009, pp.1-2

tactical flexibility. Polybius emphasises these factors as resulting in a cohesion and hierarchy that were crucial to Rome's success.<sup>10</sup> Mary Beard considers that geography provided favourable conditions, but many other areas had the same conditions and were not as successful, so geography is a facilitating condition rather than a sufficient cause.<sup>11</sup> The

Human approach considers, alongside the military prowess, manpower and citizenship, political institutions and constitutional adaptability. The range of citizenship options allowed for local autonomy but with an obligation to provide troops. This contrasts with Carthage's reliance on mercenaries, whose loyalty was transactional rather than civic. Fergus Millar concluded that participation and inclusion were the central precept to Roman power.<sup>12</sup>

Other historians who favour the Human approach, determined that Rome's success is due to its 'mixed constitution', balancing monarchy (consuls), aristocracy (senate) and democracy (popular assemblies). According to Polybius, this equilibrium prevented tyranny and stabilised governance.<sup>13</sup> The historian Robert Morstein-Marx determined that public political discourse allowed Rome to adapt to social pressures without revolutionary rupture. Mass communication promoted political stability which ensured consistent strategic direction and resource mobilisation.<sup>14</sup> This approach largely ignores the dynamic interactions between humans and the physical environment, therefore minimising the influence factors such as plate tectonics have had and continue to have on the development and success of societies.

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<sup>10</sup> Pol. *Hist.* VI

<sup>11</sup> Beard, 2015, p. 57

<sup>12</sup> Millar, 1998, p. 1

<sup>13</sup> Pol. *Hist.* VI

<sup>14</sup> Morstein-Marx, 2004, p.122

## **Environmental Determinism**

Environmental determinism, a theoretical framework suggesting a strong link between physical geography and human development, provides a way through which we can examine the influence of tectonic forces on the evolution of ancient civilizations and appears at first glance to be persuasive. Agricultural productivity is a fundamental component of human civilization, and environmental determinism suggests that the physical environment, including soil quality, influences societal development. Tectonic forces contribute to soil formation through processes like uplift, erosion, and deposition, creating diverse soil types with varying nutrient levels. In the ancient world, the impact of tectonic soil formation is evident in Roman civilization on volcanic slopes such as Vesuvius. The tectonically influenced rivers, like the Tiber, deposited nutrient-rich sediments fostering fertile soils that supported agriculture and contributed to the establishing of Rome. Environmental determinism acknowledges that societies adapt to the challenges and opportunities presented by their physical environment. Tectonic forces create hazards, including earthquakes and volcanic eruptions, which have shaped the cultural and architectural responses of ancient civilizations. In the Roman city of Ephesus, situated near the North Anatolian Fault, the ruins exhibit signs of earthquake-resistant architectural techniques. The incorporation of features such as flexible building designs showcases the awareness and adaptation of ancient civilizations to the seismic risks posed by tectonic forces.<sup>15</sup>

It recognizes the role of physical geography in shaping cultural narratives and beliefs. Tectonic features often found expression in the mythologies and belief systems of ancient civilizations. Plate tectonic theory combined with environmental determinism enhances our comprehension of how geological features, shaped by tectonic forces, held cultural and

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<sup>15</sup> <https://www.efesvakfi.org/en/yarat%C4%B1c%C4%B1-end%C3%BCstriler/efes-te-mimarlik>

religious significance for ancient civilizations. Mountains, caves, and other formations became sacred landscapes, intertwined with the spiritual beliefs of these societies. The recognition of the tectonic origin of Delphi deepens our understanding of the symbolic connection between ancient Greeks and their geological environment and the influence this understanding had on Romans.<sup>16</sup> The theory plays a crucial role in understanding the collapse and resilience of ancient civilizations facing challenges posed by tectonic forces. Societies adapted to their environmental conditions, and when faced with seismic hazards, their resilience was often tested. The environmental determinist perspective allows us to assess the vulnerabilities and adaptive capacities of societies in tectonically active regions, contributing to our understanding of the dynamics between environmental conditions and the fate of civilizations.

Environmental determinism believes that the physical environment determines the development of human societies including their culture, political systems and economic success. Its origins can be seen in both Hippocrates and Aristotle who both linked climate to temperament. This was developed by both Friedrich Ratzel and Ellsworth Huntington, linking environmental determinism to imperial and racial theories.<sup>17</sup> This approach is oversimplified as it ignores culture, political leadership and human agency. It results in contradictory evidence as societies in similar environments develop differently.

### **The More-Than-Human Approach**

David Abram in his book 'The Spell of the Sensuous', proposed a new approach, the MoreThan-Human. This approach argues that unlike the traditional human agency

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<sup>16</sup> De Boer and Hale, 2000, pp.399-412

<sup>17</sup> Huntington, 2018, p. 4

historiography which attributes Rome's success to military organisation and political institutions and the environmental determinist approach that emphasises physical factors as causal forces, Rome's rise was not solely the product of human decision-making but emerged from dynamic interactions between humans and the physical environment. Within this approach, plate tectonics plays a leading role as it shaped the peninsula's mountains, valleys, river networks and volcanic soils, creating opportunities and constraints that structured settlement patterns, agriculture, military logistics and infrastructure development, as well as having an influence on religion, society and culture. This viewpoint is supported by Eric Force, that earthquake-prone areas along the edges of tectonic plates are far more likely to give birth to great ancient civilisations than less dynamic landscapes.<sup>18</sup> The Italian Peninsula lies along a convergent boundary of the African and Eurasian plates. Tectonic activity over millions of years produced the Apennine Mountains, volcanic regions such as Campania which contains Vesuvius and the Phlegrean Fields, and sedimentary basins that became fertile plains. These geological formations resulted in natural corridors and barriers affecting trade, communication and military movement. Tectonic landscapes are therefore non-human actors with agency, shaping human options. The Romans did not create the Apennines or volcanic soil, yet they responded strategically to these features. This dissertation aims to evaluate the importance of plate tectonics on the rise of Ancient Rome within the framework of the MoreThan-Human approach.

## **Methodological Components**

Archaeological evidence including information on excavations from Pompeii and Herculaneum for example provide material data on building damage, reconstruction phases

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<sup>18</sup> Force, 2015, pp. 63-70

and architectural adaptations to seismic stress.<sup>19</sup> These findings are cross-referenced with stratigraphic records and architectural surveys, allowing for a diachronic analysis of how Roman engineering evolved in response to tectonic risk.

The research also employed geophysical and geological data sourced from published academic studies and databases maintained by institutions such as the Istituto Nazionale di Geofisica e Vulcanologia (INGV). The data includes seismic hazard maps, fault line distributions, volcanic activity records and soil composition analyses.<sup>20</sup> These sources are used to reconstruct the tectonic context of central and southern Italy during antiquity and to assess the likelihood and frequency of seismic events in various Roman territories.

Geographic Information Systems (GIS) are also employed to spatially correlate known fault zones with Roman urban and infrastructural development.

Finally, interdisciplinary synthesis forms a crucial part of the methodology. By bringing together textual interpretations, archaeological documentation, and geological modelling, the research constructs a holistic view of how tectonic forces influenced Roman life materially, socially and intellectually. This approach facilitates a deeper understanding of the entanglement between environmental forces and human agency in antiquity.

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<sup>19</sup> Picone, R et al, 2025, p. 3

<sup>20</sup> INGV. [www.ingv.it](http://www.ingv.it)

## Chapter 2 Roman Knowledge of Phenomena Related to Earthquakes and Volcanoes

### Plate Tectonics Explained

Plate Tectonics is the unifying theory of modern Earth Science. It explains why mountain belts rise and erode, why ocean basins open and close, where earthquakes and volcanoes cluster and how the Earth's surface evolves over time. The essence of the theory is simple: Earth's rigid outer shell, the lithosphere, is broken into a mosaic of plates that move relative to one another atop a more ductile layer, the asthenosphere.

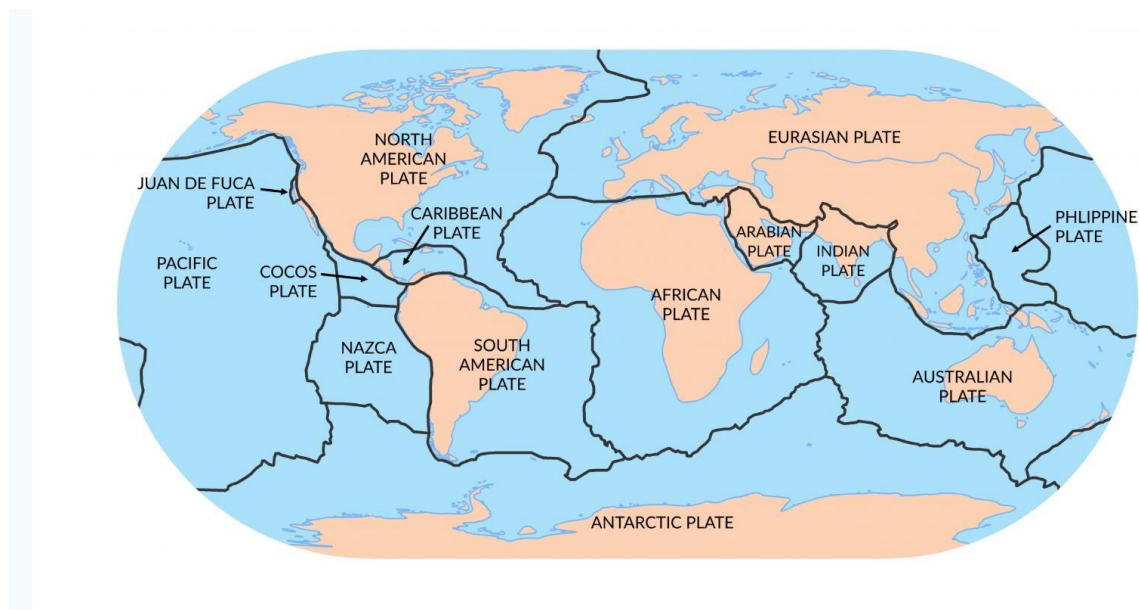


**Fig.1 The Earth's Major Plates.** <https://earthhow.com/7-major-tectonic-plates/>

The origins of Plate Tectonics lie in Alfred Wegener's 20<sup>th</sup> century idea of Continental Drift. Wegener marshalled striking, if qualitative evidence: the jigsaw-like fit of the Atlantic coastlines, which had been first noted by Francis Bacon in 1620; the continuity of mountain belts between now separated continents, such as the Appalachians and Caledonides; and the distribution of Permo-Carboniferous fossils and glacial deposits across Gondwana. He

proposed that the continents once formed a super-continent, Pangaea, that later fragmented and drifted apart.<sup>21</sup> Physicists of his era balked at his proposed mechanism, pole-fleeing forces, and the lack of a robust dynamical explanation stalled acceptance. Mid-century geophysics changed everything. World War II-era sonar mapping revealed a continuous global mid-ocean ridge system dissecting the ocean floors.<sup>22</sup> In the early 1960s, Harry Hess articulated the concept of seafloor spreading: hot mantle material upwells beneath the ridges, creating new oceanic crust that moves laterally away from the ridges like a conveyor belt before descending back into the ocean at deep ocean trenches.<sup>23</sup>

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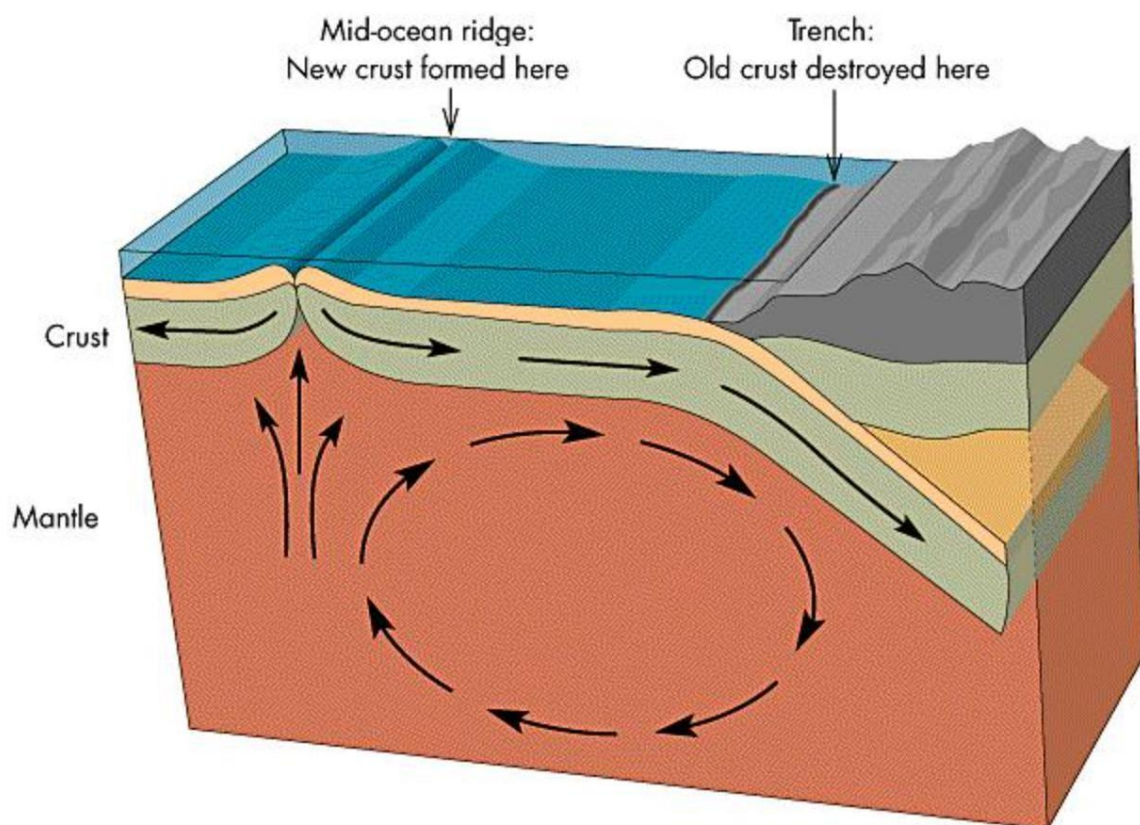


**Fig. 2** Seafloor Spreading. <https://www.sanandreasfault.org/spreadsubduct.jpg>

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<sup>21</sup> Wegener, 1929, p. viii

<sup>22</sup> Heezen, Tharp and Ewing, 1959. p. 83

<sup>23</sup> Hess, 1962, pp. 599-620

The decisive test came from palaeomagnetism as discovered by Vine and Matthews. As ironbearing minerals in basaltic lavas cool, they record the Earth's magnetic field; symmetrical 'magnetic stripes' of alternating polarity on either side of the mid-ocean ridges provided a time-stamped tape of seafloor creation and movement.<sup>24</sup>

Plate Tectonics emerged from a profound shift in geoscience during the middle of the 20<sup>th</sup> century, transforming disparate clues such as magnetic stripes on the seafloor and the youthful age of the oceanic crust, into a coherent predictive framework. Mechanically, it couples a mobile lithosphere to a convecting mantle through subduction, ridge creation and transform faulting. Historically, it cycles continents through assembly and break up, raising mountains and carving ocean basins. Environmentally, it modulates climate and biogeochemical cycles, shaping the evolutionary theatre for life. Whilst the broad strokes are secure, the details remain works in progress.

### **Plate Tectonics and Italy**

Italy sits at the crossroads of some of the most complex tectonic processes in Europe. The peninsula, the islands of Sicily and Sardinia, and the surrounding seas are all part of a region shaped by the long-term convergence between the African Plate and the Eurasian Plate. This convergence, active since the Mesozoic, has led to the creation of mountain belts, active volcanoes and frequent earthquakes.

One of the most important features in this region is the Adria microplate, a promontory of the African Plate that has played a crucial role in shaping Italy's tectonics. The Adria plate has

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<sup>24</sup> Yang, 2024, pp. 737-763

been subducting beneath the Eurasian margin since the late Cretaceous, forming the Alpine belt to the north and the Apennines to the south.<sup>25</sup>

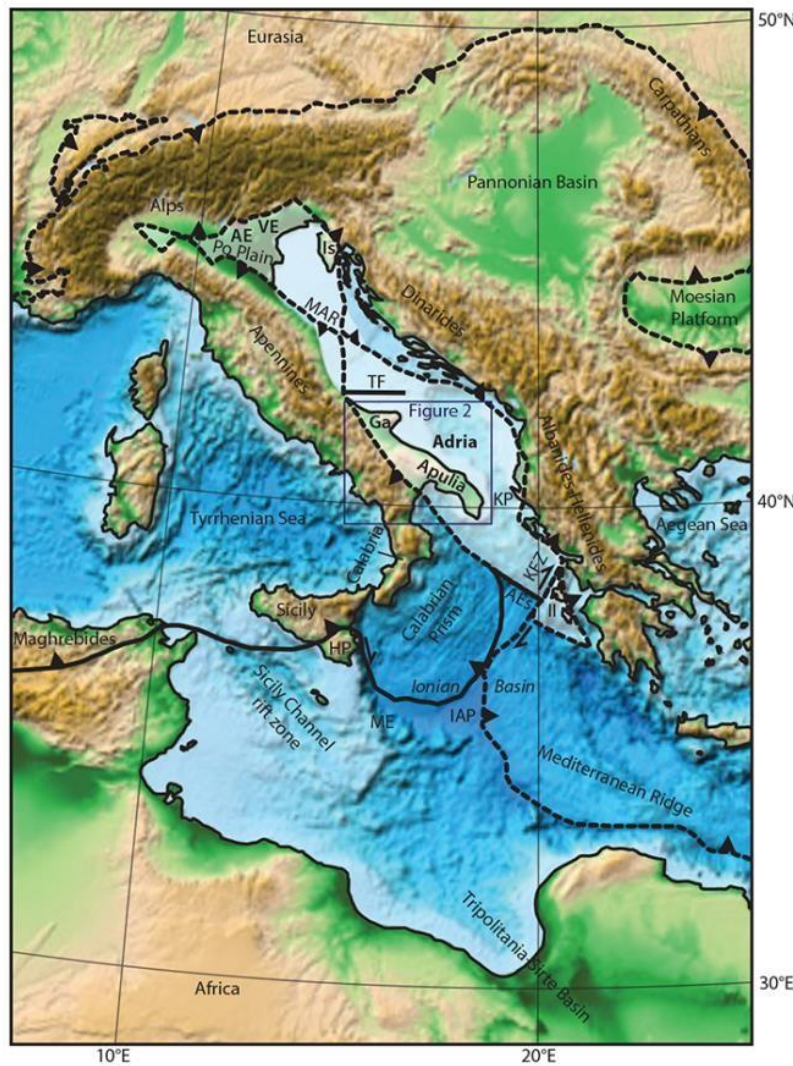


**Fig. 3.** Regional tectonic map of the Mediterranean region. AE – Adige embayment; AEs – Apulian escarpment; Ga – Gargano; HP – Hyblean Plateau; IAP – Ionian Abyssal Plain; II – Ionian Islands; Is – Istria; KFZ – Kefalonia Fault Zone; KP – Karaburun Peninsula; MAR – Mid-Adriatic Ridge; ME – Malta escarpment; TF – Tremite fault.

(D. J. J. van Hinsbergen et al.: Did Adria rotate relative to Africa? 2014)

The Alps, the product of the collision between the African and Eurasian plates, represent the zone of continent-continent collision, whilst the Apennines are associated with an east-

<sup>25</sup> Doglioni et al., 1999, pp. 1-28.

dipping subduction system that has been retreating since the Neogene. The presence of deep earthquakes in northern Italy, such as those in Friuli and the Po Plain, reflects ongoing deformation along the thrust faults marking the Alpine front.<sup>26</sup>

Italy hosts several active and historically significant volcanoes, each with unique tectonic controls, including an active supervolcano, Campi Flegri part of the Phlegrean Fields. Mount Etna, in Sicily, located on the boundary between the African and Eurasian plates. Etna, a strato-volcano, is Europe's tallest and most active volcano. It is fed by a complex magmatic system influenced by subduction-related processes.<sup>27</sup> Vesuvius, in Campania, is famous for its AD 79 eruption that destroyed Pompeii and Herculaneum. Vesuvius lies near the Bay of Naples, where subduction beneath the Apennines fuels arc volcanism. The dense population around Naples makes Vesuvius one of the world's most dangerous volcanoes. Stromboli, located in the Aeolian Islands, is known as the Lighthouse of the Mediterranean and exhibits persistent explosive activity. Minor extrusive features are also evident in Italy. These volcanoes are direct evidence of the interplay between subduction and extension in Italy's tectonic setting.

## **Plate Tectonics and Rome**

Although Rome itself is not directly on one of these major fault systems, seismic waves from the Apennines can strongly affect the city due to geological conditions. Historical records show that strong earthquakes from the Apennines have affected Rome multiple times, damaging structures despite the city not being located directly on major faults.<sup>28</sup>

Rome's tectonic setting is also linked to volcanism. The city lies adjacent to the Roman

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<sup>26</sup> Slejko et al., 1989, pp. 109-136

<sup>27</sup> Behncke et al., 2014, pp. 10-21

<sup>28</sup> Marra et al., 2022, pp. 2445-2457

Magmatic Province, a belt of Quaternary volcanic districts that includes the Alban Hills (Colli Albani), Sabatini and Vico volcanoes.<sup>29</sup> The Alban Hills, south-east of Rome, was last active about 36,000 years ago, but signs of unrest suggest residual magmatic activity remains.<sup>30</sup>

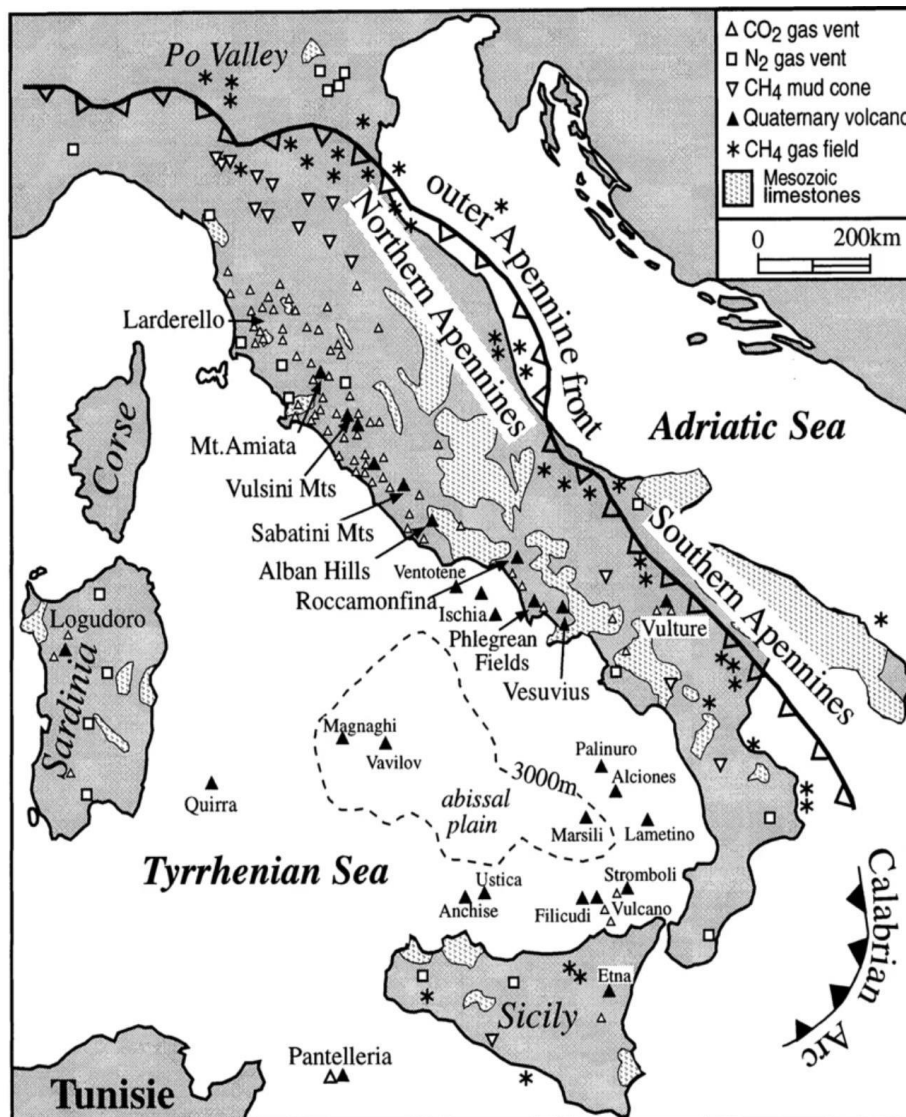


**Fig. 4** Schematic map of Italy with Quaternary volcanoes, geothermal fields, gas vents, Mesozoic carbonate outcrops and thrusting fronts. (Minissale et al., 2000)

<sup>29</sup> Marra et al. 2009, pp. 449-465

<sup>30</sup> Giordano et al., 2010, p. 6

## **Volcanoes**

Volcanoes form at sites where magma generated within the earth's mantle reaches the surface, erupting explosively or effusively. Volcanic products include lava, tephra and volcanic gases, CO<sub>2</sub>, SO<sub>2</sub> and H<sub>2</sub>O. These not only shape landforms but also influence atmospheric chemistry and climate. For example, the 1991 eruption of Mount Pinatubo released millions of tonnes of SO<sub>2</sub>, leading to temporary global cooling of about 0.5°C.<sup>31</sup>

Volcanoes pose numerous hazards: lava flows destroy property; pyroclastic density currents incinerate landscapes; ashfall disrupts air travel and agriculture; and lahars, volcanic mudflows, can bury valleys and settlements. Yet volcanoes also bring benefits: volcanic soils are fertile, supporting agriculture in regions like Campania, Italy; volcanic rocks host valuable mineral deposits such as gold, silver and lead; igneous rock provides very suitable building material as seen in Naples; and geothermal energy derived from volcanic systems provides sustainable power.<sup>32</sup> Thus, societies often inhabit volcanic regions despite risks.

## **Ancient Knowledge of Volcanoes and Tectonic Processes**

So how much did the ancient Romans understand about plate tectonic processes and the features created? The ancient Romans lived amidst some of the most volcanically active landscapes in the Mediterranean. Their understanding of volcanoes was framed by inherited Greek natural philosophy, direct observation, theological and moral interpretation particularly Aristotelian meteorology and Hellenistic physics. Roman thinkers such as Pliny the Elder, Seneca, Lucretius, and later Pliny the Younger, engaged with volcanic phenomena through their own distinctive intellectual lenses. Taken together, these writings reveal a culture that sought to rationalise nature's most violent expressions within the conceptual limits of their

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<sup>31</sup> Self et al., 1996, pp.399-404

<sup>32</sup> Fridleifsson, 2001, pp. 299-312

time. Roman thinkers did not develop a structural geodynamic theory comparable to modern plate tectonics, but they did produce systematic explanatory models grounded in elemental physics and empirical observation. Early modern scholarship frequently evaluated Roman explanations against the standards of modern geology, framing authors such as Seneca and Pliny the Elder as intellectually limited precursors to later scientific discovery.<sup>33</sup> Ancient natural philosophy was measured teleologically, assessed in terms of how close it came to anticipating plate tectonics or magmatic theory, and therefore found wanting.<sup>34</sup> Recent historiography has rejected this conclusion.<sup>35</sup> Rather than reading Roman texts as failed geology, scholars now situate them within the conceptual frameworks of ancient physics and cosmology. The subterranean wind theory, rather than seen as incorrect understanding, is now understood to be a logical extension of elementary theory and Stoic pneumatics.

In *Meteorologica* 2.8, Aristotle explains earthquakes being caused by dry exhalations trapped within subterranean cavities. When these exhalations are forced outwards, they shake the earth.<sup>36</sup> The earth, according to Aristotle, is porous and riddled with channels containing air and vapour. This explanation rests upon elemental theory, the interaction between earth, air, fire and water. Earthquakes occur when air becomes violently displaced within the earth. The same framework explains volcanic eruptions, subterranean fire ignited by compressed exhalation. Aristotle's model provided a logical explanation, linking observable phenomena, wind and flames, to subterranean actions.

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<sup>33</sup> Zeller, 1886, pp. 255-256, 266-271

<sup>34</sup> Lyell, 1830, pp. 331-332

<sup>35</sup> Taub, 2003, pp. 95-96

<sup>36</sup> Arist. *Meteor.* 2.8

The most famous account of volcanic activity remains Pliny the Younger's *Epistulae* (Letters) describing the eruption of Mount Vesuvius AD 79. In two letters to the historian Tacitus, Pliny provides a meticulous eyewitness report of the eruption that destroyed Pompeii and Herculaneum. His description of the eruption column, "a cloud, unusual in size and appearance...shaped like a pine tree" remains one of the most detailed naturalistic depictions in ancient literature. Plin. Ep. 6.16 <sup>37</sup> Modern volcanology identifies this as an expansion of an eruptive column under convective buoyancy. Pliny's account carefully notes the stages of the eruption: tremors, "There had been earth tremors for several days"; ash fall, "Already ashes were falling, not as yet very thickly. I looked around: a thick black cloud was coming up behind us, spreading over the earth like a flood."; darkness, "Soon after, the cloud sank to earth and covered the sea; it hid Capri and the promontory of Misenum from sight."; and the reactions of those fleeing, "The carriages...began to run in different directions". (Plin. *Ep.* 6.16)

Pliny's letters represent a remarkable shift toward empirical observation. Unlike mythic or theological accounts, he refrains from invoking divine causation, instead describing what he sees and hears. Haraldur Sigurdsson argues that Pliny's observations remain foundational to volcanic science.<sup>38</sup>

Modern volcanologists have used his account to reconstruct the eruption sequence, and the term 'Plinian Eruption' now honours his detailed narrative. <sup>39</sup> Catherine Connors emphasises the observational accuracy shown by Pliny the Younger. She argues that Roman writers were keen observers who recorded volcanic phenomena in detail, even if they lacked explanatory frameworks. <sup>40</sup> Roman authors did not develop a structural understanding of volcanic

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<sup>37</sup> All translations are the author's own, unless indicated otherwise.

<sup>38</sup> Sigurdsson et al., 1985, pp. 332-397

<sup>39</sup> Hughes, 2007, pp. 5-28

<sup>40</sup> Connors, 2015, pp. 121-127

processes. There is no concept of magma chambers, tectonic plates or mantle convection.

Observations such as Pliny's remained descriptive rather than analytical. Therefore, a central feature of Roman knowledge was the separation between observation and theory.

Before his death during that same eruption, Pliny the Elder had produced the *Naturalis Historia*, an encyclopaedic work that sought to gather all known knowledge about the natural world. Book II discusses fire, winds and the earth's movements. Books XXXII-XXXVII touch upon minerals and stones formed by heat.<sup>41</sup> Pliny treats volcanoes as natural phenomena, but he does not present a unified theory of their cause. Rather, he records multiple Greek explanations, including that of Anaxagoras who saw fire trapped beneath the earth, and he attempts to catalogue the world's known active volcanoes: Etna, Vesuvius, the Aeolian Islands and regions of Etruria.<sup>42</sup>

For Pliny the Elder, volcanoes were part of the earth's vital processes, evidence of natural power but also of divine order. His work reflects the Roman encyclopaedic impulse: to record phenomena systematically rather than explain them conclusively. Nevertheless, his inclusion of volcanic soils' fertility and hot springs indicates an awareness of volcanism's constructive as well as destructive roles.<sup>43</sup> Pliny's approach was less analytical than others, such as Seneca as he focused on cataloguing phenomena and preserving observations rather than the reasons for the events. Liba Taub characterises this method as encyclopaedic empiricism.<sup>44</sup> Whilst lacking theoretical synthesis, Pliny's observations provide valuable data for both ancient and modern readers.

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<sup>41</sup> Plin. *HN*. 2

<sup>42</sup> Plin. *HN*. 2.199-204

<sup>43</sup> Plin. *HN*. 2. 207

<sup>44</sup> Taub, 2003, p.188

Roman philosophical writers adopted and adapted Greek natural philosophy to explain volcanic phenomena. Seneca's *Naturales Quaestiones* (ca. AD 62-64) investigates meteorological and geological phenomena from a Stoic perspective. In Book VI, Seneca discusses Mount Etna at length, reviewing earlier explanations whilst advancing his own naturalistic interpretation. He considers whether *pneuma* (subterranean winds), the friction of the air currents, or the combustion of sulphur and bitumen could produce Etna's fire.<sup>45</sup> Although he entertains multiple hypotheses, Seneca consistently rejects mythic explanations, notably the story that Vulcan's forge lies beneath Etna and insists that natural causes suffice.<sup>46</sup> Le Blay argues that Seneca's work demonstrates the internal coherence of Stoic natural philosophy.<sup>47</sup> The concept of *pneuma* provides a theoretical basis for subterranean activity. Volcanic eruptions are therefore seen as expressions of dynamics rather than arbitrary events, an idea clearly supported by modern day plate tectonic theory. Le Blay also posits that Roman explanations should not be judged by modern scientific standards. If one considers the time in which Seneca's theories were born, then the subterranean wind theory is not irrational but consistent within the framework of elemental physics that existed at that time. However, the gap between ancient and modern knowledge must be acknowledged as Roman theories, though coherent, lacked the explanatory power of modern volcanology. A century earlier, the poet Lucretius offered an Epicurean account of volcanic fire in *de Rerum Natura* Book VII. Rejecting divine intervention, Lucretius attributes Etna's eruptions to physical processes: winds and vapours forced through subterranean cavities ignite due to friction and heat, expelling fire and smoke:

But now I will unfold at last how yonder suddenly angered flame out-blows  
abroad from vast furnaces Aetnaean. First the mountain's nature is all  
underhollow, propped about with caverns of basaltic piers. And lo, in all its grottos

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<sup>45</sup> Sen. *QNat*, 6.1-32

<sup>46</sup> Sen. *Q Nat*. 6.26

<sup>47</sup> Le Blay, 2026, chap. 16

be there wind and air – for wind is made when air hath been uproused by violent agitation. When this air is heated through and through, and, raging round, hath made the earth and all the rocks it touches horribly hot, and hath struck off from them fierce fire of swiftest flame, it lifts itself and hurtles thus straight upwards through its throat into high heav’n. And thus, bears on afar its burning blasts. (Lucr. 6.639-646 (trans. Rouse))

Lucretius’ theory, though incorrect by modern geological standards, marks a decisive step towards a naturalistic understanding of volcanism. His emphasis on invisible particles and internal air pressure foreshadows later mechanical theories of the earth.<sup>48</sup> Scholars such as David Sedley emphasise that Lucretius’ account serves an ethical purpose, that by explaining volcanic activity naturally, he removes fear of divine punishment.<sup>49</sup> Therefore, Lucretius engages seriously with a physical cause of volcanoes, even if his model is limited. Lucretius’ account of earthquakes and volcanoes emphasises the activity of natural forces independent of human or divine control<sup>50</sup> thereby presenting a world governed by non-human processes, more of an environmental determinism approach.

The geographer Strabo (ca. 64 BC-AD 24), though writing in Greek, was a key source for Roman readers. In Geography Book VI, he describes Etna, the Aeolian Islands and the Campanian volcanic fields, drawing on local reports of smoke, lava and tremors.<sup>51</sup> Strabo classifies volcanoes as part of a broader pattern of “igneous phenomena” related to the earth’s exhalations, a theory linking volcanic and seismic activity. Strabo in Geography Book V considers eruptions as being the:

...cause of the fruitfulness of the country all around the mountain...for it contains the substance that fattens both the soil which is burnt out and that which produces the fruits (Strabo 5.4.8 (trans. Jones)) and about Mount Vesuvius he deduces that “...this area was previously on fire and held craters of fire that were put out when the fuel failed.”

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<sup>48</sup> Lucr. 6.639-707

<sup>49</sup> Sedley, 1998, pp. 35-61

<sup>50</sup> Lucr. 6.535-607

<sup>51</sup> Strabo 6.2.11-12

(Strabo 5.4.8) His approach is more scientific than others: he correlates landscape observations with causal hypotheses.

Pliny the Younger's empirical method, Seneca's rationalism and Lucretius' physicalism each represent stages in the understanding of volcanology upon which modern day scientists continue to rely: the *Epistulae* for reconstructing the AD 79 eruption sequence; the *Naturalis Historia* for cataloguing ancient eruptions; and the *Naturales Quaestiones* for insight into early natural philosophy. Archaeological and geological data increasingly corroborate these ancient witnesses, revealing the intellectual depth of Rome's engagement with the earth's fire.

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When comparing the ancient with modern understanding of volcanic events it is helpful to consider causation, method, prediction, integration and cultural context. The ancient Romans believed the cause of volcanoes to be wind, fire and elemental interaction, a qualitative approach. On the other hand, modern scholarship focuses on magma dynamics and tectonics, a far more structural and quantitative approach. Roman methods incorporated observation and analogy unlike the modern day which involves measurement and experimentation. Romans had minimal ability to predict events, and even modern scientists have only limited ability yet. The ancient Roman approach to understanding was fragmented due to a lack of global perspective unlike modern day where they have a global unified scientific framework. Culturally, Romans integrated religion, philosophy and observation, unlike modern day which has a much more secular framework. Roman knowledge of volcanoes was not a failed precursor to modern volcanology, but a distinct system shaped by its historical context. Modern scholarship, particularly the work of Scarth and Le Blay, has cast light on this

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<sup>52</sup> Sottili et al. 2021 p.2

complexity, offering a more nuanced understanding of how ancient societies interpreted the dynamic earth.

## **Earthquakes**

Earthquakes are sudden ground-shaking events caused by the release of accumulated energy in the Earth's lithosphere. They are amongst the most destructive natural hazards, capable of collapsing cities, triggering tsunamis and altering landscapes. Whilst earthquakes are natural expressions of plate tectonics, their impacts are amplified by human exposure and vulnerability.

Most earthquakes occur along plate boundaries, where stresses build up due to relative plate motion. The primary hazards of earthquakes include ground shaking, surface rupture, landslides, liquefaction and tsunamis. Earthquakes are natural outcomes of plate tectonics, arising from the accumulation and sudden release of elastic strain energy along faults. They vary in scale but share the potential for widespread destruction when they intersect with human settlements.

## **Ancient Knowledge of Earthquakes and Tectonic Processes**

For many Romans, earthquakes were first and foremost signs or omens (prodigia), associated with divine displeasure or messages from the gods. The earth trembling could indicate that a god was angry, especially deities like Jupiter or Neptune. Rituals, sacrifices and prayers were often undertaken to appease such gods. Pliny the Elder in his *Natural History*, notes that

earthquakes often become prodigies: “The city of Rome never experienced a shock which was not a prediction of a great disaster.” (Plin. *HN*. 2.86)

Julius Obsequens, writing in the late Republic, compiled the Book of Prodigies (*Prodigiorum Liber*) which includes many accounts of prodigious phenomena including earthquakes. These accounts typically emphasise the portentous nature of tremors leading to entire cities being destroyed. These writings show how deeply earthquakes were woven into the religious and moral fabric of Roman society, even as more ‘scientific’ explanations were also being developed.<sup>53</sup> In 56 B.C.E., according to Cicero’s ‘*De haruspicum responsis*,’ the Roman senate consulted the Etruscan haruspices about rumbling and clattering, “*strepitus cum fremitu*” in the north of Latium. It was seen as a manifestation of divine wrath, possibly direct communication from the gods or a divine sign.<sup>54</sup> Cicero claims the rumbling was the actual voice of the gods, “*deorum immortalium vox...paene oratio*” (*Har.*63). According to Mary Beard this supports the humanist approach by presenting the principles of divination as a way of understanding and modelling political speech and behaviour, illustrating the close interrelationship of religion and politics.<sup>55</sup> Corbeill, however, in ‘Hearing The Earth Speak’ has a different interpretation of the events, that the language used in the Etruscan response, especially the ‘cacophonous combinations of consonants’ clearly show the interaction of language, nature and morality.<sup>56</sup> From a More-Than-Human perspective, this can be understood as an interaction between humans and an active environment. The earth is not inert but communicates through signs.

Alongside religious interpretations ran more empirical or philosophical attempts to explain earthquakes through natural causes. These tended to draw on Greek precedents such as the

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<sup>53</sup> Obseq. *Prodig.* 61

<sup>54</sup> Beard, 2012, pp. 20-39

<sup>55</sup> Beard, 2012, pp. 32-33

<sup>56</sup> Corbeill, A. 2023, pp. 267-269

work of Aristotle, who in *Meteorologica* argued that earthquakes were caused by subterranean dry exhalations trapped within the earth,<sup>57</sup> a theory that Roman the thinkers Seneca and Pliny adopted. Seneca's *Naturales Quaestiones*, especially Book VI is crucial. Written around AD62-64, it addresses earthquakes explicitly, partly in response to a major earthquake in Campania (62/63 C.E.)<sup>58</sup> Seneca covers many earlier theories: that earthquakes are caused by water underground; by fire; by movement of the earth; or, most prominently in his point of view, by air (winds) moving through subterranean cavities. He favours a theory emphasising air in caverns, the idea that air, trapped in underground hollows, becomes compressed by external air and causes tremors. Calm atmospheric conditions often precede earthquakes, according to this theory, because still air above lets pressure build below. Seneca does not accept that one can predict earthquakes with certainty but uses these ideas to reduce fear by giving a natural explanation.<sup>59</sup>

Seneca is also interested in effects. He notes how buildings may be damaged in a variety of ways, as some collapse whilst others survive; how ground may crack; or how whole areas suffer unevenly. This suggests Roman observational awareness of variation of damage with proximity and building type. He combines natural philosophy with ethical purpose: earthquake knowledge helps human beings manage fear.<sup>60</sup> Sigurdson interprets this evidence as indicating environmental habituation, meaning that repeated experience of minor earthquakes reduced perceived risk and normalised seismic activity.<sup>61</sup> Archaeological evidence from Pompeii supports this view. After the earthquake of 62 C.E., buildings were

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<sup>57</sup> Arist. *Meteor.* 2.8

<sup>58</sup> Sen. *Q Nat.* 6

<sup>59</sup> Sen. *Q Nat.* 6.12 (moving air in subterranean cavities); Sen. *Q Nat.* 6. 8-10 (survey of theories of earlier authors, concluding in favour of subterranean air)

<sup>60</sup> Sen. *Q Nat.* 6.3-5

<sup>61</sup> Sigurdson, 2008, chap. 4

repaired and reinforced using bricks as a facing-material for rubble walls, indicating awareness of seismic danger.<sup>62</sup> Seneca's explanation of earthquakes as movements of subterranean spiritus suggests a world in which the earth itself is active, where the spiritus (breath) is a dynamic active substance capable of causing terrestrial movement. The stone is not merely a static object upon which an external force acts. It participates in a material system of forces and relations in which air, water, earth, cavities, pressure and movement interact.<sup>63</sup> Le Blay argues that such models reflect an integrated cosmology in which natural processes are expressions of a rational living system.<sup>64</sup> From this perspective, Roman thought incorporates elements of what modern scholars would call more-than-human agency.

Pliny's Natural History Book II also discusses earthquakes. He lists causes, signs and effects. He agrees with many that subterranean air and water play roles. For example, he writes that earthquakes "never occur except when the sea is quite calm and when the heavens are so tranquil that birds cannot maintain their flight." Therefore, positing that stillness above allows movement of air underground which then forces its way out, shaking the earth.<sup>65</sup> Emanuela Guidoboni and John Ebel demonstrate that ancient textual evidence can assist modern seismic reconstruction, "They [ancient texts] may be imperfect, subject to outside influence and sometimes very unreliable, but nevertheless they are irreplaceable." (Guidoboni, 2009, p.8)

Pliny's geographic observations have contributed to mapping ancient earthquake distribution.

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<sup>62</sup> Adam, 2008, chap. 8

<sup>63</sup> Sen. *Q Nat.* 6. 1-6

<sup>64</sup> Le Blay, 2026, chap. 16

<sup>65</sup> Plin. *HN.* II.192 Part V "Of Earthquakes, Islands, Evolution and Effects of the Sea on Land."

Thus, Roman knowledge functioned not only philosophically but also archivally. In contrast Ambraseys claims that ancient accounts may over-emphasise the destruction caused by seismic events or even amalgamate events, “influenced by the dogma of catastrophism”. (Ambraseys, 2006, pp. 1008-1016)

Pliny also catalogues strange signs: unusual colouration of the sun, murky spring waters, tremors at sea, odd behaviour of animals, as possible heralds of earthquakes.<sup>66</sup> Some of these signs are used by scientists today when predicting earthquakes. Experiments in water level variations have been conducted in the Kurile Islands to predict earthquakes of 4 or greater on the Richter scale. Wells up to 670m depth at epicentral distances up to 700km are used. This is an effective technique for measuring the deformation of the earth’s crust. The model shows that 3-10 days before an earthquake the water level begins to fall. It starts rising as the earthquake strikes. This method as a form of prediction was first attributed to Pherecydes, the teacher of Pythagoras when he was drawing water from a well.<sup>67</sup> The “murky spring waters” identified by Pliny could be linked to a modern prediction of hydro-chemical precursors. Research in the Kamchatka peninsula in the far east of Russia identified increases in concentrations of dissolved minerals and gaseous components up to a week before an earthquake event. After the earthquake the concentrations returned to their normal levels.<sup>68</sup> Odd animal behaviour has since the time of Pliny been an apocryphal method for predicting earthquakes, and this has continued right up to the present day. Even Charles Darwin wrote about this in his diary:

The French Vice Consul mentioned a fact which if authentic is very curious, that the Dogs generally during an Earthquake howl, as when hearing military music,

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<sup>66</sup> Plin.*HN*.2.191-195:causes,signs,strange effects

<sup>67</sup> Plin.*HN*.2.191.

<sup>68</sup> Koplava, 2018, pp. 71-84

but that this time they all quietly left the town some minutes before the shock and were standing in the surrounding hills. (Keynes, 1988. p.302)

The Stanford Research Institute in California is monitoring the behaviour of some seventy animal species along the San Andreas Fault.

Roman authors had access to many earthquake events, especially in East and South Italy, Asia Minor and the Eastern Mediterranean. Some of the major earthquake events were well documented. One example is the Lydian earthquake of A.D. 17, which destroyed many cities in the Roman province of Asia. Tacitus, Pliny and Strabo amongst others describe the devastation with Tacitus stating that: “Twelve famous cities in Asia were overwhelmed by an earthquake.” Tac. *Ann.* 2.47. The AD. 62/63 Campanian earthquake that damaged Pompeii and Herculaneum is central to Seneca’s discussion:

Pompeii, the celebrated city in Campania, has been overwhelmed in an earthquake...Part of the town of Herculaneum fell; the buildings left standing are very insecure. In addition, they say, a flock of 600 sheep was destroyed and statues were split open.” (Sen. *Q Nat.* 3.1-6.5.3 (trans. Corcoran)).

These events allowed observations of recurring patterns: earthquakes are often accompanied by rumbling noises, sometimes preceded by stillness, sometimes followed by aftershocks. Differences in damage between types of buildings and sometimes surprises in which structures survived or collapsed were observed. Seneca remarks upon how even some buildings that “should” collapse do not and vice versa.<sup>69</sup>

The Roman world not only theorised about earthquakes but also had to deal with them in practical ways through rebuilding, relief and commemorative acts. Emperors sometimes granted funds to rebuild after major quakes; inscriptions and coins show that catastrophes were officially acknowledged. For example, after an earthquake damaged Nicomedia,

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<sup>69</sup> Sen. *Q Nat.* 6.30.5: observations on differential damage; for example, parts of walls collapse, others stand precariously <sup>70</sup> Trinacty, 2019, pp. 95-98

Emperor Hadrian issued coins bearing the legend “Restitutor Nicomediae” (Restorer of Nicomedia) to mark the rebuilding and his relief efforts. Intellectuals also attempted to soothe affected people’s fears. Seneca’s work is aimed partly at consolation. In *Natural Questions*, Seneca provides natural explanations not just to satisfy curiosity but to help sufferers cope with loss, fear and the awe such disasters provoke.<sup>70</sup>

Therefore, both Roman and modern understandings of earthquakes share a commitment to explaining the natural phenomena but differ fundamentally in their method and scope.

Romans demonstrated careful observation, philosophical coherence and practical adaptation, whilst modern seismology shows mechanistic explanation, quantitative analysis and limited predictive ability. Scholars such as Foss show that Roman knowledge should not be dismissed but understood as an historically situated system.

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<sup>70</sup> Trinacty, 2019, pp. 95-98

## **Chapter 3 Roman Responses to Such Phenomena [placation (rituals), resilience and agency]**

### **Religion and Culture**

The Italian Peninsula, at a crossroads of tectonic boundaries, was a land of frequent earthquakes and volcanic eruptions. These natural phenomena profoundly shaped Roman religion and culture. Whilst the previous section considered attempts to rationally explain phenomena linked to earthquakes and volcanic eruptions (primarily in specialist literature for elite consumption), this section addresses the wider community responses to these phenomena, including various cultic acts of communication and placation. Rather than treating such events as random disasters, Romans interpreted them as signs of divine will or cosmic imbalance, integrating them into their systems of ritual and meaning. From the worship of Vulcan and the deification of Vesuvius to the ritual responses to earthquakes in Pompeii, Roman society transformed catastrophe into an occasion for religious expression and moral reflection.

In Roman religion, volcanic fire was personified in the god Vulcan (Vulcanus) who represented the destructive and creative potential of fire. The Vulcanalia, held annually on 23<sup>rd</sup> August, sought to appease this dangerous power by offering sacrifices into open flames, with people forcing their animals over fire, often near the Tiber river.<sup>71</sup> The date itself, late August, may not be arbitrary as it coincided with the period of intense summer heat and, symbolically, with the seasonal risk of fire and drought. Religious celebration dates were also used by farmers to determine crop sowing dates. For example, Pliny the Elder in Natural History Book XVIII states that: “Our view is that it [turnips] should be sown after the feast of

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<sup>71</sup> Varr. *LL.* 6.20

Vulcan.” (Plin. *HN*. 18.74.314) This shows how plate tectonics managed to influence many aspects of life that one would not normally have considered relevant.

Vulcan had two temples in Rome one of which was the Temple of Vulcan, in the Campus Martius, near the Circus Flaminius. The Romans revered fire as a purifying force, but one that, if unrestrained, could destroy civilisation. The god’s association with subterranean fire naturally extended to volcanoes. Roman authors often described volcanic eruptions as the work of Vulcan’s forge beneath the earth. The island of Vulcano in the Tyrrhenian Sea is thought to be his forge’s chimney. Mount Etna, though more closely associated with Greek myth, was also interpreted in Roman imagination as Vulcan’s workshop, where he and his Cyclopes forged Jupiter’s thunderbolts. This imagery is clearly expressed in Virgil’s *Aetna*:

These, say they, are the kilns the Cyclops used, when bending sturdily over the anvil to their even-timed strokes, they shook the dreadful thunder-bolt with the beat of their ponderous hammers, so to give arms to Jupiter.” (Vergil. *Aetna*. 3640 (trans. Ellis))

The sight of molten rock and glowing vents fit neatly with the imagery of divine craftsmanship.

Mount Vesuvius, in Campania, likewise possessed religious significance. An inscription discovered in Capua, near Mount Vesuvius refers to ‘Iuppiter Vesuvius’ (Jupiter Vesuvius), suggesting that the mountain was conceived as a divine manifestation of Jupiter’s power.<sup>72</sup> This local cult points to a Roman pattern of sacralising natural features, mountains, rivers, springs, as embodiments of divine forces (*numina*). The fusion of Jupiter’s celestial fire with Vesuvius’ terrestrial fire symbolised both the danger and divinity of volcanic activity.

Earthquakes, like eruptions, were seen as expressions of divine displeasure or warning. The Greek identification of Poseidon as the “earth-shaker” (*Ennosigaios*) found its Roman

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<sup>72</sup> Waldstein and Shoobridge, 1908, p. 97

analogue in Neptune, who could stir both sea and land.<sup>73</sup> Romans attributed seismic events to Neptune's temperament. His unpredictable and often violent nature was believed to cause the earth to tremble, leading to earthquakes. This association is further emphasised by his trident, a symbol capable of stirring both the seas and the earth. Roman religious texts and prodigy list recorded earthquakes as portenta (omens) requiring ritual expiation. The *Annales Maximi*, maintained by the pontiffs, included records of tremors alongside eclipses and comets as signs of divine communication. The Roman historian Livy offers multiple examples of earthquakes triggering public rituals. During the Second Punic War, for instance, an earthquake occurred amid battle; both sides stopped fighting and offered expiatory rites.<sup>74</sup>

...an earthquake happened, that destroyed many Italian cities, changed the course of rivers, and flattened mountains: yet neither before nor during the battle did the combatants notice the violent tremor. (Liv. 22.5)

Earthquakes signified imbalance between gods and humans and required restoration through ritual atonement (*piacula*). The Romans established temples to Neptune, two of the most significant being: the Temple of Neptune (*Aedes Neptuni*) in the Campus Martius near the Circus Flaminius, constructed in 220 C.E. and the Basilica of Neptune near the Pantheon, constructed by Marcus Vispanius Agrippa between 33 - 25 C.E.

The Roman Senate, following such prodigies, often decreed supplicationes, days of prayer and sacrifice, to placate the gods. These rituals re-established order and reaffirmed the piety of the state. As D. Graham has observed, these Roman reactions to natural catastrophe were seen as “a cure for the breakdown.”<sup>75</sup> These were therefore not seen as merely physical events, but also civic crises. Mary Beard, John North and Simon Price argue that Roman

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<sup>73</sup> Guney, 2015, pp. 293-315

<sup>74</sup> Liv. 28.11

<sup>75</sup> Graham, 2022, p556

religion functioned as civic practice reinforcing communal order.<sup>76</sup> Ritual response was used to stabilise society during an environmental crisis.

When Vesuvius erupted in AD 79, the catastrophic event was experienced and later narrated in deeply religious terms. Pliny the Younger's letters describe the sky darkening, the earth shaking and people praying to the gods or declaring that the world was ending:

Many were raising their hands to the gods, but more were declaring the end of gods, and that this night would be eternal, and the end of all the world. (Plin. *Ep.* 6.20)

For contemporaries, the event was not merely geological, it was apocalyptic, signalling the dissolution of cosmic order. Even centuries later, Christian authors would interpret the destruction of Pompeii as divine punishment, continuing a long tradition of moralising disaster.<sup>77</sup>

Roman responses to earthquakes and volcanoes existed on a spectrum from religious to scientific. Philosophers such as Lucretius and Seneca offered naturalistic accounts: underground winds, collapsing caverns and trapped fire caused tremors and eruptions. Yet even such explanations did not exclude divine agency as natural law and divine will were seen as complementary, not contradictory. This coexistence of differing interpretations reflected Roman cultural pragmatism. Religion was less about metaphysical belief than about correct practice (orthopraxy). Whether a quake came from Vulcan's forge or subterranean vapours mattered less than how one responded – by sacrifice, purification or prayer. The

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<sup>76</sup> Beard et al., 1998, p 41-49

<sup>77</sup> Aug. *Civ.* 3.29

efficacy of ritual was social and political as well as spiritual, reaffirming the *pax deorum*, the harmony between gods and men.

Romans remembered disasters as opportunities for religious renewal. Temples destroyed by earthquakes were rebuilt grander than before; dedications and inscriptions often recorded the act of restoration as a sign of piety. For example, after the AD62 earthquake, Pompeian inscriptions recorded dedications to Isis, Jupiter and Venus, acknowledging their power and protection.<sup>78</sup> Tacitus in his writing about an earthquake that destroyed Pompeii in 63 A.D. closely links the response to religion:

An earthquake also demolished to a large extent the populous Campanian town of Pompeii; and the debt of nature was paid by the Vestal Virgin Laelia, whose place was filled by the appointment of Cornelia, from the family of Cossi. (Tac. Ann. 15.22 (trans. Jackson))

Disasters thus reinforced, rather than undermined, the Roman religious order.

Moreover, the very landscape of Italy, pocked with craters, fumaroles and sulphurous lakes, became a living reminder of divine presence. The Campi Flegrei (Phlegrean Fields), west of Naples, were imagined as gateways to the underworld, as shown in Vergil's *Aeneid*, where Aeneas was guided by the Sybil of Cumae to Lake Avernus, the entrance to the underworld, where the earth's fires connected the world of the living and the dead.<sup>79</sup> The Alban Hills (Colli Albani) are the site of the remnants of a volcanic complex and the location of the sanctuary of Jupiter Latiaris. The Sibillini Mountains in central Italy are steeped in legend, especially concerning the prophetic figure known as the Sibyl.<sup>80</sup> The region's rugged terrain

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<sup>78</sup> Beard, et al., 2008, p.121

<sup>79</sup> Verg. *Aen.* 6.98-155, 264-294.

<sup>80</sup> Bentley and Pitts, 2018, p.1

and seismic activity have contributed to its mystical reputation. In such places, geology and theology converged.

Volcanoes and earthquakes, in Roman understanding, were not random acts of nature but manifestations of the sacred. They revealed both the power and volatility of the gods.

Through ritual, myth and architecture, Romans attempted to domesticate these forces, embedding them within the rhythms of civic life, annual festivals and personal devotion.

The dominant historiographical tradition in classical studies has long been humanist in orientation. It focuses on texts, ideas and cultural meaning, interpreting earthquakes and volcanoes primarily through the lens of Roman intellectual frameworks.

As has already been shown, Roman authors such as Seneca and Lucretius sought to explain earthquakes and volcanoes through natural philosophy.<sup>81</sup> Their accounts emphasise rational causation rather than divine intervention. This is an environmental determinism approach, one that takes the focus away from human influence. This perspective is clearly supported by recent research into the super-volcanic eruption of Okmok in Alaska in 43 BCE, linking it to the events that followed the assassination of Julius Caesar on the Ides of March 44BCE: the unusual climate, crop failures, famine and disease. The scientists posit that this played a significant role in the first century BCE fall of the Roman Republic.<sup>82</sup> The research emphasises the transformative impact of such events, portraying volcanoes as agents of historical change. Similarly seismic destruction across the Roman Empire influenced urban development, economic patterns and demographic shifts. However, this approach is limiting because Roman responses to earthquakes and volcanoes were not dictated solely by

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<sup>81</sup> Sen. *Q Nat.* 6; Lucr. 6

<sup>82</sup> McConnell et al., 2020, pp. 15443-15449

environmental forces; they were, as seen by the humanist approach, mediated by cultural, religious and intellectual frameworks.

Religion also has a role to play in Roman understanding of tectonics events as evidence of divine displeasure which require a ritual response such as those omens recorded by Julius Obsequens in his 'Liber Prodigiorum'. The humanist approach, including the work of scholar Mary Beard, emphasises that these interpretations reflect systems of meaning rather than empirical understanding.<sup>83</sup> Earthquakes and volcanic eruptions become cultural experiences embedded in religious and social structures. However, this approach risks minimising the material impact of environmental events. By focusing on interpretation there is the chance that the extent to which earthquakes and volcanoes physically shaped Roman society will be underplayed

The More-Than-Human framework seeks to move beyond the dichotomy of humanism and environmental determinism by focusing on the entanglement of human and non-human actors. In this approach, earthquakes and volcanoes are not passive forces but active participants in shaping Roman experience. The earth itself becomes a dynamic agent. Roman texts provide some support for this perspective. Seneca describes the earth as internally active, animated by spiritus.<sup>84</sup> This suggests a view in which natural processes are dynamic rather than inert. The More-Than-Human approach highlights the interconnectedness of geological processes, built environments, social practices and religious systems. These processes were not separate but interdependent. Environmental events influenced cultural responses which in turn shaped how societies adapted to future events. Foss's emphasis on

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<sup>83</sup> Beard et al., 1998, p.22

<sup>84</sup> Sen. *Q Nat.* 6

material adaptation aligns with this framework, showing how Roman urban life was shaped by seismic activity. This can be clearly seen in the siting of temples and religious buildings.

## **The Siting of Temples and Religious Buildings**

The monumental temples and sanctuaries of ancient Rome are usually studied through religion, politics and art. However, the siting, materials, and even the longevity of Rome's sacred buildings were profoundly influenced by the region's geological and tectonic history: the African and Eurasian plate boundary produced the volcanic rocks, hills and stable ground that made the temple construction possible.

The tectonic activity which generated the Apennine mountain range, created the volcanic provinces of Latium, and repeatedly covered the area where Rome now stands, with pyroclastic flows and volcanic ash.<sup>85</sup> These eruptions, dating from roughly 600,000 to 36,000 years ago, deposited thick sequences of tuff (consolidated volcanic ash) and pozzolana (volcanic sand).<sup>86</sup> The alternating processes of uplift, subsidence and erosion associated with the Tyrrhenian margin created a series of plateaux and valleys along the Tiber River. As a result, the topography of Rome, its famous 'Seven hills', is a direct legacy of tectonic and volcanic processes. The Capitoline, Palatine and Aventine hills, for example, are remnants of resistant tuff layers elevated through volcano-tectonic uplift and subsequent river erosion.<sup>87</sup> These landforms became the literal and symbolic high places of Roman religion.

In early Roman religion, temples were not randomly located: they were placed on sites that combined visibility, stability and symbolic elevation. The availability of solid volcanic rock,

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<sup>85</sup> Giordano and Mazza, 2010, p. 4

<sup>86</sup> Kearsey, 2019, p. 2

<sup>87</sup> Heiken et al., 2011, p.32

particularly compact tuff, made the construction of heavy masonry podiums feasible. The Capitoline Hill, home to the Temple of Jupiter Optimus Maximus, is composed largely of tufo lionato, a lithified pyroclastic deposit from the Alban Hills volcano.<sup>88</sup> The choice of this hill was not only religious but also geological; its bedrock provided a stable foundation resistant to flooding and subsidence.

Similarly, the Palatine Hill, where the Temple of Apollo Palatinus stood, is made of tufo del Palatino, another compact volcanic tuff.<sup>89</sup> The strength of the tuff and its ease of quarrying facilitated both the excavation of foundations and the raising of monuments. In contrast, areas of the Campus Martius underlain by alluvial sediments of the Tiber, were initially unsuitable for heavy religious structures due to poor load-bearing capacity and high flood risk.<sup>90</sup> Only with later Roman engineering such as drainage and terracing, did these floodplains accommodate large sanctuaries like the Pantheon and the Temple of Isis and Serapis. Therefore, the siting of temples followed a geological hierarchy: elevated plateaux of tuff for early sanctuaries; reclaimed alluvium for Imperial projects. Both choices were informed by the tectonically produced landscape.

The plate tectonic forces that formed Rome's terrain also produced the materials that built its temples. The volcanic tuffs of Latium – tufo Lionato, tufo Giallo della via Tiberina, and Lapis Albanus – provided the principal building stones for Roman sanctuaries.<sup>91</sup> These materials are all products of explosive volcanism linked to the African-Eurasian convergence.

Archaeometric studies of temples at the Sant Omobano site, one of the earliest religious sanctuaries in Rome, demonstrate sophisticated geological selection by early builders.

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<sup>88</sup> Diffendale et al., 2019, pp.187-99.

<sup>89</sup> Diffendale et al., 2019, pp.187-99.

<sup>90</sup> Panei, 2010, pp. 39-43.

<sup>91</sup> Diffendale, 2024.

Brocato identified that the temple podium was built from a non-local tuff quarried in the Anio Valley, chosen specifically for its resistance to weathering compared with local tuffs.<sup>92</sup> This indicates not only technical understanding, but also a reliance on regional geological diversity shaped by tectonic forces.

In addition to tuff, tectonically induced hydrothermal activity around central Italy produced travertine, a dense, banded form of limestone precipitated from hot springs. The best-known source, Tivoli (ancient Tibur), lies east of Rome along a tectonic fault zone associated with the subduction of the Adria microplate.<sup>93</sup> Travertine became a favoured material for temple podiums and porticoes from the late Republic onwards, as seen in the Temple of Hercules Victor near the Forum Boarium. Its hardness and durability were geological advantages that complemented the workability of the tuff.

Therefore, even the decorative and structural diversity of Rome's religious buildings reflects the influence of plate tectonics: volcanism provided tuff; hydrothermal systems yielded travertine; and tectonic uplift exposed both to human use.

Roman religion attached deep meaning to the landscape. Hills were seen as places where the human and divine realms met, whilst rivers and springs marked boundaries of ritual purity.<sup>94</sup> The very hills and valleys that structured the topography of Rome were shaped by the uplift and erosion tied to tectonic activity. The geological forms became sacred forms: Amongst the Alban Hills, the remnants of a volcanic complex, on the highest peak, Mount Cavo the sanctuary of Jupiter Latialis was sited. It was a significant religious centre for the Latin

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<sup>92</sup> Brocato et al., 2019, pp.114-136.

<sup>93</sup> Heiken et al., 2011, p. 52.

<sup>94</sup> Cornell, 1995, pp. 60-62

League; the Sibillini Mountains in central Italy have a mystical reputation enhanced by the seismic activity in the area.<sup>95</sup>

This connection between sacred geography and geology underscores the indirect but profound role of plate tectonics in Roman religion and can be traced back to the Delphic Oracle in Greece where recent research into the geological origins have found clear links to the siting of the temple and plate tectonics. J.Z. De Boer and J.R. Hale's research into the area discovered a WNW-ESE fault zone below the site. They believe that the faults broke through a bituminous limestone formation and during seismic events hydrocarbon gases including methane, ethane and butane may have escaped producing narcotic effects and influencing the inspiration for the predictions.<sup>96</sup> This effect was written about by Diodorus:

It is said that in ancient times goats discovered the oracular shrine, on which account even to this day the Delphians use goats preferably when they consult the oracle. They say that the manner of its discovery was the following. There is a chasm at this place where now is situated what is known as the " forbidden " sanctuary, and as goats had been wont to feed about this because Delphi had not as yet been settled, invariably any goat that approached the chasm and peered into it would leap about in an extraordinary fashion and utter a sound quite different from what it was formerly wont to emit. The herdsman in charge of the goats marvelled at the strange phenomenon and having approached the chasm and peeped down it to discover what it was, had the same experience as the goats, for the goats began to act like beings possessed and the goatherd also began to foretell future events. (Diod. Sic. 16.26.1-3 (trans. Oldfather))

The Delphic Oracle sessions were never held during the winter months when the cold temperatures would have reduced the ability of the gas to rise through the faults due to snow and ice.

The Romans also had Oracles whose sites were closely linked to geology and plate tectonics.

The Oracle of the Dead was to be found at Baiae near lake Aornos. It was located within a tufa tunnel at the junction of two boiling springs where the river 'Styx' was said to be located.

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<sup>95</sup> Bentley and Pitts, 2018, p.1

<sup>96</sup> De Boer and Hale, 2000, pp. 399-412.

<sup>97</sup> The Cumaean Sibyl occupied caves in volcanic tuff in the Phlegraean Fields, at lake Avernus and Cumae, where geothermal vapours, fissures and sulphurous gases symbolised entrances to the underworld and similarly to the Delphic Oracle, enabled trances to be induced. <sup>98</sup> These examples show the influence of the environment on human behaviour, maybe leading towards an Environmental Determinism approach, however one cannot ignore the importance of the human interpretation of these geological features and their ability to incorporate them into their religious beliefs and practices. This highlights the relevance of the More-Than-Human approach, appreciating the symbiotic relationship between the physical and human environments.

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<sup>97</sup> Hill, 2017, p.3

<sup>98</sup> Smith, 1875, pp.836-843

## Chapter 4 Roman Exploitation of Volcanic Resources

How important were the resources created by plate tectonics to ancient Rome and its inhabitants?

### Infrastructure, Urban Planning, and Resources

Italy's architecture since ancient times owes a great deal to the geology created by plate tectonics, from the marble sourced from across the world, the pozzolana mortars to the tufa brickwork.

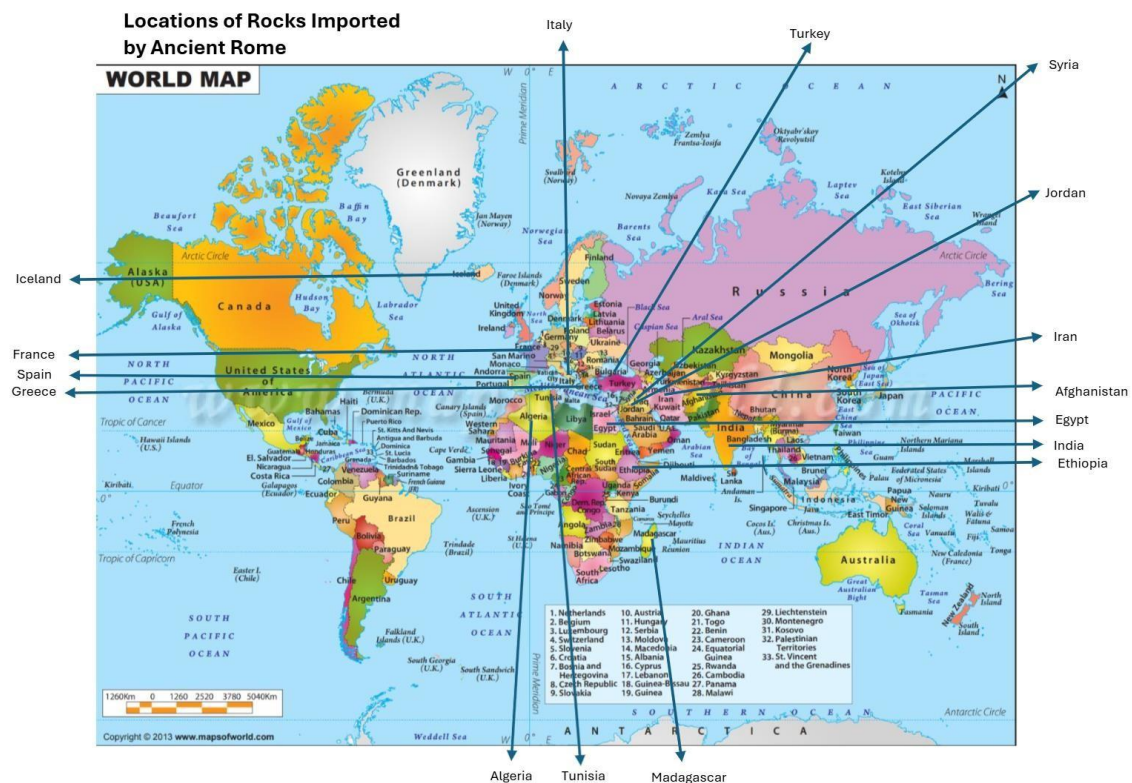


Fig. 5 Origins of rocks imported by Ancient Rome

Marble and hard stone were some of the most important materials in Roman architecture, symbolising not only luxury but also the reach of the Roman Empire as seen in the map above showing the sources of marble used by Rome. The Romans inherited the aesthetic

marble from Greece but developed it into an Imperial industry. The shift from Republican austerity to Imperial opulence was marked by the increasing use of marble in public architecture. Pliny the Elder remarked critically that “Luxury began to prevail when the marble walls appeared,” (Plin. *NH.* 36.48) associating stone splendour with moral decline. Suetonius, however, described marble as the very expression of Imperial achievement. According to him, Augustus, declared that he had found Rome a city of brick and left it a city of marble.<sup>99</sup> These contrasting voices illustrate both moral anxiety and political pride tied to the material. The most famous Roman white marble was marmor Lunense, from the quarries of Luna (modern Carrara) in northern Italy. Strabo, writing in the early 1st century C.E. praised it: “Luna marble is the best and large blocks of it are transported by sea.” (Strab. 5.2.5). Carrara marble became the standard for Roman architecture and statuary, appearing in the Pantheon and Trajan’s Column.

Greek marbles also remained in use. Parian and Pentelic marbles, long exploited in classical Greece, continued to be imported for statuary and temple work. Strabo notes that Paros “contains the finest marble in the world,” (Strab. 10.5.3) and Roman patrons imported it for high-status commissions. The continued use of Greek marbles symbolised both cultural continuity and Rome’s dominium over the Greek world. While fine-grained white marble dominated sculpture, coloured stones came to define Roman decorative style. Numidian yellow marble (giallo antico) from Chemtou in North Africa, green cipollino from Euboea, red rosso antico from Cape Matapan and purple porphyry from Egypt adorned Imperial palaces and baths. These stones carried geographical prestige, visual proof that Rome controlled the resources of the known world. Pliny marvelled at this variety, though not without irony: “We now look for the most expensive stones from all over the earth...as if each

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<sup>99</sup> Suet. *Aug.* 28.3

mansion were to rival the temples of the gods.” (Plin. *NH.* 36.48) Such commentaries reveal the Roman elite’s fascination with exotic materials and the moral tension surrounding the luxury.

By the 1<sup>st</sup> century C.E., many quarries were under Imperial administration. Inscriptions from Docimium (modern Afyon, Turkey) record the presence of Imperial officials overseeing the extraction of pavonazzetto marble. The porphyry quarries of Mons Porphyrites and the granite quarries of Mons Claudianus in Egypt were also directly managed by the state. Ostraca from these sites record the logistics of quarry labour, including the work of military detachments and convicts. Transport was central to the marble economy. Massive blocks were moved from mountain quarries to harbours using sledges, rollers and wooden cranes, then shipped on special *naves lapidariae* (stone carriers). Strabo’s mention of the sea-borne Luna marble underlines how access to navigable waters determined which quarries flourished. Rome’s control of the Mediterranean trade routes made this large-scale movement of stone possible.

Marble was not only a construction material but also a political instrument. The Forum of Augustus, sheathed in stunning white Luna marble and accented with coloured imports, was a visual claim to Imperial splendour and divine sanction. Each type of stone carried its own symbolism: Egyptian porphyry formed as part of the Dokhan volcanic suite was reserved for Imperial statuary and sarcophagi, its purple hue created due to the inclusion of haematite, evoking royal exclusivity. It was especially popular during the reigns of the emperors Trajan and Hadrian.<sup>100</sup>

Pliny catalogued these marbles with a mixture of admiration and criticism, remarking that “there are endless varieties of marble, because every place has a different vein and colour.”

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<sup>100</sup> Abu El-Enen et al., 2018, pp. 1-4

(Plin. *NH.* 36.55) In contrast, moralists such as Seneca lamented that the old Roman virtues of simplicity had been replaced by a passion for stone:

“A man now thinks of himself a shoddy pauper unless his walls gleam with large and costly mirrors, unless his Alexandrian marble has a contrasting inlay of Numidian and a mosaic border all around of many colours laid out like a painting...We have reached such a pitch of luxury that we don’t even want to walk unless we tread on precious stones.” (Sen. *Ep.* 86.6-7 (trans. Graver and Long)).

Archaeological science now confirms the geographic spread described by ancient authors. Isotopic analysis and petrography allow scholars to match ancient artefacts to their quarry sources, validating Strabo’s and Pliny’s geographical accounts. Excavations at Chemtou, Dokimeion and Carrara reveal sophisticated quarrying techniques – channel cuts, wedge holes and standardised block sizes – testifying to organised, large-scale production. The extraction and deployment of exotic Egyptian stones became an expression of Roman imperial ideology. Dodge argues that obelisks transported from Egypt to Rome functioned as “victory monuments and symbols of imperial ideology”, while Egyptian granite and purple porphyry from Mons Claudianus and Mons Porphyrites subsequently participated in this ideological display.<sup>101</sup>

Marble was not the only type of stone imported by the Romans. They imported a variety of other igneous and metamorphic rocks. Lapis Lazuli from Afghanistan for inlay and jewellery; andesite from Egypt’s Eastern Desert, used in St. Mark’s Basilica, Venice; granite from France, used as pillars in the Baths of Caracalla in Rome; obsidian from the lava flows of

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<sup>101</sup> Dodge, 2020, p.45

Iceland and Spain, and smoky quartz from Madagascar, for carvings; basaltic lava from Lazio, Italy for paving the Flaminian Way; and granite from Turkey, used as columns in Hadrian's Villa, Tivoli. (See appendix 1 for a more complete table of sources and uses.)<sup>102</sup>

## **Varieties of Materials for building**

Tufa was the commonly used stone for building in ancient Rome, up to the beginning of the 1<sup>st</sup> century B.C. They were mined from a variety of places and each variety had its own characteristics. Cappellacio, a relatively poor quality tufa was mined under the Palatine, Capitoline and Quirinal hills of Rome for terracing, drains and the Republican City Walls. Peperino was a quality tufa, being even-textured, hard and compact. It was quarried in the Alban Hills, near Marino and was used for sculpture as well as the outer facings of buildings including the tomb of Scipios due to it weathering more slowly than most other tufas. Vitruvius wrote about the most effective way to use tufas: "...take them from the quarry in summer, not winter exposing them to the air in a place that is sheltered for two years before using them." (Vitr. *De arch.* 2.7) This results in the rocks losing the 'quarry sap' and becoming more resistant to weathering.

Tufa and marble show the importance of geology in providing both the building materials for Ancient Rome and the ability to show wealth and prestige through the choice of materials. This was only made possible through the spread of Rome's influence across the Mediterranean and the creation of trading routes and harbours enabling the safe transportation of these materials. The physical world provided the materials, Environmental Determinism; the might of the military enabled access to the quarries and the material therein, Human Approach; but it is only the interaction of these factors that allowed the building of the cities,

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<sup>102</sup> Price. *The Sourcebook of Decorative Stone: An Illustrated Identification Guide*, 2007

the remains of which we are able to view today, the More-Than-Human approach. Geology was an active participant in shaping Roman politics and religion. Roman identity was intertwined with stone. The marble imported from around the world connected Rome to distant provinces and from a More-Than-Human perspective these stones carried their own geological histories spanning millions of years, embedding deep Earth time within the political life of the Empire.

## **Roman Catacombs**

The underground burial complexes beneath Rome, commonly referred to as the catacombs, are often thought of as purely cultural or religious phenomena. Yet their formation, location and architecture are deeply entwined with geology, and ultimately with plate tectonic processes that shaped the region's volcanic activity, terrain and rock types.

Over time, the volcanic material erupted from the Alban Hills and Monti Sabatini covered the lower Lazio plain.<sup>103</sup> The Romans were aware of the local tuff deposits and building stone was widely quarried.<sup>104</sup> Tuff is relatively soft and workable compared to many igneous or metamorphic rocks, which made it attractive for excavation and construction.<sup>105</sup> The geology of Rome thus offered not only building stone but also the possibility of hollowing the subsurface.

The geological layering beneath Rome played a crucial role. The soft tuff layers sat beneath an upper weathered layer and above harder lithoid tuffs; the ease with which the soft layers

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<sup>103</sup> Giordano and Mazza, 2010, p.4

<sup>104</sup> Diffendale et al., 2019, pp.187-199

<sup>105</sup> Jackson and Marra, 2006, as cited in B.S.R. article The Roman Tuffs Revisited: "Tuff is a pyroclastic rock...in the region of Rome."

could be excavated, and the existence of pre-existing quarries, made the subterranean voids accessible.<sup>106</sup>

Human activity had already removed large volumes of tuff through quarrying. According to the British Geological Survey:

The rock under a large amount of Rome comes from two volcanic calderas...the tuff has been extensively mined...Some of these [quarries] were re-used as catacombs but many [were] lost and became a subsidence risk. (Kearsey, 2022)

The excavation of tuff created networks of voids, tunnels and galleries that later Christian and Jewish communities in Rome exploited for burial. The underground burial galleries of the catacombs often followed and extended previous quarry workings in the tuff.<sup>107</sup>

The soft tuff made tunnelling easier and more economical: “Its relatively soft and porous nature allowed for the excavation of underground catacombs.”<sup>108</sup> Geologists note that in the catacomb-bearing zones, the tunnel galleries average about 2-3 metres in height and about 1 metre in width, dimensions shaped by rock quality, pre-existing voids and socio-economic factors.<sup>109</sup> In short, the geological substrate made the creation of extensive subterranean burial networks practical.

Plate tectonics in central Italy drove volcanic activity which deposited ash and pyroclastic materials that became tuff. This geological substrate, in turn, shaped the city of Rome: the hills, the valleys, the quarries, the building material, and the underground voids. The catacombs are possible because the rock was sufficiently soft to excavate, underpinned by volcanic processes initiated by tectonics; they were located where subterranean voids existed; and they survived, because the rock mass had structural integrity. The catacombs represent

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<sup>106</sup> International Catacomb Society, 2024

<sup>107</sup> Kearsey, 2022.

<sup>108</sup> Ancient Rome Live, Geology of Rome.

<sup>109</sup> International Catacomb Society, 2024.

not just early Christian burial practice but also geological processes: the shifting plates under the Mediterranean, the volcanic eruptions of the Alban Hills and the human exploitation of their legacy.

## **Pozzolana sand**

The engineering achievements of Ancient Rome remain amongst the most studied and admired accomplishments in world history. Roman roads crossed continents, aqueducts transported water across valleys, harbours resisted violent seas, and monumental domes still standing today, two thousand years after they were built, reflect an advanced understanding of construction techniques and materials.<sup>110</sup> Central to these achievements was pozzolana sand. Pozzolana sand is a fine-grained material composed of ash or pumice, the result of volcanic eruptions. One of its uses was as major component in the making of mortar. Mortar was used extensively during ancient Roman times and covers many of the walls of the Roman catacombs. The mortar was created using a mixture of the sand, volcanic rock aggregates and lime. This mortar has a high strength, is insoluble and even hardens underwater, all of which were known to the ancient Romans. Vitruvius comments on its properties in Book II of his ‘Ten Books on Architecture’:

There is also a kind of powder which from natural causes produces astonishing results. It is found in the neighbourhood of Baiae and in the country belonging to the towns around Mt, Vesuvius. This substance, when mixed with lime and rubble, not only lends strength to buildings of other kinds, but even when piers of it are constructed in the sea, they set hard under water. (Vitr. De arch. 2.6.47 (trans. Morgan))

The significance of pozzolana extended far beyond its practical use as a building material. It enabled Rome to expand militarily, administer a vast empire, sustain growing urban

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<sup>110</sup> Flohr et al., 2025, p. 97

populations and express political authority through architecture. Without pozzolana, many of the structures that symbolise Roman civilisation would have been impossible to build on the same scale or with the same durability. Roman engineers discovered that when volcanic ash was mixed with lime and water, it created an hydraulic cement capable of hardening even underwater. This innovation revolutionised construction and gave the Romans capabilities unmatched by earlier Mediterranean civilisations.

The importance of pozzolana can therefore be understood through multiple perspectives. Scientifically, it represented a major advance in materials engineering. Economically, it lowered costs and accelerated construction. Militarily, it supported ports, fortification and transportation systems. Socially, it improved urban life by enabling baths, aqueducts, amphitheatres and housing to be built. Culturally, it became the foundation for monuments that projected Roman power and civilisation across Europe, North Africa and the Near East.

The term ‘pozzolana’ derives from Pozzuoli, a town located near Naples in Southern Italy. The region lies within an area of intense volcanic activity associated with Mount Vesuvius and the Phlegrean Fields. Volcanic eruptions over thousands of years deposited ash rich in silica and alumina, producing the fine material that Roman builders recognised as being exceptionally valuable. Pozzolana was not however limited to this location. Due to the tectonic nature of Italy, pozzolana is found across the country.<sup>111</sup>

Ancient writers such as Pliny the Elder described pozzolana and praised its unusual properties:

dust, on the hills of Puteoli encounters the waves of the sea and as soon as it is submerged turns into a single mass of stone that withstands the attacks of the waves and becomes stronger every day, especially if it mixed with broken quarystone from Cumae. (Plin. *NH*. 35.166 (trans. Rackham)

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<sup>111</sup> Lancaster, 2005, pp. 13-16

These writings reveal that Roman builders understood the practical significance of pozzolana even if they did not possess a scientific explanation for its properties.

The natural geography of Italy therefore contributed directly to Rome's rise, thus supporting the Environmental Determinism approach. The same volcanic forces that often threatened and destroyed settlements, also provided one of the Empire's greatest technological advantages. In this sense, pozzolana demonstrates how environmental resources can shape the course of civilisation.

The extraordinary importance of pozzolana stemmed from its chemical properties.

Limepozzolana mortar is created from mixing aggregate and lime. To obtain the lime, limestone had to be heated to around 900°C. This produced quicklime which was then mixed with water to create slaked lime. To create the final cement Romans added pozzolana sand along with quartz and local rocks. The resultant cement was fast hardening, easy to handle and of a high strength, even underwater.<sup>112</sup>

The Romans mastered the practical techniques necessary to exploit these reactions. Builders experimented with varying ratios of lime, aggregate and pozzolana. Vitruvius, in Book V of *De Architectura* recommends one part lime to two parts pozzolana.<sup>113</sup> The cement should also comprise of 15-20% water. This practical knowledge was transferred through generations of engineers and craftsmen.

The scientific importance of pozzolana therefore lies not only in the material itself, but also in the Roman ability to systematically apply empirical observation. Roman engineering was grounded in experimentation, adaptation, and accumulated expertise. This very much

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<sup>112</sup> Sanchez-Moral, S et al., 2005, pp. 1555-1565

<sup>113</sup> Vitr. *De arch.* 2.5.1

supports the Humanist approach: pozzolana became the centrepiece of a construction revolution because Roman society possessed the organisational capacity to use it effectively.

One of the clearest demonstrations of pozzolana's importance can be seen in Roman architecture. Roman concrete allowed architects to move beyond the limitations of traditional stone construction and create structures of unprecedented scale and complexity. Earlier Greek architecture relied heavily on cut stone and post-and-lintel systems. Whilst aesthetically impressive, these techniques limited the size and shape of buildings. Roman concrete, strengthened by pozzolana, enabled the widespread use of arches, vaults and domes. These forms distributed weight more efficiently and allowed builders to cover vast interior spaces. Perhaps the greatest surviving example is the Pantheon in Rome.<sup>114</sup> Constructed during the reign of Emperor Hadrian, the Pantheon featuring a massive concrete dome measuring 142 feet, remains the largest unreinforced concrete dome in the world.<sup>115</sup> The structure would have been impossible without pozzolana-based concrete.

Amphitheatres, basilicas, baths and temples also benefited from concrete construction. The Colosseum combined stone and concrete to create an entertainment venue capable of holding tens of thousands of spectators. Public bath complexes such as the Baths of Caracalla used concrete vaulting to create enormous interior halls. The substructures of the Baths of Caracalla required 280,000m<sup>3</sup> of tufa and mortar, the vaults 210,000m<sup>3</sup> of concrete. Other igneous rocks were also used within the interior: 6,300m<sup>3</sup> of marble and granite including 252 column shafts; walls were covered with marble veneer; and the floor was a fish-scale mosaic of alternating red and green porphyry, numidian yellow and a selection of grey

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<sup>114</sup> MacDonald, 1976, pp. 5-29

<sup>115</sup> <https://citywonders.com/blog/guide-incredible-history-of-the-pantheon>

marbles.<sup>116</sup> The grand buildings created by the Romans would not have been possible without the variety of materials provided by the result of plate tectonics.

Concrete construction also accelerated the building process. Instead of relying entirely on labour-intensive stone carving, Roman builders could pour concrete into wooden moulds. This flexibility enabled faster expansion of cities and infrastructure throughout the empire. The architectural importance of pozzolana extended beyond practicality. Monumental buildings served as symbols of Roman authority, wealth and civilisation. Emperors used architecture to legitimise their rule and impress both citizens and conquered peoples. The largest tomb in the Roman world was the Mausoleum of Augustus. Its facing was travertine with a tufa rubble and concrete core. The entrance was flanked by two red Aswan granite obelisks.<sup>117</sup> Concrete, therefore, made it possible to create spaces that embodied imperial grandeur.

The Roman Empire depended heavily on maritime trade and naval power. The Mediterranean Sea functioned as the central artery of imperial communication, commerce and military movement. Pozzolana played a decisive role in enabling Rome to dominate this maritime world. One of the most important uses of pozzolana concrete was in harbour construction. At Puteoli formations of natural concrete were found at sea level, formed due to the percolation of groundwater saturated with calcium carbonate through layers of the pozzolana.<sup>118</sup> This discovery by Roman engineers that concrete mixed with volcanic ash could harden underwater, allowed them to build durable piers, breakwaters and docks. This capability gave Rome significant strategic advantages. Strabo states that Puteoli:

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<sup>116</sup> Claridge, 2010, p.75

<sup>117</sup> Claridge, 2010, pp.204-205

<sup>118</sup> Oleson et al., 2004, pp.199-299

has become a great trade centre due to its man-made harbours because of the natural quality of the sand. The sand forms a strong bond when measured in correct proportion to the lime and sets solid. As a result, by mixing the sand-ash with the lime they can build breakwaters into the sea so that the biggest merchant ships can safely moor there. (Strab. 5.4.6 (trans. Jones))

The harbour at Ostia, Rome's principal port, illustrates the importance of hydraulic concrete.

<sup>119</sup> As the city of Rome grew to over one million inhabitants, securing reliable grain imports became essential. Massive harbour works constructed with pozzolana concrete enabled ships from Egypt, North Africa and other provinces to unload cargo efficiently.

Roman naval operations also benefited from improved maritime infrastructure. Ports allowed fleets to dock safely, repair ships, and maintain supply networks. This strengthened Rome's military control over the Mediterranean, which the Romans famously called *Mare Nostrum*, 'Our Sea.' This epitomises the More-Than-Human approach, where human ingenuity combined with natural resources allowed for Roman dominance, as without pozzolana, Roman maritime expansion would have faced severe limitations. Traditional stone construction was less adaptable and more vulnerable in marine environments. Hydraulic concrete enabled Rome to reshape coastlines and create stable harbours where nature had provided few advantages. Thus, pozzolana contributed directly to Roman economic growth, naval supremacy and imperial expansion.

Roman infrastructure has long been celebrated for its durability and efficiency. Roads connected distant provinces, aqueducts supplied cities with water, and bridges linked communities across rivers and valleys.

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<sup>119</sup> Keay, 2012, pp. 77-95



**Fig. 6.** Map of the Roman Empire including main roads.

[https://www.heritagehistory.com/ssl/cds/ancient\\_rome/maps/dow/dow003.jpg](https://www.heritagehistory.com/ssl/cds/ancient_rome/maps/dow/dow003.jpg).

Pozzolana-based concrete was central to many of these projects. Roman roads formed one of the largest transport networks in the ancient world.<sup>120</sup> Whilst roads themselves were primarily constructed from layers of stone and gravel, concrete was frequently used in foundations, bridges, tunnels and drainage systems associated with road construction. Durable infrastructure facilitated trade, military mobility and administrative communication. Modern scholars like Thomas Holland and Mary Beard view the road networks not just as transport, but as the central nervous system of the empire. The ability of the *cursus publicus*

<sup>120</sup> Laurence, 1999, pp 1-20

(the state courier system) to dispatch messages across vast territories allowed Rome to govern with unprecedented administrative speed.<sup>121</sup>

Bridges especially benefited from hydraulic concrete. Roman engineers used arches and concrete piers to span rivers with impressive stability. Structures such as the Pons Fabricius in Rome demonstrate the long-lasting nature of Roman engineering. Aqueducts, such as the Aqua Claudia, also relied heavily on pozzolana concrete. These systems transported water over long distances using carefully calibrated gradients. Concrete linings made channels waterproof, whilst arches supported elevated sections across valleys. Reliable water supplies transformed urban life. Public fountains, baths, toilets and private residences all depended on aqueduct systems. The availability of water contributed to sanitation, hygiene and social life in Roman cities. Large bath complexes represented another important application of concrete technology. Heated rooms, pools and vaulted ceilings required materials capable of enduring moisture and temperature changes. Pozzolana-based concrete provided the necessary resilience. Roman baths played many roles. They were far more than just a place to get clean; they were the social centre of Roman life.<sup>122</sup> Roman baths were social and political hubs where Romans of all ranks mingled to negotiate trades, exchange news and increase social visibility. Some, such as the famous ancient thermal springs at Aquae Sulis (modern-day Bath) were deeply spiritual. Urban development reflected broader Roman values. Monumental architecture expressed civic pride and imperial generosity. Emperors often sponsored construction projects to gain public support and demonstrate benevolence. The

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<sup>121</sup> Beard, 2015, p.357

<sup>122</sup> Yegul, 1992, p.1

widespread use of pozzolana therefore contributed directly to the creation of Roman urban culture. Cities became showcases of Roman order, engineering and civilisation.

The cumulative effect of these infrastructure projects was immense. Efficient transportation and communication helped maintain imperial control across vast territories. Cities became more liveable and economically productive, Trade networks expanded. Armies were able to move rapidly in response to threats. It required human ingenuity to recognise the importance of the sand, so clearly supports the More-Than-Human approach as pozzolana supported the practical foundations of Roman civilisation, creating the infrastructure that integrated the empire politically, economically and culturally.

Pozzolana had enormous economic significance for the Roman Empire. Construction projects stimulated employment, trade and resource extraction across the Mediterranean world. The production and transport of pozzolana created commercial networks linking volcanic regions with distant provinces.<sup>123</sup> Quarrying, shipping and construction industries employed large numbers of workers. Concrete construction also reduced costs compared to exclusive reliance on cut stone. Stone masonry required highly skilled labour and extensive transportation. Concrete by contrast, could incorporate locally available aggregates and rubble. This flexibility made large-scale building projects more economically feasible. Public works projects stimulated economic activity by improving transportation. Roads facilitated trade, harbours expanded maritime commerce and aqueducts supported urban growth.

Modern scientists have become increasingly interested in Roman concrete because of its durability. Many ancient structures have survived earthquakes, seawater exposure and centuries of weathering. Researchers studying Roman materials hope to develop more environmentally sustainable forms of concrete inspired by ancient techniques. This modern

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<sup>123</sup> Temin, 2013. pp. 95-113

interest highlights the enduring significance of pozzolana. Roman engineering not only transformed the ancient world but also continues to influence contemporary materials science. Roman concrete influenced architectural traditions throughout Europe and helped to shape the development of modern engineering. Many Roman structures remain standing today, serving as tangible reminders of the material's durability.<sup>124</sup> Studies such as those by Professor Marie Jackson from the University of Utah, US suggest that interactions between volcanic ash and seawater created self-strengthening mineral formations.<sup>125</sup> The grandeur of Ancient Rome cannot be fully understood without recognising the essential role played by the humble volcanic sand that made Roman concrete possible.

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<sup>124</sup> Moore, 2011, pp. 112-128

<sup>125</sup> Jackson, 2014, pp.1146-1154

## Chapter 5 Conclusion

So how important was the role of plate tectonics in shaping the environmental, infrastructural and societal dynamics of ancient Rome? And the answer is ‘very.’ Without plate tectonics, Rome would have been deprived of many of the foundations of its success. There would have been no tufa with which to build their cities, no marble with which to impressively decorate them. Pozzolana would not have existed and so there would not have been the ability to build their harbours, roads, bridges, baths and viaducts with the long-lasting durability the sand provided.

Plate tectonics also influenced religion with the use of tectonic features for religious locations, and the gods chosen by Romans to worship, including Vulcan. Romans extended Greek understanding of natural processes such as volcanoes and earthquakes, as has been seen in the writings of Pliny the Elder. Their observational skills of these events have also been incorporated into modern science, such as Pliny the Younger’s description of the eruption of Mount Vesuvius.

What has also been interesting to explore has been the attitude of scholars to the importance of plate tectonics and the role it has played. Environmental determinism, as espoused by Friedrich Ratzel is tempting, because without the features created by plate tectonics there would be no volcanoes or earthquakes and therefore no pozzolana or marble. However, this is I believe too simplistic. At the other end of the scale is the Humanist approach, promoted by the likes of Mary Beard, that humans determine the success, or failure of a civilisation, that it is down to human ingenuity. This is more persuasive but is not possible without the resources provided by nature which are greatly minimised by this approach. Finally, we have the MoreThan-Human approach, first proposed by David Abram, and this I believe needs to be considered seriously. It combines both previous approaches into one more considered idea.

Nature provides the materials and human ingenuity uses them to their advantage as can be seen with the use of pozzolana sand to create cement. The durability of Roman architecture such as the Colosseum, the Pantheon and Roman roads demonstrate the agency of stone in shaping human behaviour. Its durability enabled it to outlast generations, continually influencing patterns of urban life and historical memory. Jeffrey Jerome Cohen argues that stone possesses temporalities that exceed human lifespans, reminding us that geological materials are not passive objects but enduring participants in history.<sup>126</sup> The surviving ruins of Rome continue to shape tourism, archaeology and cultural identity, illustrating stone's ongoing agency. This reduces human arrogance as it acknowledges the need for a symbiotic relationship but also respects the roles that both sides play and therefore is, I believe the most relevant approach.

This thesis could have been focused on any region of the world, any civilisation, because plate tectonics, by its very nature, is global in its influence. Ancient Rome was an important choice because they, almost more than any other civilisation utilised the materials provided by plate tectonics to allow them to increase the size of their empire and their influence. Plate tectonics was crucial in aiding the expansion of their trade routes and therefore their economy; enabling military success across the mediterranean and western Europe; allowing the building of decorative masterpieces as well as harbours, aqueducts and baths; and influencing society through religion, both the gods worshipped and the siting of temples for worship.

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<sup>126</sup> Cohen, 2015, pp.1-24

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