Ref. Ares(2021)8019871 - 31/12/2021

H2020-MSCA-RISE-2019 – YADES

Grant Agreement

872931

MARIE SKŁODOWSKA-CURIE ACTIONS
RESEARCH AND INNOVATION STAFF EXCHANGE

Deliverable 7.1: "End Users Requirements"

Deliverable number:	7.1
Deliverable title:	End Users Requirements
Dissemination level:	Public
Author Institution:	National Technical University of Athens (NTUA)
Leading partner:	National Technical University of Athens (NTUA)
Participating partners:	NTUA, METBALTIC, RG, ERRA, GMCY, AUTh, CUT, RED SPA, POLIMI
Official submission date:	31/12/2021
Actual submission date:	31/12/2021

This work is a part of the YADES project. YADES has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no 872931. Content reflects only the authors' view and European Commission is not responsible for any use that may be made of the information it contains.

Modification Index	
Date	**Version**
06/12/2021	0.1
24/12/2021	0.2
30/12/2021	1

Table of Contents

Table of Figures

Table of tables

Nomenclatures

Lava: This the general term for erupted material of magma which extruded on to the earth surface

Lithospheric Plates: This is the solid and surface portion of the earth. It includes the crust and part of the upper mantle and is of the order of 100 km in thickness.

Ma: Millions of years before the present.

Mesozoic: This is an era of geologic time from about 225 to about 65 million years ago.

Plate tectonics: This is a theory in geology which explains that the lithosphere is divided into a number of rigid bodies (plates). These plates that interact with another at their boundaries, causing seismic and tectonic activity along these boundaries.

Seismic activity (Seismicity): The relative frequency and distribution of earthquakes in a region.

Tectonically complex zone: The structures (for example, bedding, faulting, folding) and features of the displayed geological units in a region which have resulted from forces or movements coming from different directions.

Ophiolite: The group of mafic and ultramafic igneous rocks. (Mafic: This is the composition of an igneous rock, which contains ferromagnesian and dark-coloured minerals. Ultramafic: This is the composition of an igneous rock, which has been composed chiefly by mafic minerals).

Cracking: probably due to weathering, flaws in the stone, several static problems, rusting dowels, too hard repointing mortar. Vibrations caused by earth tremors, fire, frost may also induce cracking. (ICOMOS, 2008)

Conflagration: an extensive fire which destroys a great deal of land or property.

Disintegration: detachment of single grains or aggregates of grains. (ICOMOS, 2008)

End-user: an end-user is defined as a person or group in a position to apply the information or tools being produced, evaluated or transferred through a project.

Erosion: loss of original surface, leading to smoothed shapes. (ICOMOS, 2008)

Stakeholder: is anyone who is affected by or has an interest or stake in an issue. Examples of stakeholders include members of national, regional, local agencies, governmental/state bodies, business leaders and industry representatives, representatives from non- profit groups or other citizen organizations. All end-users could also be considered stakeholders, but not all stakeholders are end-users.

Stiffness: The measure of the resistance offered by a construction to deformation. D7.1 – End User needs and practices report Dissemination Level: PU YADES GA #872931-6

Structural Capacity: Maximum loading that can be sustained without exceeding the allowable values for normal, extreme, or survival conditions and still maintain functional requirements.

Material degradation: deterioration of mechanical properties of the material when exposed to an environment resulting in the loss of that material.

Retrofitting and Structural rehabilitation: a process of reconstruction and renewal of a facility or its structural elements. This involves determining the origin of distress, removing damaged materials and causes of distress, as well as selecting and applying appropriate repair materials that extend a structure's life.

Eustatism: worldwide changes in sea level, caused by the melting of ice sheets, movements of the ocean floor, sedimentation, etc.

Exposure: the elements at risk (persons, buildings, infrastructure, goods, etc.) that, due to their location, are exposed to one or more perils (e.g. earthquakes, floods).
Fortification: a defensive wall or other reinforcement built to strengthen a place against attack.
Hazard: is anything associated with a peril that may affect the normal activities of people. This includes, for example, ground shaking for earthquakes or wind action for storms.
IOC/UNESCO: The Intergovernmental Oceanographic Commission of UNESCO (IOCUNESCO), established in 1960 as a body with functional autonomy within UNESCO, is the only competent organization for marine science within the UN system.
Landslide: a collapse of a mass of earth or rock from a mountain or cliff.
Thawing: the process of ice, snow, or another frozen substance becoming liquid or soft as a result of warming up.

Executive Summary

Deliverable D7.1 “End Users requirements” documents the work performed in Task 7.1 “End-users’ needs” during the first months of the project’s duration. This deliverable includes the description of specific Cultural Heritage buildings that are of great importance within those areas as well as buildings of great importance to the business continuity and financial sustainability of the areas. For each area of study, an overview of the infrastructure that will be modelled and monitored is provided, emphasizing details about building materials, already available infrastructure and hazards related with the geographical location of the cities as well as area specific topologies. In addition, current practices and mitigation measures are described in detail. Gaps in the process, areas of improvement and needs of the areas are also identified and presented. The deliverable is mainly intended for internal use, in particular by the partners involved in the specification of the system requirements, the use cases and the overall system architecture.

1 Introduction

The deliverable D7.1 “End User requirements” is one of the initial milestones of the Yades project. It is an important document as the current user needs and current practices followed to date are being reported. All the information gathered within the D7.1 deliverable document, will form a basis for the further YADES project implementation since its pre-requisite to collect all user needs as a reference point for the actions to be proposed and taken. The organization of the document is being described in “Document Organisation” section, in the following page.

This deliverable D7.1 “End User requirements” is focusing on the infrastructure stakeholders, the analysis of their current practices they follow and their expectations from the YADES project. Our scope is to collect the information needed from the sites and their respective regions, from a technical, financial and regulatory point of view so as to summarize the risks related to the historic sites and their assets, as well as the practices that they were following to date and proven to be successful for their goals. Moreover, we are analysing separate user-cases per CH site, while describing the potential interactions between the users and YADES and collect their anticipated results.

2 Description of the sites and the regions where they are located

In this Section a detailed description of the study areas is given. Each city describes in detail the specific area that is of interest, the Cultural Heritage (CH) buildings that are of importance to them, their availability for sensor installations as well as buildings that are of importance in regard to the Business Continuity. In detail, the monitoring levels are defined in three tiers:

- **Tier 1:** A CH building of high importance for the area where there are already existing monitoring sensors or a permission can be obtained for the installation of sensors by the project. For this building detailed modelling will be provided. Each city can propose one or more building as Tier 1 buildings.
- **Tier 2:** Here, there are two types of buildings that can be included. The one type is a CH building of high importance for the area where it is not possible to install sensors, either due to permission issues or material degradation. The other type includes buildings that are no-CH buildings but very important for the Business Continuity of the area such as fire houses, hospitals and airports.
- **Tier 3:** The overall area that will be modeled/studied within the scope of the project. Given that no-CH buildings are expected to be in some distance from historical areas, it is not mandatory for tier 2 buildings to be inside the Tier 3 area. Finally, a list with all the available infrastructure, both in local and national level, covering the study area is provided by each city. This list will be further defined and analysed by technical partners in order to identify external data sources that are of interest to the project objectives and should be incorporated to the overall system architecture

2.1 The city of Milano, Italy

Milan is the second most populous city in Italy after Rome, with a population of about 1.4 million, while its metropolitan area has 3.26 million inhabitants. It is the main economic and financial centre of the Italian Republic and led its industrial development. Especially during the years of the economic boom the city experienced an impressive industrial and urban growth that also involved neighbouring cities. This generated a large and continuously built-up urban area which stretches beyond the administrative boundaries and is considered the fourth largest in the EU with 5.27 million inhabitants. The uncontrolled urban growth and the densification pressure posed serious threats to the historical centre and Cultural heritage of the city, that only in recent decades started to be recognized and protected.

The city has a long and layered urban history, whose traces are still recognizable in the present urban fabric. The first urban structure dates back to classical period, when the Romans conquered the area, replacing the previous Celtic populations. With the lex Iulia of 48a.c the settlement became the municipality of Mediolanum and the urban structure was defined through a regular grid of *insulae* (blocks) oriented in accordance with the centuriation of the surrounding countryside. Since ancient times, the name *Mediolanum*, from which derives the current name of Milan, clearly identify the main feature of the city, i.e. the central and strategic location in the Po Valley, at the crossroads of trade routes and junction between the Italian peninsula and continental Europe. Since Roman times, a radial trend of urban development can be observed and the first waterway, the Vettabia canal, was made to connect the city to the Lambro river. These prefigured two key characters of Milan, namely the radial pattern and the complex network of waterways connecting the city to the territory.

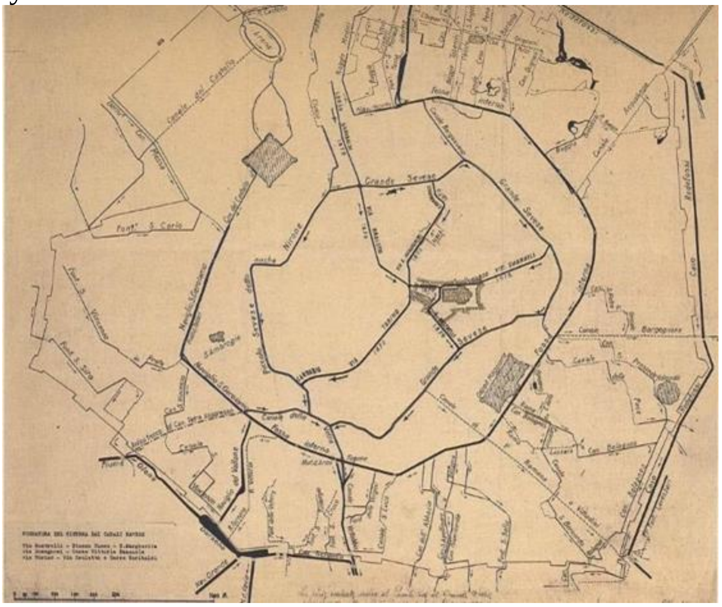


Figure 1: The hidrographic network of Milan in the XIX century

Figure 2: The Vettabbia canal in 1880

In the late antiquity, the radiality is accentuated thanks to the realization of a system of paleo-Christian basilicas placed in the periurban area that will influence the road structure and subsequent urban developments. Later in the Middle Ages, the city underwent a demographic contraction and was fortified with a city wall and a moat, while in the

surrounding area the relevant settlement of Cistercian communities from France profoundly transformed the agricultural setting of the area.
Milan then experienced a period of the lordships with the Visconti family in the 14th century and the Sforza family in the 15th century. Important architectural traces remain from this period, such as the Palazzo della Ragione, the Loggia degli Osii, the Sforza Castle and the Ospedale Maggiore. The construction of Milan cathedral and the creation of the Navigli circle, that is the transformation of the medieval moat into a navigable canal, also date back to this period. The hydrographic system of Milano was rapidly enriched in the 15th century, also thanks to the technical innovations of Leonardo da Vinci, who was hosted at the court of Ludovico il Moro.
The sixteenth century and the period of Spanish domination coincides with a new phase of urban expansion represented by the erection of a new wide city wall, demolished at the end of the nineteenth century.

Figure 3: Perspective plan of Milan of 1573 by Antonio Lafrery, reprinted by Peter von Brachel in 1575 in Cologne

Nowadays the trace of the medieval walls and of the Navigli circle has been replaced by a sequence of vehicular roads, quite intensely trafficked. While the trace of the Spanish walls corresponds today to another traffic lane with some linear green and to a densely built perimeter. The medieval city encloses an area of 2.6 km^2, while the wider perimeter of the Spanish walls defines an area of 7 km^2. Given the large size and complexity of the area, for the purpose of this project, a smaller sector was selected that goes from the Cathedral to the medieval perimeter (Via Senato). The most important Cultural Heritage building on the selected area is the Metropolitan Cathedral-Basilica of the Nativity of Saint Mary, better known as Duomo, that has been identified as main focus for instrumental monitoring (Figure 3- Tier1). In the surrounding area several other buildings of interest for cultural of functional reasons can be identified (Figure 7- Tier2)such as the buildings in Piazza della Scala (Palazzo Marini, Teatro alla Scala, Palazzo della Banca Commerciale Italiana, and Palazzo Beltrami), the XIX century gallery connecting this square to the Cathedral, several other historical palaces, such as the XVIII century Palazzo Anguissola Antona Traversi and the XIX century Palazzo Brentani Greppi (currently hosting the museum Gallerie d'Italia), the Poldi Pezzoli museum and the Manzoni theatre. The whole area of analysis however can represent the urban Cultural Heritage of Milano city centre, due to its characters of compactness, continuity and historical layering (Figure 4- Tier3).

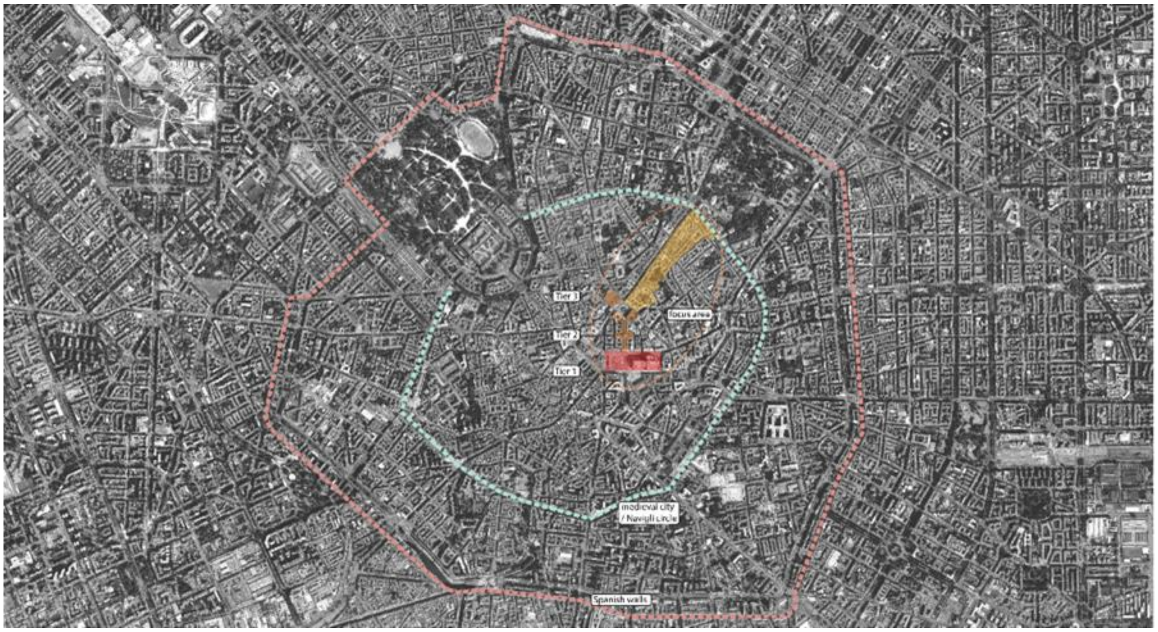


Figure 4: Milano historical centre: the traces of the medieval and Spanish walls are identified with dashed lines and the buildings/areas selected for this study are highlighted

Returning to the historical excursus, in the modern age the city of Milano experienced several disruptive historical events, such as the plague of 1630, and political changes, as the passage to the Austrian domination, then French with Napoleon, then again Austrian after the Congress of Vienna and finally the annexation to the Kingdom of Sardinia in 1859 and to Kingdom of Italy in 1861.
In the meantime, in the 18th century, the city underwent the transformations related to the industrialization process: the Milan-Monza railway line was built in 1840 (the second one in Italy), in 1864 the central station was inaugurated and in 1883 the first thermoelectric power plant in continental Europe was opened, right near the Cathedral (Figure *5*).


Figure 5: Historical view of the Cathedral and the chimney of the Santa Radegonda thermoelectric power station

In the second half of the 19th century, the area around the Cathedral underwent profound changes: in 1875 the Rebecchino block was demolished to make room for the current Piazza del Duomo, the works on the Cathedral factory continued uninterruptedly until it reached its current configuration and the neo-Gothic facade was added in 1888, between 1865 and 1877 the Vittorio Emanuele II shopping gallery designed by Mengoni was built, connecting the new Piazza del Duomo with Pizza della Scala, created in 1858 through the demolition of various buildings.


Figure 6: Duomo square in 1870, before the demolition of the urban block of Rebecchino(left) and Duomo square nowadays (right).

In Piazza della Scala in 1861 (the year of the unification of Italy) the municipal administration is installed in the 16th century Palazzo Marino, which is equipped with a new facade designed by Beltrami. The same architect also designed the Palazzo della Banca Commerciale Italiana, which closes the square to the north, and Palazzo Beltrami, on the south side. The system of the two squares, Duomo and Scala, thus creates a new important social and cultural polarity in the city.


Figure 7: Aerial view of Piazza della Scala(left) and Palazzo Marino (right).

Figure 8: Palazzo della Banca Commerciale italiana(left) and Teatro alla Scala (right)

At the end of the 19th century, the first urban development plan by Cesare Berruto (1884) was drafted. It decreed the demolition of the Spanish walls and the management of the space thus regained with a program that was very much in favor of public green spaces, which, however, was disregarded during its approval and implementation. Numerous new plans were approved at the beginning of the 20th century to govern rapid urban growth. In 1929 the network waterways of Navigli was covered in order to address the problem of water contamination and to facilitate vehicular traffic.

Figure 9: Naviglio canal in Via Senato before (1870), during (1920's) and after (2020) the covering.

In the 20th century (and even the 21st) Milano established itself as a dynamic, innovative and avant-garde city. In the historical centre transformations slowed down in parallel with the progressive recognition and protection of the architectural and urban heritage that had been consolidated in the previous centuries. However, the bombings of the Second World War did not spare the area and reopened spaces for intervention.

Figure 10: Map of the bombing damages after the Second World War (left) and damages to the sculptures and statues on the roof of Cathedral after the Second World War (right).

1. Milan Cathedral

The Milan Cathedral was erected between 1386 and 1813. It is the most representative landmark of the city of Milan and one of the largest masonry monuments ever built. The church exhibits a unique style of architecture, which is characterized by a fusion of European Gothic style and Lombardy tradition, with the presence of neo-classic, neo-gothic and even renaissance influences due to the long period required by the construction works. The current archiecture is the result of a long construction process and many additions throughout the centuries (Figure 11).

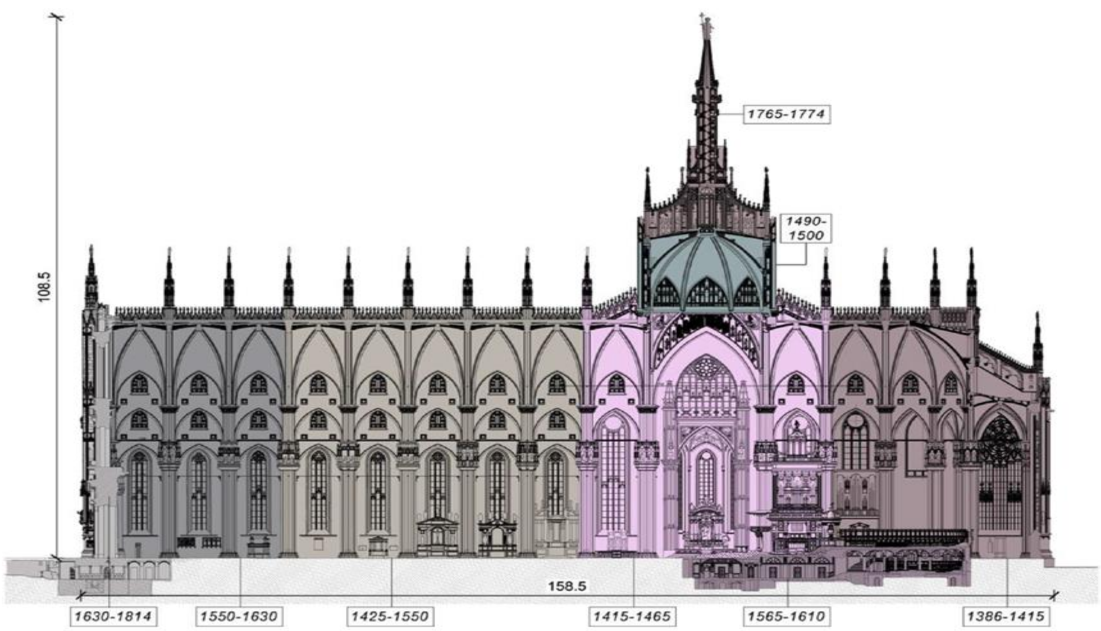


Figure 11: Longitudinal section of the Milan Cathedral (dimensions in m) and chronology of the main construction phases (source: Veneranda Fabbrica del Duomo di Milano).

The Milan Cathedral is characterized by a cross-shaped plan. The longitudinal limb (E-W) exhibits a central nave and two couples of side aisles and ends into an apse. The transept is about 49 m long and 86 m wide. The crossing between main nave and transept is capped with a main dome, supporting the Main Spire and surrounded by an octagonal tiburio. The overall dimensions of the Latin cross-shaped plan are about 66 m x 158 m, with the central nave and the side aisles spanning 18.2 m and 9.6 m, respectively. The building spreads over an area of more than 10400 m^2, with a volume of about 300000 m^3, being the second largest Gothic cathedral in the world by volume and area.

The load-bearing structure is made up of pillars and perimeter walls reinforced by buttresses. This characteristic differentiates the Milan Cathedral from transalpine cathedrals, limiting the opening of the large windows. The buttresses have a triangular shape and serve to contain the lateral thrusts of the arches. The basement is made of masonry, as are the internal parts of the walls and other elements, while a serizzo stone core was used in the pillars; the vault sails are also made of brick. The exposed facing, which also has a load-bearing role, not just a covering, is instead in pinkish white Candoglia marble with grey veins: the quarry, from the time of Gian Galeazzo Visconti, is still owned by the Fabbrica del Duomo. The perimeter load-bearing walls are built in dry masonry of varying thickness, with coatings in pink-veined white marble from the Candoglia quarries. The same material is also used for all the spires and the statues. The structural arrangement of the main limb includes the presence of double masonry vaults and of permanent metallic tierods placed under each arch.

The vaults exhibit decreasing heights according to a specific proportion worked out by mathematician Gabriele Stornaloco in late 14th century. Moreover, the adoption of iron tierods is unique in Gothic cathedrals, where wooden or metallic ties were used as provisional elements and removed at the end of the construction: on the contrary, the tension bars of the Milan Cathedral were designed to reduce the horizontal thrust on the slender lateral buttresses and are still active in resisting the thrusts.

The terraced roof (also in marble) is unique in Gothic architecture, and is supported by a double crossed order of minor vaults. A 'forest' of pinnacles rises up at the pillars, connected by rampant arches. The pinnacles in this case do not have a structural function, in fact almost all of them date from the first half of the 19th century. The last gate of the church was inaugurated on January 6th, 1965 and this is usually considered to be the end of monument construction.

Figure 12: The roof of Milan Cathedral

2.1.1 Current equipment/infrastructure available

The study area presents different scales of analysis to be considered, from the architectural-monumental scale of the Milan Cathedral to the urban scale for the portion of urban fabric under examination. The available data and sources are therefore different.

2.1.1.1 Monitoring The Cathedral of Milan

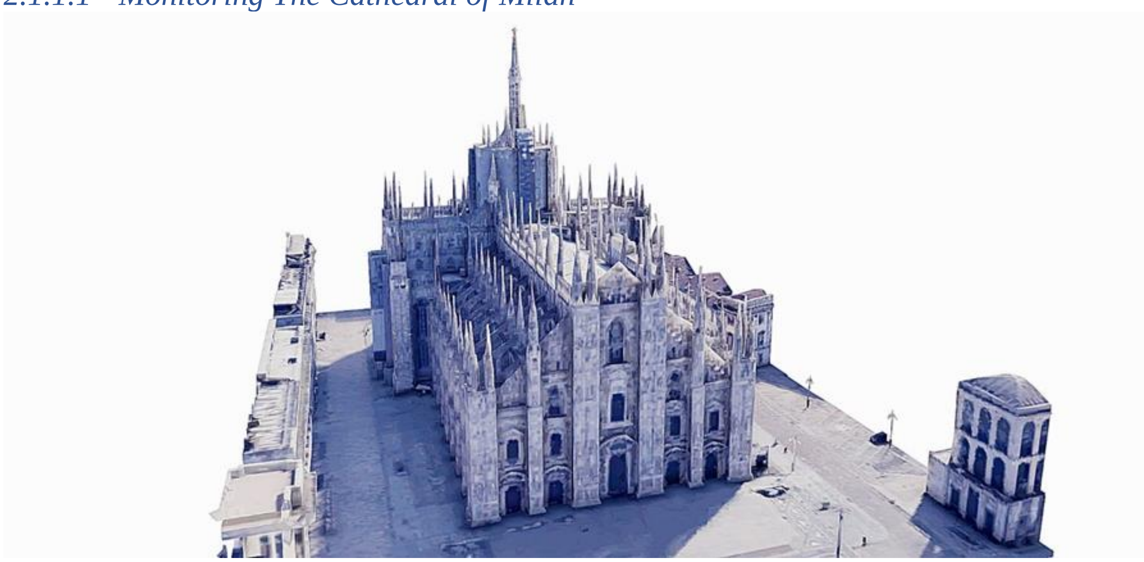


Figure 13: Cathedral of the Milano

Since it is the city's main church and cultural symbol, the Cathedral has long been the object of careful comprehensive monitoring, which has concerned and still concerns both environmental conditions and structural behaviour. Politecnico di Milano has long been involved in these study and monitoring activities and has also contributed to the design of innovative restoration and structural reinforcement solutions.

The cathedral is administered by the Veneranda Fabbrica del Duomo di Milano, the historic body responsible for its conservation and enhancement. Established in 1387 by Gian Galeazzo Visconti, it has been working for over 630 years to protect and enhance the Cathedral.

The perimetinternal area is currently equipped with a video surveillance system, which is able to record continuously from 00:00 to 12:00 midnight every day of the week, throughout the entire year. The system was authorized by the Territorial Directorate of Labor of Milan with Provisional Protocol No. 6040861, dated February 23, 2017. In all areas under surveillance by the system, there are brief notice placards, as suggested by the authority, regarding the protection of personal data. The Objective and purpose of the processing of personal data carried out through the use of the are related with reasons of public safety and protection of heritage, particularly for the purposes of: i) protecting the religious, historic, artistic, cultural and civic heritage of Milan Cathedral; ii)

ensuring the safety of the faithful, visitors and, in general, the community inside and outside the Milan Cathedral; iii) minimizing the risk of any criminal activity; iv) facilitating the work of the police and armed forces for the protection of

public order; v) facilitating the exercise, in civil and criminal proceedings, of the right to defense through the use of images in cases involving illegal activities; vi) possibly obtaining evidence; vii) protecting employees as well as all guests and visitors to the Milan Cathedral; and viii) allowing early intervention in the activation of the fire-alarm system.

The traditional collaboration between Politecnico di Milano and Veneranda Fabbrica del Duomo di Milano produced throughout recent years several activities of continuous monitoring and some focused study due to specific issues.

The main activities and results are listed below:

Analysis of the state of the art of Milan Cathedral and planning of ordinary and extraordinary maintenance interventions related to the monumental works and technical infrastructures, such as energy and lighting; technical-scientific support concerning the survey, knowledge, preservation and monitoring of the structures and surfaces of the Cathedral and the works connected to it in order to optimize ordinary and extraordinary maintenance interventions; research and experimentation of new materials, technologies, solutions and whatever is necessary for an ever-improved safeguarding of the materials that make up the Cathedral, in order to improve the effectiveness and durability of ordinary and extraordinary conservation and maintenance work. The study is performed through a collaboration with Joint Research Centre (JRC)[1].

[1] https://www.polimi.it/it/ricerca-scientifica/la-ricerca-al-politecnico/joint-research-centres-jrc/index.html

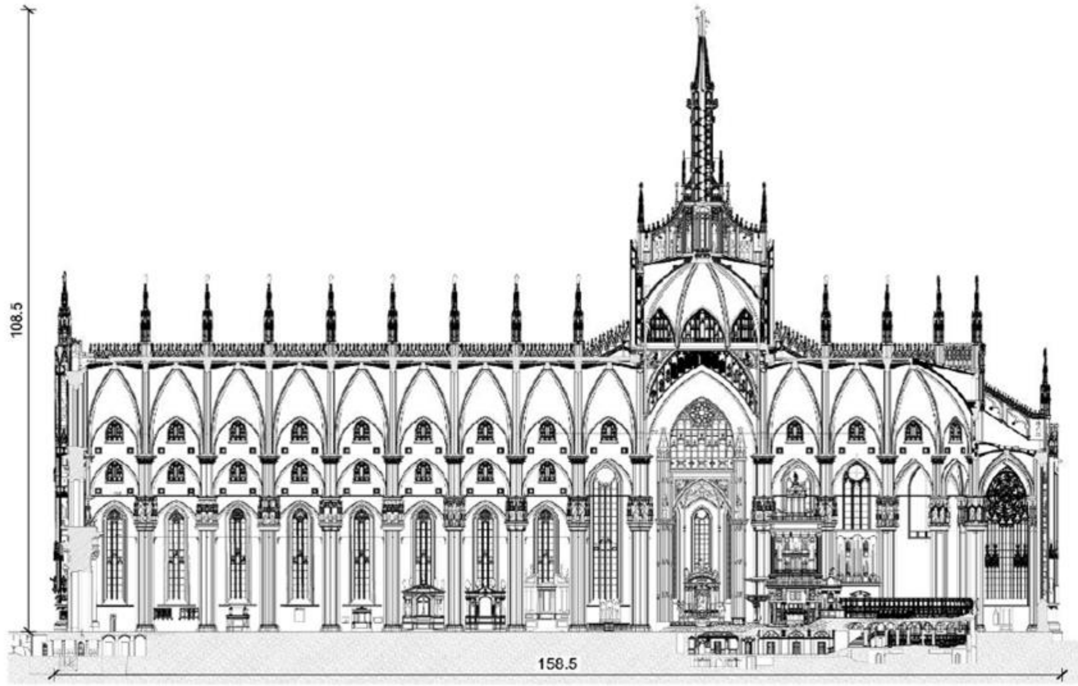


Figure 14: Longitudinal section of the Milan Cathedral (dimensions in m).

Since 2008, an intense survey activity has been underway in the Milan Cathedral. In the first years, the main techniques have been laser scanner and photogrammetry choosing or integrating the different methodologies according to the needs, concurrently with the evolution of the method and the software. The main focus of conservation activities are the marble blocks and surfaces of the Cathedral. Several activities took place to identify the areas that are in need of intervention and to identify which blocks will be affected by replacement operations, tessellation, or consolidation. The objective of the survey activities and the subsequent modeling phase was to build a detailed 3D model in which the marble blocks are easily recognizable in terms of their shape, size, position, and texture (only for the outer part). All the elaborations produced, the 3D models, the two-dimensional representations, and the orthophotos, allow for the identification of the blocks, as to provide proper technical support for site operations. In parallel with the survey and modeling activities, an ad hoc online information system was created to support the construction site activities in a smart manner. The system allows for the consultation and the sharing of the 3D models and all the data necessary for maintenance operations of the entire Cathedral.

In 2008, a survey campaignwas launched in 2008 focused on the “Guglia Maggiore”, in preparation for the later extraordinary restoration of the following years. The adopted techniques were photogrammetric survey, which was initially limited by the size of the object itself, and the experimentation of the emerging semi-automatic image-based techniques in the following years.

Many tests were conducted both with unconventional range-based (Zeb1, DOT DPI 8,Heron backpack) and image-based methods (fisheye photogrammetry, camera rigs, and panoramic cameras). The final 3D point cloud format model of the Cathedral derives from the contribution of different survey systems.

In 2018: inventory of the sensing devices installed in the Cathedral in the previuous years and remotion of all the outdated or out of order sensors were. Only the system based on geometric leveling, established to measure the horizontal deflection of the piers, turned out to be fully operating and was kept in function. Although this system is not computer based, it has been active in measuring the piers deformationat pre-selected intervals (May and November) since more than 50 years. Once identified the key parameters to monitor for assessing the structural health of the Cathedral and addressing its condition-based structural maintenance, the installation of two new long-term monitoring systems was carried out, one static and the other dynamic. (Gentile et al, 2019)
In 2019, the survey of the whole interior Cathedral was almost completed, so it is possible to explore the 3D model of the Cathedral in a point cloud format. The final size of the point cloud does not allow for management through a single file; the data was segmented following the logic of the site areas of the Veneranda Fabbrica (inferior nave, middle nave, central nave, apse, and choir). This allows to efficiently use the data during the restitution phase. The survey of the external facades, of the roofs and the falconature, has been realized only through photogrammetry. The main goal was to produce high-resolution orthophotos of the facades with a restitution scale equal to 1:50; while the sectors of the roof, delimited by arches and falconature, were elaborated at a 1:20 scale. The complete 3D dense point cloud model of the Cathedral is in the end a raw model that can be used for visualization, measurement operations, features extraction or as a base for orthophoto generation. (Achille et al., 2020)

2.1.1.2 Monitoring The Urban Area

With regard to the urban scale of the portion of the historical fabric under consideration, there are different data available from different sources.
Environmental monitoring and air quality data - stable data acquisition: at a regional level, the body responsible for environmental monitoring is ARPA Lombardia[2] (), which has several fixed monitoring stations distributed throughout the Milanese territory. In the proximity of the study area there is the MILANO-SENATO station, which measures 24/7 at regular time intervals the levels of Benzene, CO, NO2, PM10 and PM2.5. Data are continuously updated and freely downloadable.

[2] https://www.arpalombardia.it/Pages/ARPA_Home_Page.aspx

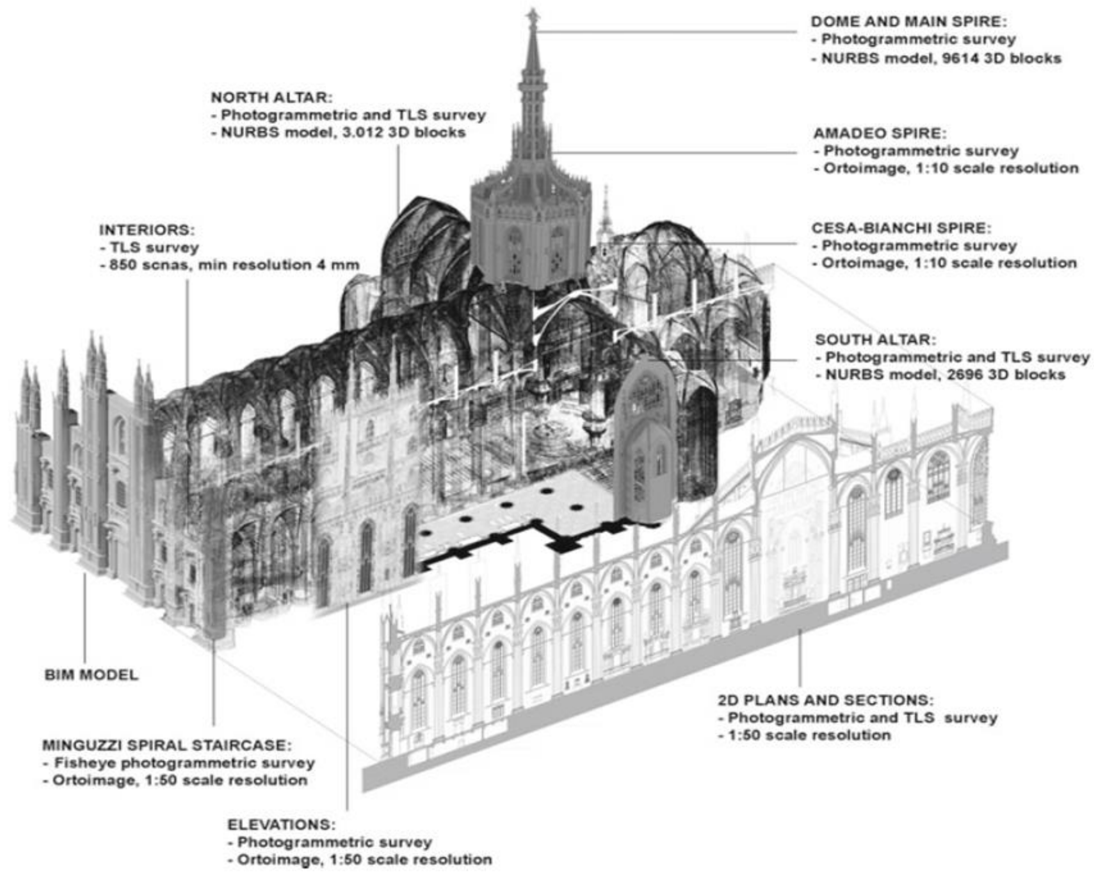


Figure 15: The point clouds produced bit by bit are generating the complete 3D dense point cloud model of Milan Cathedral.

Environmental monitoring and air quality data - mobile data acquisition: a mobile instrumental campaign has also been peformed in autumn 2021, in several inner courtyards of the area. The measured parametres are T(°C), RH(%), PM2.5(μg /m³), PM10(μg /m³), particles, HCHO(mg /m³), TVOC(mg /m³) and an overall Air Quality Index is estimated. Data related with existing Green Infrastructure and architecturale features of the Cultural Heritage (oil materials, facades materials, heights of the buidings, etc.) have also been registered in a database.

2.1 The archaeological area of Pafos, Cyprus

Paphos, situated in the District of Paphos in western Cyprus, is a serial archaeological property consisting of three components at two sites: the town of Kato Paphos (Site I), and the village of Kouklia (Site II). Kato Paphos includes the remains of ancient Nea Paphos (Aphrodite's Sacred City) and of the Kato Paphos necropolis known as Tafoi ton Vasileon ("Tombs of the Kings"), further to the north.

The village of Kouklia includes the remains of the Temple of Aphrodite (Aphrodite's Sanctuary) and Palaepaphos (Old Paphos). Because of their great antiquity, and because they are closely and directly related to the cult and legend of Aphrodite (Venus), who under the influence of Homeric poetry became the ideal of beauty and love, inspiring writers, poets, and artists throughout human history, these two sites can indeed be considered to be of outstanding universal value.

Paphos, which has been inhabited since the Neolithic period, was a centre of the cult of Aphrodite and of pre-Hellenic fertility deities. Aphrodite's legendary birthplace was on the island of Cyprus, where her temple was erected by the Myceneans in the 12th century BC and continued to be used until the Roman period. The site is a vast archaeological area, with remains of villas, palaces, theatres, fortresses and tombs. These illustrate Paphos' exceptional architectural and historic value and contribute extensively to our understanding of ancient architecture, ways of life, and thinking. The villas are richly adorned with mosaic floors that are among the most beautiful in the world. These mosaics constitute an illuminated album of ancient Greek mythology, with representations of Greek gods, goddesses and heroes, as well as activities of everyday life.

Cyprus was a place of worship of pre-Hellenic fertility deities since the Neolithic period (6th millennium BC). Many of the archaeological remains are of great antiquity; the Temple of Aphrodite itself dates from the 12th century BC, and bears witness to one of the oldest Mycenaean settlements. The mosaics of Nea Paphos are extremely rare and are considered amongst the finest specimens in the world; they cover the Hellenistic period to the Byzantine period. One of the keys to our knowledge of ancient architecture, the architectural remains of the villas, palaces, fortresses, and rock-hewn peristyle tombs of Paphos are of exceptional historical value. The religious and cultural importance of the cult of Venus, a local fertility goddess of Paphos that became widely recognized and celebrated as a symbol of love and beauty, contributes to the Outstanding Universal Value of this property[3].

The archaeological area of Pafos (UNESCO World Heritage Site), which is located in Kato Pafos, includes monuments that date back to prehistoric times, the Middle Ages, and the Roman period. At the heart of this archaeological park is the site's most prized possession. Considered among the finest in the eastern Mediterranean, the intricate floor mosaics are feted for their excellent preservation and vibrant colours, depicting various scenes from Greek mythology.

1. **The Odeon**

[3] Statement of Outstanding Universal Value (SOUV) http://whc.unesco.org/en/list/79/

One of the most prominent attractions at the Pafos Archaeological Park is the Ancient Odeon. Built around the 2nd Century AD into the side of the Fabrica Hill, this beautiful amphitheatre is comprised of carved limestone, and is believed to have been altered by the Romans and used until the 5th Century AD. Today, the extensively restored Odeon is the site for open-air musical and theatrical performances in the summer.

Figure 16: Panoramic view of Odeon

The Odeion of Nea Paphos is located in the eastern side of the hill, on top of which Paphos' lighthouse is situated about, 250m away from the northern side of the House of Dionysos. This is a small theatre building, dated to the beginning of the 2nd century A.D. It was used exclusively for musical events. This exceptional, unique building with its large crude stones and dressing of limestone blocks, consists of the auditorium, preserved till the first section with an external diameter of 47.3m. The semi-circular orchestra with a diameter of 11.3m, of the scena (stage), wherefrom the audience entered. The lower part of the auditorium is separated into seven rows of bleachers and six flights of stairs. From all the rows of bleachers, 13 are still preserved. Their dressing with limestone slabs had been removed in the past. The Odeion had been destroyed by the middle of the 4th century A.D. earthquakes; by that time till the Arabic raids it was used as a metallurgical workshop. After its discovery it had been partially restored by the Department of Antiquities, under the direction of Greek architect I. Travlos.

Figure 17: Odeon view from Google maps

2. The Agora

Figure 18: A photo of the Agora

The Agora, or forum, was the central square court of the city, surrounded by four porticoes of granite columns with white marble Corinthian capitals. The Odeon and the Asklepieion form part of the complex.

The city's - Roman Forum has been discovered directly in front of the Odeion. It is a large square colonnaded courtyard with dimensions of 95 x 95m, from which only the foundations and in some parts the stylobates are preserved. The missing columns of its porticoes (stoae) were smooth and made of gray granite, supporting Corinthian capitals. The Agora was built after the Odeion, around the middle of the 2nd century A.D. and crumbled into ruins as a result of the earthquakes in 332 and 342 A.D.

Figure 19: The Agora view from Google maps

3. The Asklepieion

The building in the southern side of the Odeion also falls in the same period as the Agora of the city. This has been identified with Asklepeion, the Sanctuary of Asklepius, god of medicine, used also as an infirmary. This was a large building complex with three unified spaces, which communicated directly with the adjacent buildings of the Odeion and Agora. The first space consisted of two rectangular rooms, built on both sides of a large corridor, the second one of an apsidal room, framed by two other square rooms which led to a subterranean room, while the third one of another rectangular room with the entrance in its southern side, communicating with a square roofed court with two large rooms on both sides right and left. The Odeion and Argora of Nea Paphos, as well as the Asklepeion of the city were all completely destroyed by earthquakes in the middle of the 4th century A.D.

Figure 20: A photo of Asklepieion

4. Saranta Kolones

The castle known as Saranta Kolones (Forty Columns) is located near the Pafos port, south of the Agora. Built around the 7th Century AD, this historic landmark features a collection of granite columns that once served to protect the port and the city of Nea Pafos from potential Arab raids. The site remained in use until 1223 after an earthquake destroyed it.

The castle was erected around 1200 A.D, after the Frankish conquest of Cyprus, on the site of an earlier Byzantine fort. It was destroyed by the earthquake of 1223 and never rebuilt. The building was a compact fortress surrounded by a massive external continuous wall with eight towers and a moat. The outer entrance of the castle was situated in the east square tower and was approached by a wooden bridge over the ditch. The interior of the castle consisted of a square yard with four towers.

Figure 21: Photos of Saranta Kolones Castle

The Byzantine Fortress is located on a small elevation a short distance from the city's harbour and very close to the Odeion and the "House of Dionysos" at the site "Saranta Colones. The site's name is owed to the numerous fragments of granite columns, which covered the archaeological site before it began to be excavated and which were initially thought of as ruins from the Aphrodite's Sanctuary at Nea Paphos. The area has been partially researched between 1957 and 1959 by the then director of Antiquities A.H.S Megaw. Under the same direction the excavations have been gradually repeated from 1966 till 1970 and from 1980 till 1985 by the cooperative Expedition of the British School of Athens and the American Dumbarton Oaks Byzantine Studies Centre.
According to the results of the excavations the Fortress was built in the 7th century A.D, evidently in order to protect the Nea Paphos harbour and the city from the Arab raids. The entire construction is surrounded by a massive quadrilateral wall, 70 x 70m and 3m thick, as well as by a trench. At this wall there were eight towers of various shape, among them a pentagonal in the north-eastern corner. The fortress's entrance was at the eastern square tower and was approachable by three parallel arches. In the same wall there were seven flights of stairs leading to an equal number of exits to the trench. The inner part of the fortress consisted of an open square courtyard 35x35m with one tower in each corner. At the courtyard's four sides there was an equal number of massive piers-bearing arches supporting the walls of the second storey. Several flights of stairs led to the storey; only a very few of them have been preserved. At the courtyard's eastern side there was also a fifth, horse-shoe shaped tower with a door, serving as the main entrance.
During the long period of the disarmament, agreed upon between the Byzantines and the Arabs the fortress was abandoned, but was remodified around the end of the 10th century,

when Cyprus has already come under the absolute control of the Byzantines, and in the end of the 12th century to the Lusignan dynasty. It was finally destroyed by the earthquake of 1223 and has never been rebuilt.

5. The Lighthouse

Situated on the peninsula known as Paphos Point, and rising 36 metres above sea level, the Pafos lighthouse is an impressive, albeit relatively modern construction built in 1888 when Cyprus was under British rule. Acting as a marker for ships heading towards Pafos harbour from the United Kingdom, its light is visible for 17 nautical miles, beaming every fifteen seconds.

Figure 22: A photo of the Lighthouse

6. The Walls

The ancient city of Nea Pafos featured extensive fortifications that once surrounded the city, protecting it against possible attack. Though the precise date of the walls remains unknown, archaeologists assume the fortifications date back to the Roman period. Certain parts have always been visible, whereas others have been uncovered over time through archaeological excavations. Sections of the natural rock feature carvings used as foundation trenches.

Figure 23: Photos of the Walls

Although the upper levels of the wall are in ruins, the exact course of the fortifications is visible at certain parts of the city, largely due to the natural rock carvings. Preserved sections of the walls are in the north and north western sides of the city. Further sections of the walls are evident on the eastern side of the city, comprising the foundations of a rectangular tower. It appears that the walls had three gates with the most preserved located on the north western side. The gate featured a tower on both sides with a bridge, carved out of natural rock, leading to the external side of the fortification.

7. Toumpallos

Initially identified as a Ptolemaic army camp, and later believed to have functioned as a temple to the god Apollo, Toumpallos is a splendid underground complex carved into the natural rock. This superb site features halls and corridors and is currently undergoing systematic excavations by the Italian Archaeological Mission from the University of Catania.

The Ministry of Communications and Works, Department of Antiquities, recently announced the completion of the 21st season of excavations at Kato Paphos-Toumpallos, the area of the so-called "Garrison's Camp"[4].

"Toumballos" is situated very near the north gate of the city wall, just opposite the subterranean rooms of the probable Hellenistic Sanctuary of the town. It has been discovered by the on-going excavations of the Italian University at Katania, that began in 1987 under the direction of Ph. Giudice. It is a small church of the 4th century A.D., consisting of the nave, the narthex, a double apse and a space between the two apses, leading to a possible crypt, which is dated from the 7th to the 10th century A.D., and is believed that it constitutes the martydom of St Hilarion.

[4] https://mstirontravel.blogspot.com/2020/03/cyprus-excavations-at-kato-paphos.html

Figure 24: Toumpallos view from Google maps

The subterranean rock-cut complex of the Apollo probable Sanctuary and military encampment Garrison's Camp
A large subterranean corridor with domed roof and open western side is found at "Toumballos", near the northermost end of the residential area of the city and very close to the northern cate of the defensive wall. It contains successive rock-cut chambers along the length of the eastern and northern walls. A rock-cut stepped dromos behind the northern side chambers leads to a lower subterranean space with similar chambers. Along the exposed western wall of the corridor remains of small rooms can be seen. The entire building comples falls within the end of the 4th century B.C, and possibly constituted a combination of a sanctuary with temporary military encampment.

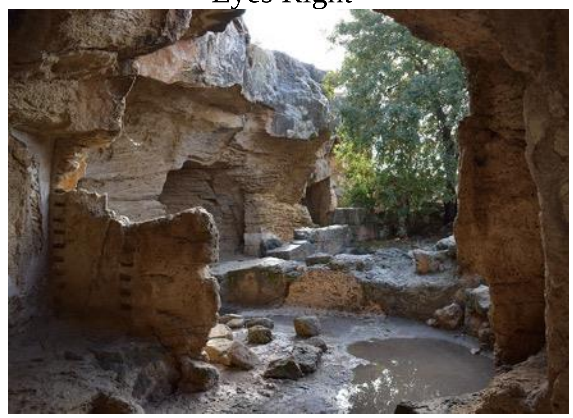
Table 1: Table of photos from Toumpallos camp

	
The Basilica	The Entrance

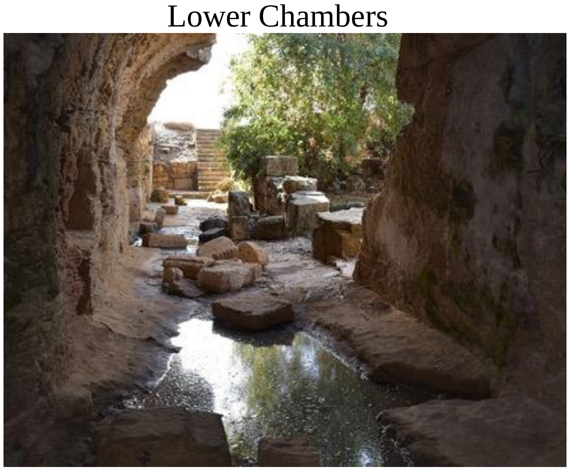
Eyes Left

Eyes Right

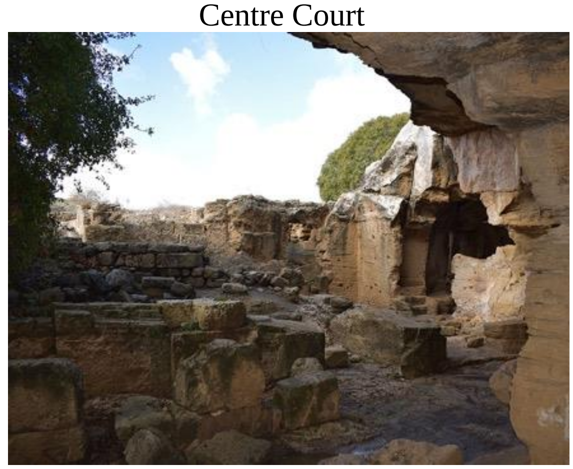
Lower Chambers



Centre Court



Inner Cave



More Chambers

Linked Chambers

Toumpallos Heights

8. Pafos Mosaics

Figure 25: Pafos mosaics position from Google maps

The chance discovery of fragments of mosaic floors led to a systematic excavation that brought light to a remarkable residence dating back to the Roman period. Originally thought to be the palace of a Roman proconsul, it later became clear that the elaborate and ornate décor characterised that of a wealthy residence from the same period. Painstakingly crafted from limestone, these incredibly preserved mosaics belong to the last buildings that we erected in the area, over the ruins of older ones.

9. The House of Dionysos

Occupying an area of 2,000 square metres, of which 556 are covered with mosaics, the site is named after the Greek god of wine, Dionysos, who is depicted throughout the intricate flooring. Built in the 2nd Century AD, it was later destroyed by an earthquake in the 4th Century. The original size of the residence comprised of 40 rooms, including 15 mosaic floors that are testament to the inhabitants' high standards of living during the Roman period.

Figure 26: Photo of a mosaic in House of Dionysos

10. **The House of Theseus**

The largest building of all known public buildings from the Roman period in Cyprus, The House of Theseus is a 2nd Century villa with a preserved mosaic depicting the scene of Theseus fighting the Minotaur from Greek mythology. The building itself features over 100 rooms, organised in four wings around a colonnaded open courtyard. Residential, domestic, working, and communal areas are in the eastern, western, and northern sections of the house, whereas the ritual areas are sited in the southern wing. This historical landmark also features ruins of baths that were unearthed in the south-eastern part of the building.

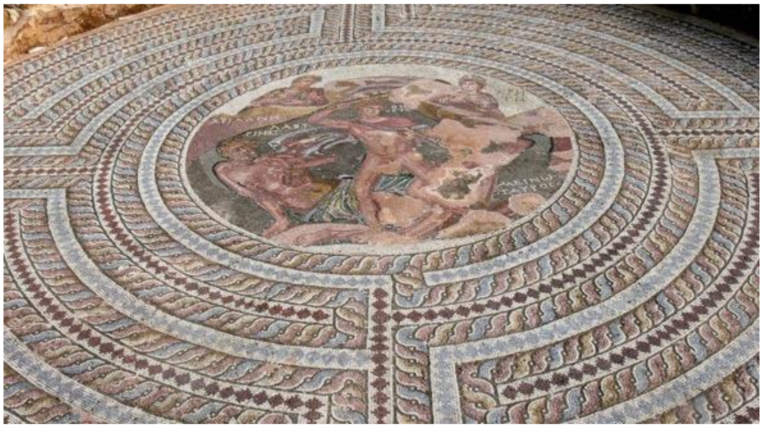


Figure 27: Photo of a mosaic in House of Theseus

11. **The House of Aion**

Dating back to the 4th Century AD, the figural mosaics located in The House of Aion depict five different mythological scenes such as Leda and the Swan, the Epiphany of Dionysos, the beauty contest between Cassiopeia and the Nereids, the punishment of Marsyas, and in the centre of the composition, the depiction of the god Aion – the personification of time – whose name was given to the house.

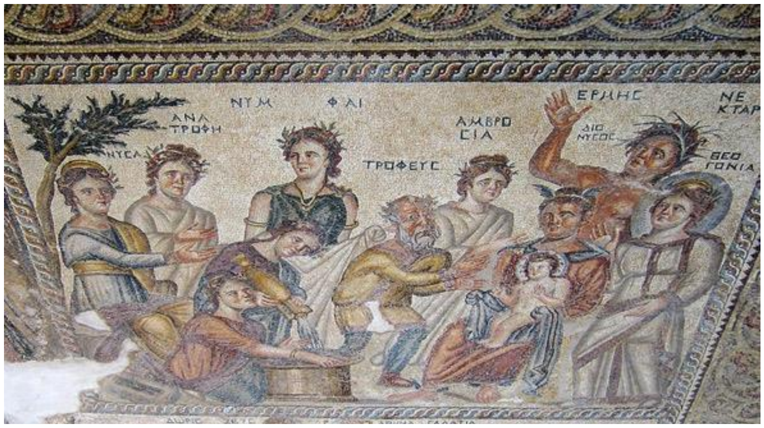


Figure 28: Photo of a mosaic in House of Aion

12. The House of Orpheus

Typical of a wealthy Greco-Roman House from the 3rd Century AD, The House of Orpheus features a central court with its reception hall decorated with a mosaic floor depicting Orpheus and his Lyre among the beasts. Other mosaics include Hercules and the Lion of Nemea and the Amazon.

Figure 29: Photo of a mosaic in House of Orpheus

13. Medieval Castle of Pafos

Located at the west end of the town’s harbour, the Pafos Castle is one of Cyprus’ most iconic landmarks. Originally a Byzantine fort built to protect the harbour, the castle was rebuilt by the Lusignans in the 13th Century and was later dismantled in 1570 by the Venetians. The Ottomans rebuilt it in the 16th Century when they conquered the island. Today, the castle reflects the Ottoman restoration of the western Frankish tower with its Venetian additions.

The castle, built by the Frankish rulers of Cyprus in the 13th century, replaced the Byzantine fort of "Saranda Colones", which was destroyed by an earthquake. In fact, the Frankish Lusignans had built two towers, which later in the 14th century went through changes by the Genoese rulers, while the Venetian rulers later, in the 16th century, destroyed what was left of the towers after another earthquake, so that the Ottomans would not use them. The Ottomans restored the castle in 1780, which is what one can see today.
As well as being a fort for protection, it was also used as a prison and for other military purposes. In more recent times, under British colonisation, the castle was even used as a storehouse for salt.

Figure 30: A photo of the Medieval Castle of Pafos

Throughout its long-standing history, the Pafos Castle was used as a prison, and even as a storage area for salt when Cyprus was a British colony. In 1935, it was declared an ancient monument and has now become a major tourist attraction. The landmark site also serves as the official venue and backdrop to the annual, world-renowned Pafos Aphrodite Festival, an artistic operatic event that takes place in September, attracting an audience of thousands from across the globe.

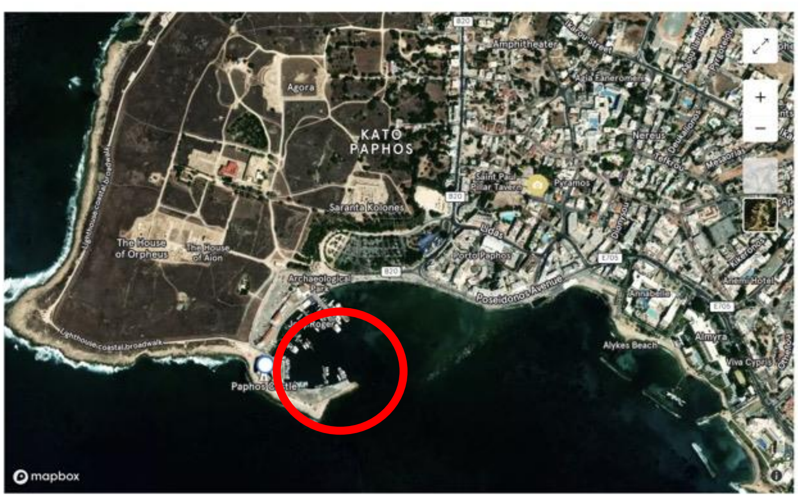


Figure 31: The Medieval Castle of Pafos position from Google maps

14. The Hellenistic –Roman Theatre of Pafos

Built by the Ptolemies of Alexandria c. 300 BC on the slope of a hill of the ancient wall city, the site of the remarkable theatre of Nea Pafos is in the modern town of Kato Pafos. Having survived until the late 4th Century AD, the building represented the evolution of the performing arts during the Greek and Roman periods.

Figure 32: A photo of the Hellenistic –Roman Theatre of Pafos

The theatre reveals five major phases of building and renovation during its history, and the responses to earthquake damage.

The site of the ancient theatre of Nea Paphos is located in the modern town of Kato Paphos. The theatre was built by the Ptolemies of Alexandria around 300 BC, on the southern slope of a hill, on the north-east of the ancient walled city. It survived until the late 4th century AD. It is possible to identify at least five (I, II, III, IV, V) major phases of building and renovation during the theatre's history, representing the changing nature of performances during Greek and Roman periods and the responses to earthquake damages. At its peak, under the Roman Antonine emperors, in the mid-second century AD, the stage building was façaded in marble. The theatre measured m 90 from side to side and had a cavea with seating capacity for over 8000 spectators and angle of rise of 26.5 degrees. By the end of the third century AD, probably after the devastating earthquake of 365 AD, the theatre was abandoned and much of the stonework was robbed and reused elsewhere in the town. After a period of abandonment, the site of the ancient theatre sees renewed activity in the 12th and 13th centuries AD, when the harbour of Paphos became once again a major economic point of activity, this time for the Crusaders on their way to the Holy Land.

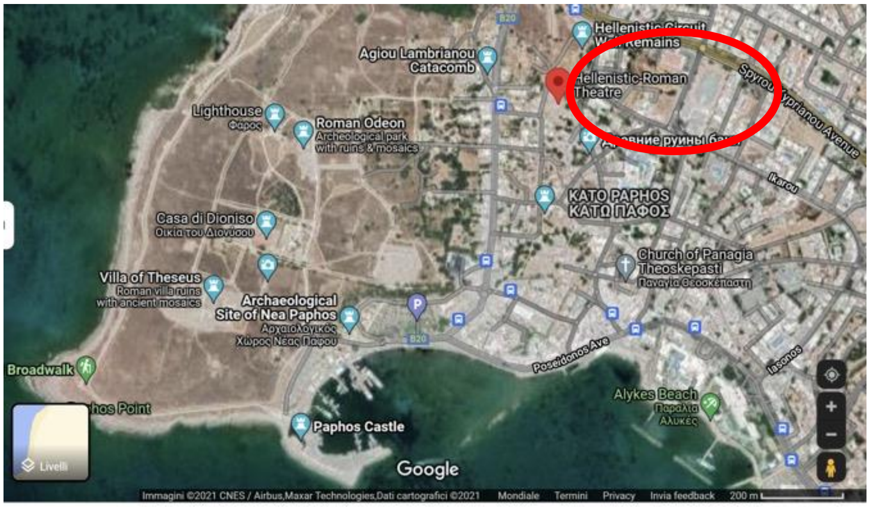


Figure 33: The Hellenistic –Roman Theatre of Pafos position from Google maps

15. Tombs of the Kings

Located approximately two kilometres north of Kato Pafos' picturesque harbour, Tombs of the Kings is a vast necropolis of unique, well-preserved underground tombs and chambers. Dating back to the 4th Century, the impressive UNESCO World Heritage Site from the Hellenistic and Roman periods features a desert-like landscape with tombs carved out of solid rock, including an impressive atrium below ground level, surrounded by columns. High officials rather than royalty were buried here; the magnificence of the tombs gave the locality its name.

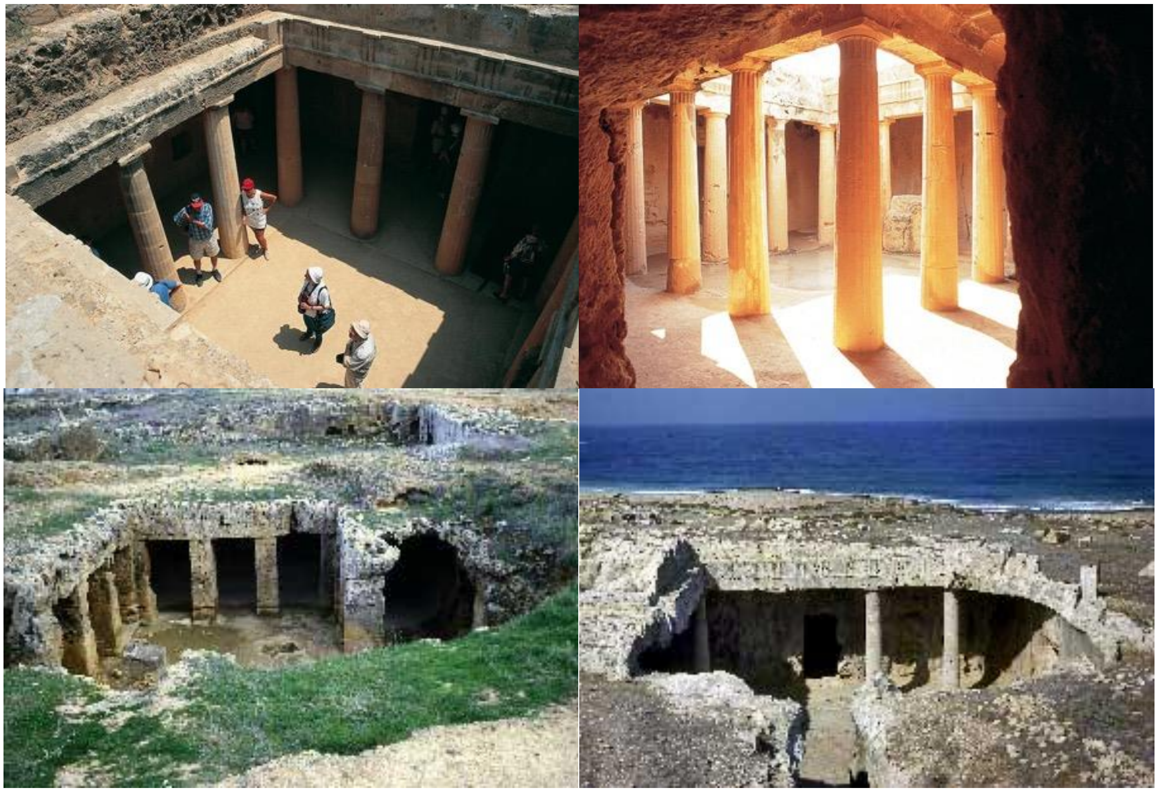


Figure 34: Photos from the tombs of the kings

The 'Tombs of the Kings' is the impressive necropolis that is located just outside the walls, to the north and east of Pafos town, about two kilometres north of Paphos harbour. It was built during the Hellenistic period (3rd century B.C.) to satisfy the needs of the newly founded Nea Paphos. Its name is not connected with the burial of kings, as the royal institution was abolished in 312 B.C., but rather with the impressive character of its burial monuments. The 'Tombs of the Kings' was the place where the higher administrative officers and distinguished Ptolemaic personalities as well as the members of their families were buried. The necropolis was continuously used as a burial area during the Hellenistic and Roman periods (3rd century B.C.-beginning of 4th century A.D.). There is sufficient evidence to support the fact that the first Christians also used the site for their burials, while at the same time the site constituted an endless quarry. Squatters established themselves in some of the tombs during the Medieval period and made alterations to the original architecture.

The existence of the site was already known from the end of the 19th century by Cesnola, who severely looted the tombs. In 1915-16 the then curator of the Cyprus Museum, Markides excavated some shaft tombs, while the honorary curator of Paphos Museum Loizos Philippou started clearance work in a few others tombs in 1937. But it was in 1977 that systematic excavations were undertaken by the Department of Antiquities, which brought to light eight large tomb complexes.

Most of the tombs are characterised by an underground, open aired, peristyled rectangular atrium completely carved into the natural rock. Columns or pillars of the Doric style supported the porticoes, which surrounded the atrium. The burial chambers and the loculi for single burials were dug into the portico walls. It seems that the walls were originally covered with frescoes although today only small fragments are preserved. The tombs' architectural characteristics directly relate them to Hellenistic prototypes from Alexandria, Delos, Pergamon and Priene.

The underground tombs, many of which date back to the 4th century BC, are carved out of solid rock, and are thought to have been the burial sites of Paphitic aristocrats and high officials up to the third century AD (the name comes from the magnificence of the tombs; no kings were in fact buried here) (Agapiou et al). Some of the tombs feature Doric columns and frescoed walls (Milàn et al). Archaeological excavations are still being carried out at the site. The tombs are cut into the native rock, and at times imitated the houses of the living.

The tombs have been known and casually explored for centuries (Herscher et al). The oldest modern account was written by Richard Pockocke, in 1783 (Carstens et al). Almost a century later, in 1870 the first archaeological excavations were conducted by Luigi Palma di Cesnola, the Italian-born American consul to Cyprus. In 1915 the first excavations under scientific supervision took place, led by Menelaos Markides, who was the curator of the Cyprus Museum. Systematic excavations took place in the late 1970s and the 1980s under the direction of Dr Sophocles Hadjisavvas, former Director of Antiquities of the Republic of Cyprus.

Part of the importance of the tombs lies in the Paphian habit of including Rhodian amphorae among the offerings in a burial. Through the manufacturing stamps placed on the handles of these amphorae, it is possible to give them a date and, through them, the other material from the same burial.

Thus, it is hoped to develop a more secure chronology for archaeological material in the Eastern Mediterranean of the Hellenistic and early Roman periods.

It is reported that much of the information related to the tombs was lost over time. Several factors contributed to that: It is believed that many of the tombs were rich in expensive grave goods, despite that very few of such goods were to found by the official archaeological missions, and thus it is believed that grave robbers of the past were responsible. Also, the tombs' proximity to the sea side hindered the preservation of the buried bodies. Despite those obstacles, the historical significance of the Tombs is well established among experts and locals.

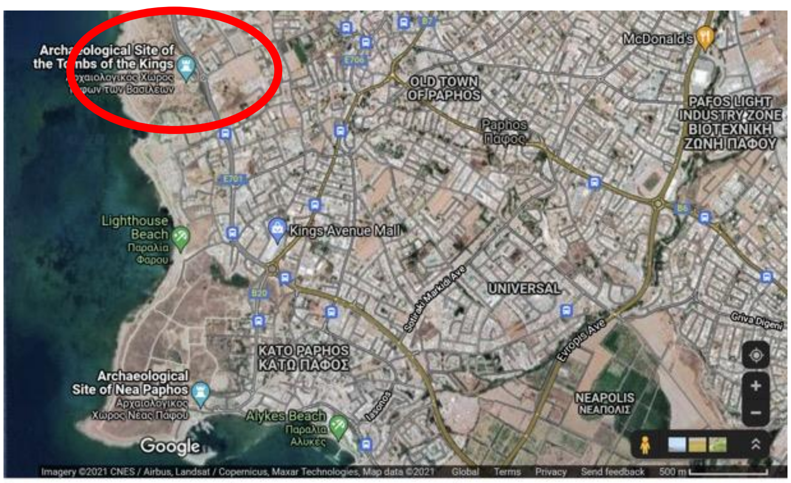


Figure 35: The tonbs of the kings position from Google maps

16. Panagia Chrysopolitissa

Panagia Chrysopolitissa Church was built in the 13th Century over the ruins of the largest Early Byzantine Basilica on the island. Originally seven-aisled, the church was later reduced to five and features some of the most well-preserved floor mosaics and standing Corinthian-styled columns made of granite and marble. Following extensive restoration, Panagia Chrysopolitissa Church is used as a place of worship for Anglican, Catholic, Greek Orthodox, and other Christian denominations, and is also a popular wedding venue.

Figure 36: Photos of Panagia Chrysopolitisa

The Basilica of Chrysopolitissa is part of the World Heritage site. It was built in the second half of the 4th century AD and was one of the largest churches on the island. It was destroyed by invaders but there's still lots to see in the ruins that remain. Elevated walkways have been built over the excavations of the original basilica, allowing you to look down and see some of the impressive mosaic floors that have been preserved. You'll also be able to get a sense of the scale of the basilica, which would have dominated this part of the city.

Originally it had seven aisles, which were reduced to five during alterations in the 6th century. In the central aisle, three unique figural scenes representing Christian allegories are preserved.

As you come into the church's ground, you'll also notice St Paul's Pillar. Legend has it that this is where St Paul was whipped due to his efforts to preach Christianity, before the Roman Governor Sergius Paulus was converted to Christianity.

In the middle of the site you will also find a medieval church, built around 1500 AD. It is still operational and is used as the main Anglican church in Pafos. You can go inside and see some beautiful traditional religious artwork. If you're lucky, you may even catch a wedding taking place.

Figure 37: Panagia Crysopolitissa position from Google maps

17. St Paul's Pillar

Located within the compound is Saint Paul’s Pillar where, according to tradition, Saint Paul was punished and sentenced to thirty-nine (forty but one) lashes for evangelising Christianity in Pafos. Considered an important pilgrimage stop, it is at this location where Saint Paul, in 45 AD, was flogged before Roman Governor, Sergius Paulus, in an attempt to convert the ruler. He was eventually successful in his efforts, making Cyprus one of the world’s first Christian states. Today, St Paul’s Pillar lies amongst a series of ancient ruins surrounding Panagia Chrysopolitissa Church, including the remains of an Early Byzantine basilica and a mosque dating back to the Ottoman period.

2.1.1 Current equipment/infrastructure available

- **The Seismological Station network:** Today, the Geological Survey Department (GSD) operates a modern and automated seismological station that has the capacity to record with accuracy a large number of earthquakes occurring in the Cyprus region (33.5°-37.0° N, 31.0°-35.5° E). The first attempt to establish a seismological station was made in 1984 with the installation of a single seismometer and a recording unit (seismograph) at Mathiatis. With continual expansions and upgrades, the seismological station has been operating since November 1998 with seven substations The recordings from all substations are made at the GSD office in Nicosia either on computers or some of them in the traditional way on paper, which are used for visual control as well as for easier observation and understanding by pupils, students, and the general public.In the northern part of Cyprus, the first attempt to establish a seismological station was made in 1985 by the Meteorological Department in cooperation with Kandilli Observatory and the Earthquake Research Institute Seismological Service, with the installation of a single seismometer and a recording unit (seismograph) at Pentadaktylos. In the last few years another three stations have been installed in order to cover the northern part of Cyprus from west to east. The data are shared with the GSD, Kandilli Observatory and the Earthquake

Research Institute Seismological Service, for more accurate determination of the earthquakes occurring in the Cyprus region.

- **Environmental Impact Assessment (EIA)**: This process has been enforced through legislation and is applied to many developments, which are expected to have a significant effect on the environment. After the application of the EIA process in Cyprus, for more than ten years the situation with the environment has improved considerably. People are also becoming more sensitive and demanding on environmental matters, because they have the opportunity to become involved in the EIA process.

- **Aquifers:** Four aquifers have been recognised in the Pafos area: a) The Lefkara Chalk Aquifer; b) The Terra Limestone Aquifer; c) The Coastal Plain Aquifer; and d) The Alluvial Aquifer.

    - a) The Lefkara (Massive) Chalk Aquifer is best developed in the Mesogi–Tsada area and its water is used for domestic and irrigation purposes. As replenishment is very low the capacity of the aquifer has been reduced considerably.

    - b) The Terra Limestone Aquifer is also of local importance and is better developed in the Pegeia area where its thickness reaches 60 m. Water quality is normally good and the aquifer covers local demands for domestic use and irrigation. Other Terra Limestone Aquifer occurrences have been mapped in the Akoursos–Trimithousa and Geroskipou-Anarita areas.

    - c) The Coastal Plain Aquifer has an area of 86 km^2 and extends from Chapotami in the southeast to Coral Bay in the northwest. It consists of biogenic calcareous sandstones of Pleistocene age, 10-15 m thick, resting on Pliocene or Pakhna marls. Its annual replenishment is about 8 million m3. Borehole yields range between 5 and 20 m^3/h and can only serve local irrigation needs. Water quality is good with chloride concentrations ranging between 100 and 300 ppm.

    - d) The Alluvial Aquifer is the most important aquifer in the Pafos Area with the water in storage exceeding 40 million m^3. It includes the alluvial deposits of Ezusa, Xeros and Diarizos rivers, consisting of gravels of igneous and sedimentary origin, sands and silts. In many places the aquifer behaves as semi-confined due to the presence of semi-pervious layers. The thickness of the alluvial deposits varies from 30 to 50 m at the coastal plain decreasing upstream to 5-20 m near the contact with the Troodos pillow lavas. The alluvial deposits are quite permeable. The water of the alluvial aquifer is generally of good quality for domestic supply and irrigation. In the lower half of the Ezusa River there is introduction of sulphates from gypsum. The sulphate concentrations that are obtained render this water unsuitable for domestic use.

3 Demonstration City related Hazards

3.1 The city of Milano, Italy

The city of Milan is located in the middle of the Po Plain. This plain stretches for over 400 km in a roughly east–west direction from the Western Alps to the Adriatic Sea. It is the largest alluvial plain of Italy with a surface of approximately 46000km^2 and a population density of 450 inhabitants/km^2. Within this plain, the Milan Province covers 1989 km^2 wide, contains 189 municipalities. The Po Plain is, in itself, a “simple” morphological region. However, a certain level of complexity derives from the interactions among different overlapping processes: spatial displacements of the coastline, due to eustatic phenomena, have taken place several times and were extensive. These displacements also interfered with tectonic movements and with the overall evolution of the sedimentary basin. Sediment supply from both Alpine and Apennine slopes differed in time. Lastly, anthropic morphogenesis overlapped everything, creating changes in trend but also, in certain cases, rigidity in evolutionary development of coastal and river landforms.
So, three key aspects are the following: the role of recent and active tectonics; the sequence of depositional and erosive events in time; and the environmental theme. The overall consideration to b kept in mind is that the Po Plain is a young morphogenetic system, fragile and, especially as regards the most recent Holocene, «sensitive» to human intervention.

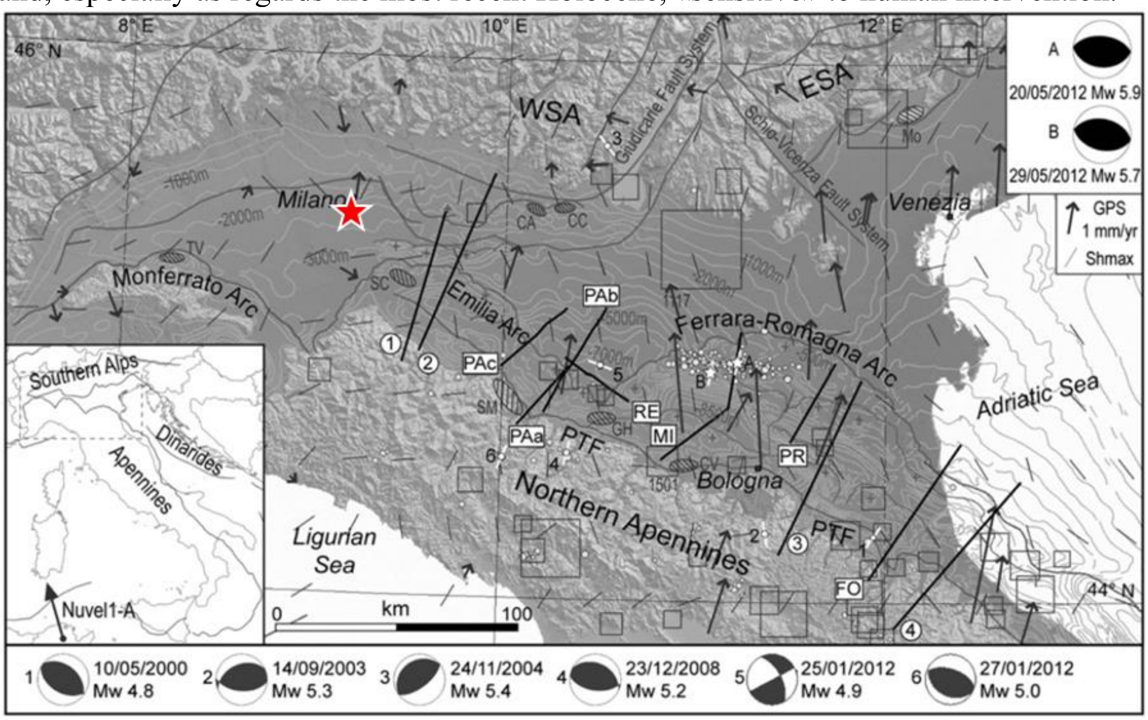


Figure 38: Schematic structural and seismotectonic map of the Po basin

3.1.1 Geology Of Milan Area

The Po Plain is located between the Alps and the Apennines. It was the foreland basin of the Northern Apennines (NA) and of the Southern Alps (SA) during the Paleogene. The River Po, the longest watercourse of Italy (652 km) with a 74,970 km2 wide catchment, flows eastward within a completely embanked meandering course, from the western Alps to the Adriatic Sea. Geologically the Po Plain comprises the foreland area of the two actives, oppositely verging fold-and-thrust belts: the NA, to the south, and the SA, to the north and to the west. Their uplifted, tightly folded and intensely eroded accretionary wedges encircle the Po Plain in all directions but to the east, marking its morphological boundaries. The outer deformation fronts of the two belts are currently buried below the thick Pliocene–Quaternary, marine to continental succession that fills-in the Po Plain; for this reason, the surface evidence of the ongoing activity of the thrusts of the two belts is restricted to their exposed margins and to a few isolated spots in the plain proper. An active process of shortening across the NA and SA fronts is currently ongoing, with velocities up to 2.5 mm/yr.

Five physiographic units can be distinguished in the Po Plain. According to the stratigraphic order they are:

1) Holocene deposits in the central sector of the plain constitute the Holocene Flood plain unit, formed by aggradation of the River Po and its right tributaries.

2) A less extensive surface is located near the Apennine boundary of the Po Plain. It is made up of a system of coalescent fluvial fans developing at the Apennine foothills, the so-called Late Pleistocene *bajada* unit, related to the great number of sediments produced during the Last Glacial Maximum

3) In the northern part of the Po Plain, adjacent to the glacial amphitheatres, the Main Level of the Plain unit has been identified. It consists of a complex of alluvial fans with their apex located on the Alpine foothill, coeval with the Late Pleistocene bajada unit, slightly inclined towards the River Po, made up off fluvioglacial and fluvial sediments. At present, the Alpine rivers flow in deepen trenched valleys carved into this unit because of an intense erosional phase occurring during the Late glacial. The southern boundary of the Main Level of the Plain is constituted by an escarpment resulting from fluvial erosion, due to the northward migration of the River Po during the Holocene.

4) At the margin of the Alps and Apennines, a series of fluvioglacial and fluvial terraces have been included in the old terrace's unit. These terraces have rubified soils and polygenetic loess covers, which constitute the remnants of the ancient Po Plain surface, prior to the Last Glacial Maximum, they were isolated by intense erosional phases resulting from deglaciation.

5) At the foothills of the Alps, the glacial amphitheatres unit is found. This physiographic unit includes moraines and valleys scoured by glaciers during the Pleistocene.

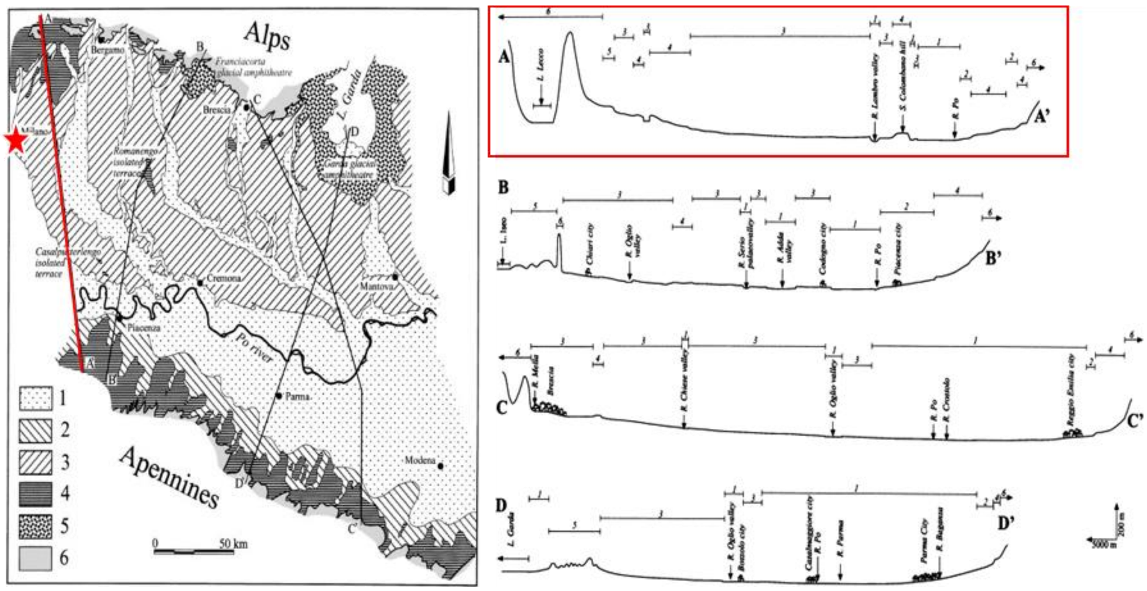


Figure 39: a) The physiographic units of the Po Plain: 1)Holocene Floodplain unit; 2)Late Pleistocene bajada unit; 3)Main Level of the Plain unit; 4)old terraces unit; 5)glacial amphitheatres unit; 6) bedrock; 7) hydrography; and b) Sections across the Po Plain

Regional geological and tectonic setting

The stratigraphic succession of the Po basin is characterized (from base to top) by a late Palaeozoic–Mesozoic evaporitic–siliciclastic and carbonatic sequence deposited on the Adriatic paleo margin and covering the Variscan basement, by Cenozoic deposits of the SA and NA foredeeps, and by Quaternary shallow marine and continental sediments deposited in a generally regressive sequence.

The geological evolution of the Po Plain

The geomorphological evolution of the Po Plain has been mainly driven by tectonic uplift and climate change interplay. In particular, the activity of the Apennine thrusts has produced a generalized northward shifting of the River Po and its tributaries. In addition, climate change has caused significant sea level variations, which directly influence fluvial dynamics. Anthropogenic activities, especially in past centuries, are an important factor modifying the landscape. In, fluvial and hydraulic interventions (such as meander cutting), channelization, quarrying activities, land use changes and deforestation have increased over time. Recent and active tectonics explain the existence of this structural trench, enclosed between mountain chains which are approaching each other. The effects of compressional tectonics in various phases led to the development of new accretionary wedges along their advancing fronts in the Pliocene and Quaternary: the Apennines and, in the Southern Alps, mainly the Prealps of the Veneto. At present the plain belongs almost entirely to the Apennine foredeep, so that it may be interpreted as a complex monocline dipping south-southwest. The Alpine thrust front in Lombardy was essentially active until the Miocene, while the Apennine front, accompanied by a much deeper foredeep, is still active. New accretions have come into being along the Alpine thrust front mainly in the eastern section, in the Veneto and Friuli Prealps.

3.1.2 The Seismicity of Milan Area

Earthquake activity in flat alluvial plains poses an especially insidious threat as most of the population and the largest industrial facilities normally take advantage of these gentle landscapes. The Po Plain does not escape this general rule as it hosts nearly a third of Italy's population along with important historical centers, many industrial facilities and lots of critical infrastructures. The city of Milan and its suburban area represents a particularly developed area from the industrial and productive point of view. Moreover, the concentration of material heritage and population in the city clearly constitutes an increase in vulnerability and exposure to risks. Even though on average the seismic hazard of the Po Plain is comparatively low, the area is not exempt from clearly perceptible, though not destructive, seismic events.

A clear knowledge about how tectonic strain is partitioned across the different faults and so about their slip rates is a crucial information for ranking the different active portions of the Po Plain and describing the spatial variability of seismic hazard, and hence of seismic risk. The main difficulty is dealing with blind thrusts that occursin the Po Plain. Indeed, when blind faulting occurs in flat terrains like the Po Plain the associated hazard is generally not perceived by the population and by the decision makers — and sometimes even by scientists — due to the lack of associated morphologies. Moreover, the low strain rates that are typical of the Po Plain result in long earthquake return times, further stressing the perception of a low local hazard.

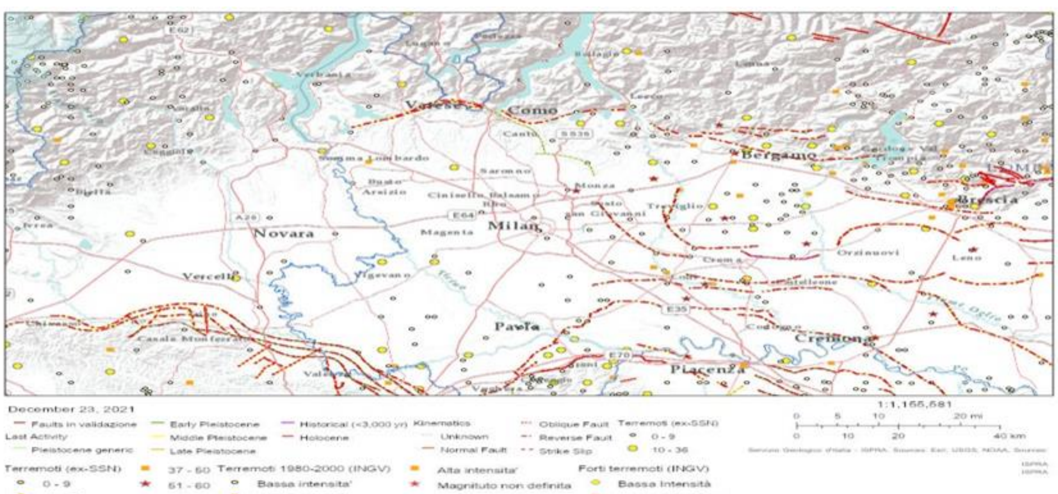


Figure 40: Historical seismicity and active faults in Milan area (Source: ISPRA)

3.1.3 The hydrogeological system of Milan area

As already mentioned, the Po alley is an alluvial plain, characterized by a very high density of urban, industrial and agricultural activities. The area has a very rich natural hydrographic network, as well as a man-made one, which historically influenced the economic and productive development of the area. In particular, with reference to the Milan Province, 71% of the land is used for agricultural purposes. In the province area a total of 7583 wells were identified and located, 3472 of which have a stratigraphic log. Tese wells represented for decades the main source for hydrogeological studies in Milan region. However, the high heterogeneity of the sediments of fluvial environment that constitute the the subsoil of the middle Lombardy plain, required to be further integrated with geognostic surveys to integrate the previous knowledge and provide a detailed reconstruction of the main stratigraphic surfaces intercepted by subsurface investigations. The state of the art of hydrogeologic knowlede of Milan area is resumed in Sheet 118 of the national mapping project named CARG[5].

The natural hydrographic network is represented by the Adda and Ticino rivers. The hydrogeological system consists of fluvial and fluvio-glacial deposits, mostly gravel and sand with discontinuous silt and clay confining layers. Such deposits correspond to the Mindel, Riss and Wurm fluvioglacial deposits and to the ancient floods. From the hydrogeological point of view, an unconfined shallow aquifer is underlain by deeper confined aquifers.

The unconfined and confined aquifers of the Milan area of the Po River plain, have a vertical extension within a range of 80 to 200 m. The upper surface of the investigate sedimentary body is defined by the topographic surface. The lower surface represents the physical lower limit of the deep aquifer only in the northern part of the area where the wells are deeper. A surface related to the maximum average depths reached by the wells for the exploitation of ground water in the Milan.

[5] The project started at the end of the 1980s, with the aim of creating a national geological cartography at a scale of 1:50,000, and was carried out in collaboration with the Regions and Autonomous Provinces, the CNR and the Universities and is coordinated by the Geological Survey of Italy in its capacity as the cartographic body of the State (L. 68/60). The CARG Project foresees the realisation and computerisation of the 636 geological and geothematic sheets at a scale of 1:50,000 that make up the puzzle of the 50,000 coverage of the entire national territory. CARG - Cartografia geologica e geotematica — Italiano (isprambiente.gov.it)

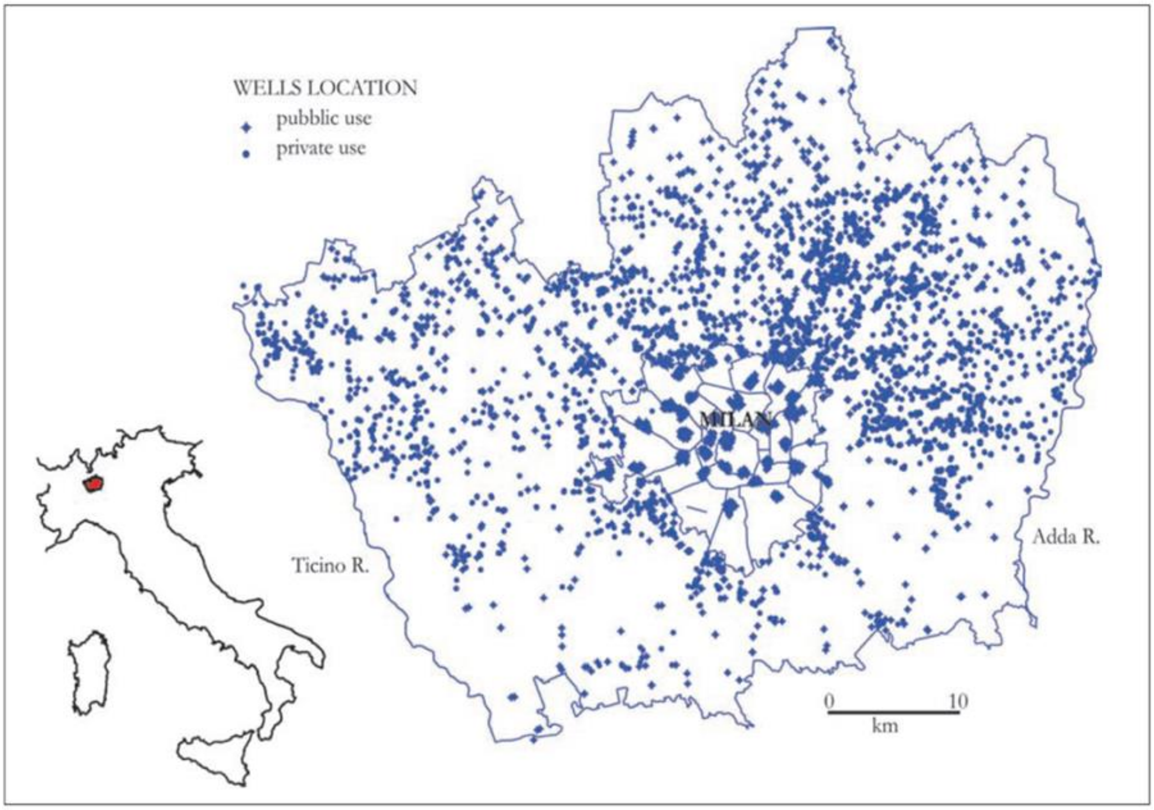


Figure 41: Distribution of the wells in the Province of Milan, located in the northern part of the Po River plain.

3.1.4 Environmental and Climatic Hazards in Milan Area

The city of Milan developed a good awareness of the importance of risk assessment and prevention before other Italian cities did. It was the first city in Italy to open a department of the municipality specifically dedicated to urban resilience, even before the Ministry of Ecological Transition was established at the national level. In addition, since years studies aimed at outlining the city's risk profile have been financed and conducted. Here we refer specifically to the studies carried out in the framework of the Euro-Mediterranean Centre's PON-Metro project and to the Local Climate Profile (LCCP) elaborated by the Municipality of Milan and ARPA Lombardia.

The main environmental, economic and social shocks and stresses affecting the city are discussed below. They include chronic stresses, understood as slow-moving disasters that weaken the fabric of a city, and acute shocks as sudden events that threaten an urban context.

The latest update in 2018 highlighted river flood risk and urban flooding as major shocks, and heat waves and extreme heat as stresses, both of which are directly related to climate change impacts. The Municipality has planned to constantly update these data, whose first revision will be in 2023.

3.1.5 Heat waves

The analytical risk assessment at the census section scale showed a high level in semi-central districts, i.e. in areas with lower permeability and presence of vegetation and higher population density and socio-economic exposure. These areas are also those with higher concentraton of Cultural Heritage, considered as pilot area for the purpose of this project. Considering the increased frequency of heat waves as a hazard, as a probabilistic qualitative variable, and then combining it with the analysis of vulnerability and socio-economic exposure it is possible to identify the areas with higher exposure for sensitive population groups, but also for heritage.

Three indicators are considered here with regard to temperature:

- *Hot nights*. This indicates the number of days with a minimum temperature higher than 20°C. This is a very important value for assessing the impact of climate change on people's physical well-being.
- *Very hot days*. Indicates the number of days on which the daily maximum temperature exceeds 25°.

These two indicators are important for studying the impact of climate change on people's health and on energy consumption for cooling.

- *Cold days*. The number of days on which the temperature falls below 0°C.

From the graph showing the annual trend of the indicators (see Figure 42), it can be seen that warm nights and very warm days follow an upward trend over the period 1989-2020, while cold days show a decrease over the same period. The increase in temperatures also results from the analysis of the number and average duration of annual heat waves and tropical nights, which have almost doubled in number over the last thirty years (1991-2017) compared to the first reference period (1961-1990). The three indicators together show a consistent trend towards the same direction, namely warming.

The analysis of climate variability identifies several significant trends, including a 0.2-0.5°C/decade increase in seasonal mean minimum and maximum temperatures, resulting in an increase of about 2°C in annual mean temperature. This occurs both through less severe winter temperatures and a decrease in the annual number of days with frost and through higher summer maximum values.

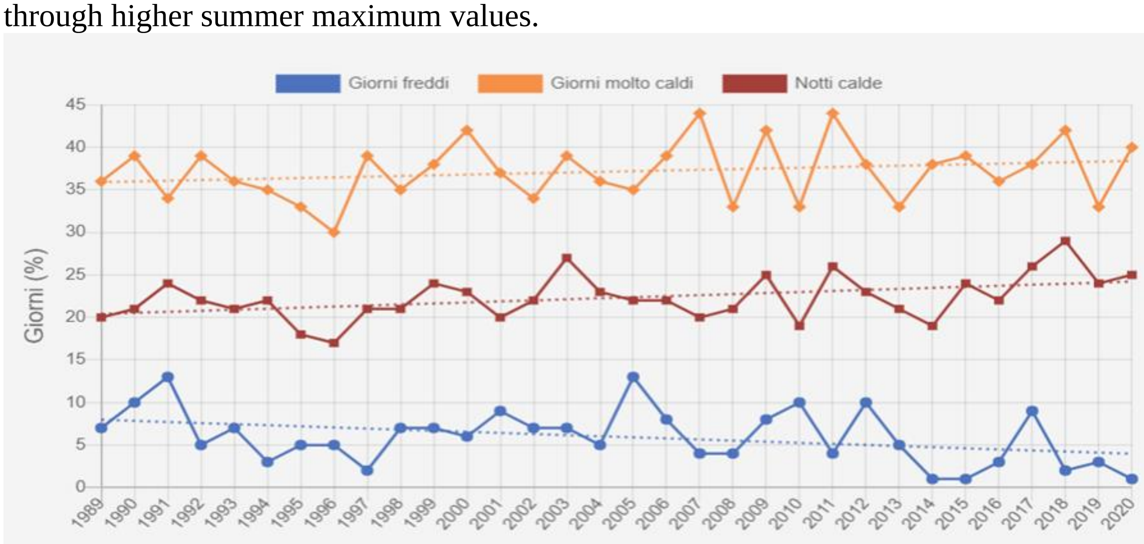


Figure 42: Annual annual trends (percentage of days per year) for indicators that are described in the text as frost days (blue line), tropical nights (red line) and very warm days (orange line) over the period 1989-2020. (Source: Report Milano - CMCC)

In addition to the general climatic trends, there are also the effects of the intense urbanisation and anthropic presence that characterise the Milan metropolitan area. The result is an accentuated Urban Heat Island phenomenon, which produces a significant increase in temperatures in the central areas, i.e. in the historic centre (Figure 43). This phenomenon, in addition to constituting a serious threat to people's health, also represents an additional stress for the cultural heritage.

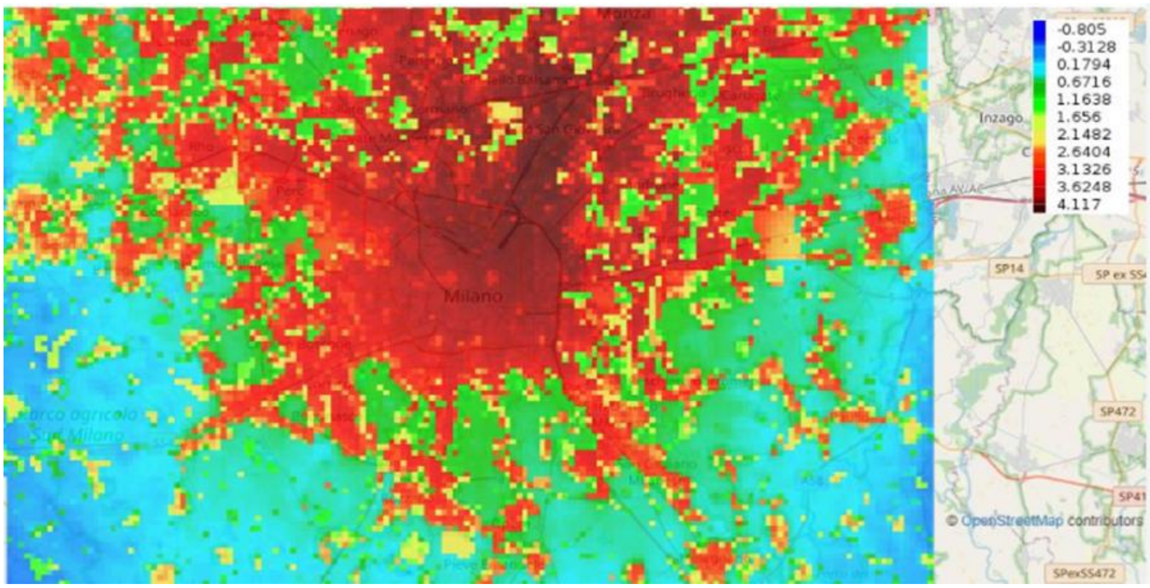


Figure 43: Distribution of heat island intensity within the City of Milan (Source: https://www.urban-climate.eu/services/eu_cities/)

3.2 The archaeological area of Pafos, Cyprus

Cyprus is located in a tectonically complex zone in the Eastern Mediterranean Sea where three continental plates meet: the African plate to the south, the Eurasian plate to the north and the Arabian plate to the east.

The movements of these three plates relative to each other (separation, collision, parallel movement) since the early Mesozoic (about 200 Ma ago) has led to a number of geological features such as the formation or destruction of ocean basins (areas where sedimentary rocks are formed) and the formation of mountains (orogenesis). The main relative movements of the plates include rifting (the plates move away from each other), collision (the plates move towards each other and collide or crash) and wrenching (the plates move parallel to each other but in a different direction, e.g. the plates are in contact with each other and one moves to the right and the other to the left).

The combination of the movements of the African, the Eurasian and the Arabian plates over the geological time has produced a number of features in the region, which include Cyprus itself (the Troodos Ophiolite), the Hellenic Arc to the west and its continuation to the east, the Eratosthenes seamount and the Levantine basin to the south, the Aegean graben system to the northwest, the Anatolian microplate to the north, including the northern and eastern Anatolian fault zones, the Red Sea rift to the south, and the Dead Sea

Transform Fault to the southeast. There are numerous ophiolite complexes within this area of the Eastern Mediterranean and Middle East, of which the Troodos Ophiolite or Massif on Cyprus is one of the largest and best studied as well as well-preserved and most complete (including the entire suite of ophiolite rocks).

3.2.1 Geology of Cyprus

In order to describe the geology of an area, geologists usually group areas of the same geological structure, evolution and age into what they call “Geotectonic Zones”. At a smaller scale, rocks of the same age, composition and genesis (way of origin) are called ‘Formations’. Usually, the names of the formations are derived from the names of areas where these rocks are most widespread.
Cyprus is divided into four geological zones: (a) the Pentadaktylos (Kyrenia) Zone; (b) the Troodos Zone or Troodos Ophiolite; (c) the Mamonia Zone or Complex; and, (d) the Zone of the autochthonous sedimentary rocks (autochthonous means that the rocks were formed in the place where they are now found) (Figure 44).

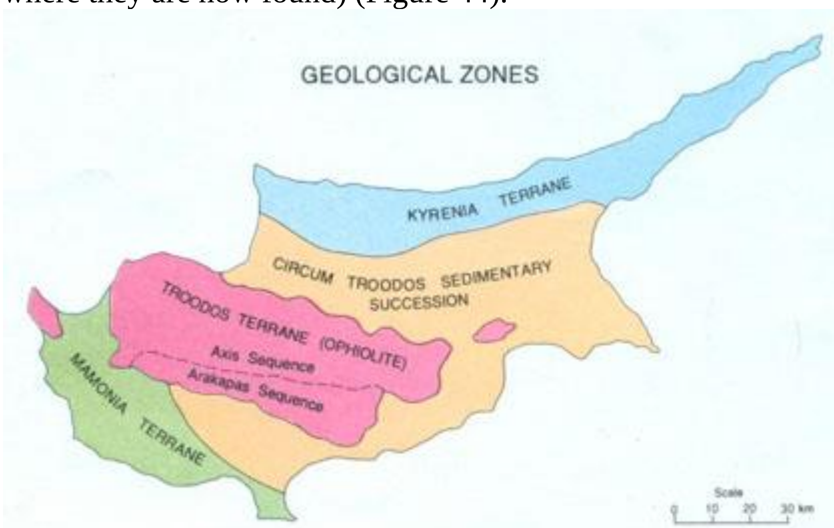


Figure 44: Map of Cyprus showing the geological zones (Map from Geological Survey department)

The Pentadaktylos (Kyrenia) Zone is the northern-most geological zone of Cyprus and is considered to be the southern-most portion of the Tauro-Diranide Alpine Zone. It has an arciform disposition with an east-west direction and is characterised by southward thrusting (movement of placement to the south). The base of the Zone is mostly composed of a series of allochthonous (were formed elsewhere than in their present place) massive and recrystallised limestones, dolomites and marbles of Permian–Carboniferous to Lower Cretaceous age (between 350–135 Ma). These are stratigraphically followed by younger autochthonous sedimentary rocks of Upper Cretaceous to Middle Miocene age (67–15 Ma), on which the older allochthonous formations have been thrust southward.
The Troodos Zone or the Troodos Ophiolite dominates the central part of the island, constitutes the geological core of Cyprus (Figure 45), appears in two regions (main mass of the Troodos Mountain range and in the Limassol and Akapnou Forests south of the range) and has a characteristic elongated domal structure. It was formed in the Upper

Cretaceous (90 Ma ago) on the Tethys Sea floor, which then extended from the Pyrenees through the Alps to the Himalayas (Tethys was an ocean that occupied the general position of the Alpine-Himalayan orogenic belt; the Mediterranean Sea is a remnant of Tethys). It is regarded as the most complete and studied ophiolite in the world. It is a fragment of a fully developed oceanic crust, consisting of plutonic, intrusive and volcanic rocks and chemical sediments.

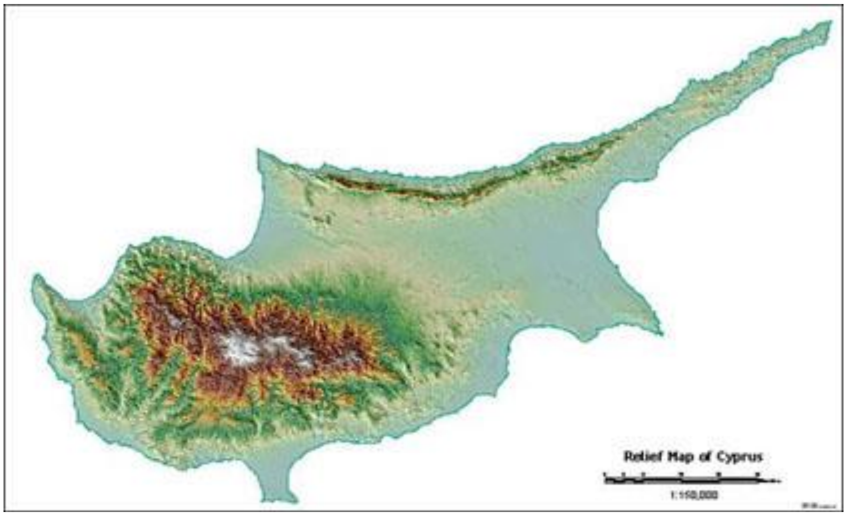


Figure 45: A topographic relief map of Cyprus showing the Troodos and the Pentadaktylos Ranges (Map from Geological Survey department)

The stratigraphic completeness of the ophiolite makes it unique. It was created during the complex process of oceanic spreading and formation of oceanic crust and emerged and was placed in its present position through complicated tectonic processes relating to the collision of the Eurasian plate to the north and the African plate to the south. The stratigraphy of the ophiolite shows a topographic inversion, with the lower suites of rocks outcropping in the highest points of the range, while the upper rocks appear on the flanks of the ophiolite. This apparent inversion is related to the way the ophiolite was uplifted (diapirically) and to its differential erosion. The diapiric rising of its core took place mainly with episodes of an abrupt uplift in the Pleistocene (2 Ma).

The Mamonia Zone or Complex appears in the Paphos district in the south-western part of the island. It constitutes a series of igneous (rocks that solidified from molten material, i.e. from magma), sedimentary (rocks that formed by deposition and consolidation of sediment) and metamorphic rocks (derived from pre-existing rocks), ranging in age from Middle Triassic to Upper Cretaceous (230–75 million years). These rocks, which are regarded as allochthonous in relation to the overlying autochthonous carbonate successions and the Troodos Ophiolite rocks, were placed over and adjacent to the Troodos Ophiolite during the Maestrichtian.

The Zone of the autochthonous sedimentary rocks, ranging in age from Upper Cretaceous through to Pleistocene (67 million years to recent), covers the area between the Pentadaktylos and Troodos Zones (Mesaoria) as well as the southern part of the island. It consists of bentonitic clays, volcaniclastics, mélange, marls, chalks, cherts, limestones, calcarenites, evaporites and clastic sediments.

3.2.1.1 The Troodos Ophiolite

The Troodos Ophiolite consists of the following stratigraphic units, in ascending order: Plutonics (mantle sequence and cumulates); Intrusives; Volcanics; and, Chemical sediments.

The mantle sequence is thus termed because the rocks that form this suite are considered to be the residuals after the partial melting of the upper mantle and the formation of basaltic magma, from which the remaining rocks of the ophiolite have been derived. It is mainly composed of harzburgite and dunite with 50-80% of the original minerals altered to serpentine, and serpentinite (with or with-out concentrations of asbestos) where the alteration is almost complete.

The cumulate rocks are the products of crystallisation and concentration of the crystals at the floor of the magma chamber, beneath the zones of sea floor spreading. The main cumulate rocks (Figure 46) include dunite with or without chromite concentrations, wehrlite, pyroxenite, gabbro and plagiogranites, which are observed in small, discontinued occurrences.

The intrusive rocks (Sheeted Dyke Complex - Diabase) have a basaltic to doleritic composition and were formed by the solidification of the magma in the channels, through which it intruded from the magma chambers at the bottom of the oceanic crust, feeding at the same time the submarine extrusion of lava on the sea floor.

The Sheeted Dyke Complex is followed by a suite of volcanic rocks that consist of two series of pillow lavas and lava flows, mainly of basaltic composition.

Figure 46: Outcrop photograph of harzburgite (background) and gabbro (foreground) in a tectonic contact

The pillow lavas (Figure 47) have a characteristic spherical to ellipsoidal pillow shape, 30–70 cm in diameter, which were formed as a result of submarine volcanic activity. Between the intrusive rocks and the pillow lavas a transitional zone known as the Basal Group occurs. Dykes dominate the Basal Group while pillows are less common.

Figure 47: Outcrop of pillow lavas near Skouritotissa

The Perapedhi Formation is composed of umber (chemical sediment), radiolarites and radiolaritic shales. These were the first sediments to be deposited over the ophiolite rocks as a result of hydrothermal activity (hot solutions rich in Fe and Mn) and sedimentation on the sea floor.

3.2.1.2 The Autochthonous Sedimentary Rocks

The geological history of Cyprus from the Upper Cretaceous (67 Ma) is characterised by marine sedimentation in a sea, which becomes gradually shallower. Sedimentation begins with the deposition of the Kannaviou Formation (bentonitic clays, volcaniclastics), followed by the deposition of the Moni and Kathikas Formations (mélange). Carbonate sedimentation begins from the Palaeocene (65 Ma) with the deposition of the Lefkara Formation, which includes pelagic marls and chalks (Figure 48) with characteristic white colour, with or without cherts.

Figure 48: Road cut consisting of bedded chalks and marls of the Lefkara Formation

The classic development of the Formation is represented by four members: Lower Marls; Chalks with layers of chert; massive Chalks (Figure 49); and, Upper Marls.

Figure 49: Massive chalks of the Lefkara Formation

The Lefkara Formation is followed by the Pakhna Formation (Miocene age, 22 Ma), which consists mainly of yellowish marls and chalks. The colour of the rocks, the presence of calcarenitic layers and the occasional development of conglomerates are characteristics that differentiate the Pakhna Formation from the Lefkara Formation. Sedimentation in the

Pakhna Formation began and terminated in a shallow-water environment with the development of reef limestone (Terra Member at the base and Koronia Member at the top of the Formation) (Figure 50).

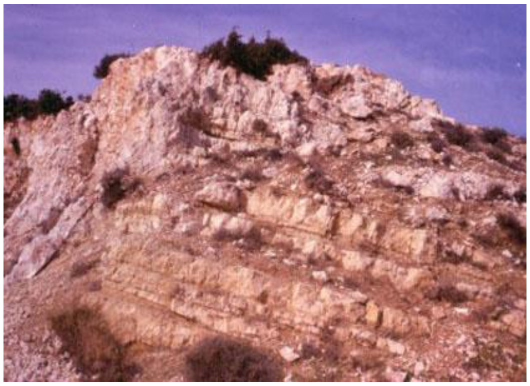


Figure 50: Reef limestone capping bedded limestone near Armenochori

The deposition of the evaporites of the Kalavasos Formation followed in the Upper Miocene (Messinian, 6 Ma), as a result of the closure of the Mediterranean Sea from the Atlantic Ocean and the evaporation of its waters. The Formation is composed of gypsum (Figure 51) and gypsiferous marls that cover extensive areas. Gypsum occurs in four types: sugary (crystalline); laminated ('marble'); selenite (transparent with large twin crystals); and, alabaster (massive semitransparent). With the reconnection of the Mediterranean Sea with the Atlantic Ocean, a new cycle of sedimentation began (Pliocene, 5 Ma).

Figure 51: A gypsum outcrop

The Nicosia Formation was deposited first and contains siltstones (grey and yellow) and layers of calcarenites and marls (Figure 52).

Figure 52: Calcarenite of the Nicosia Formation in Mammari. It was used in the past as building material

This is followed by the Athalassa Formation (Pliocene–Pleistocene, 2 Ma) consisting of calcarenites, which are interlayered with sandy marls. Finally, the Fanglomerate is a Pleistocene formation and includes clastic deposits (gravels, sand and silt). The stratigraphic column of the Troodos Ophiolite and the autochthonous sedimentary cover is shown in (Figure 53)

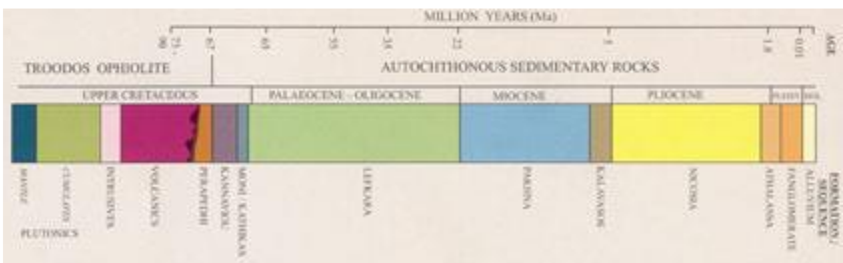


Figure 53: The stratigraphic column of the Troodos Ophiolite Complex and the overlying autochthonous sedimentary formations

3.2.1.3 The Pentadaktylos Zone

The three main geological formations (Triassic–Lower Cretaceous, between 250–135 Ma) are the Dhikomo, Sykhari and Hilarion Formations, which form the main carbonate masses of the Kyrenia Range. The Dhikomo Formation consists of deformed thinly bedded limestones with layers of grey and green phyllites. The Sykhari Formation is composed of massive to thickly bedded dolomitic limestones. The Hilarion Formation consists of medium-bedded to massive limestones, which were subjected to a very low degree of metamorphism. These formations were placed southward over the younger autochthonous marine sediments, which are known as the Lapithos, Kalogrea-Ardana (Belapais) and Kythrea Formations. Impressive and continuous outcrops of limestones occur in the central part of the range, whereas in the eastern part occur in the form of olistholiths over the younger sediments. These limestones (olistholiths) are referred to as the Kantara Formation (Permian–Carboniferous, 350–250 Ma).

3.2.1.4 The Mamonia Zone

The Mamonia Zone is also referred to in the geological bibliography as the Mamonia Complex. The name is derived from the village of Mamonia in Paphos, where classic outcrops of the Zone occur. It consists of a series of volcanic, sedimentary and, in smaller proportions, metamorphic rocks of Middle Triassic to Upper Cretaceous age (230–75 Ma ago). It includes: (a) volcanic (lavas) and sedimentary rocks (recrystallised limestones) of the Dhiarizos Group; (b) pelagic sedimentary rocks (limestones, mudstones and quartzitic sandstones) of the Ayios Photios Group; and, (c) metamorphic rocks (schists and marbles) of the Ayia Varvara Group (these rocks were derived from the metamorphism of the Dhiarizos Group. The rocks of the Mamonia Zone have been intensely deformed and mixed with large fragments of the Troodos Ophiolite rocks.

3.2.1.5 The Geological Evolution of Cyprus

The genesis of Cyprus took place through a series of tectonic episodes (Figure 54). It originated with the subduction of the African plate beneath the Eurasian plate and the formation of the Troodos Ophiolite (Upper Cretaceous, 90 Ma), continued with its detachment and sinistral (anticlockwise) rotation of 90° and the attachment to its southern and western part of older rocks ranging in age from 230 to 75 million years (Mamonia Zone). A period of relative tectonic inactivity followed, spanning in time from approximately 75 to 10 million years, and was characterised by carbonate sedimentation and gradual shallowing of the sedimentary basin (Lefkara and Pakhna Formations). The placement of the Pentadaktylos Range in the northern part of the Troodos Zone and the uplift of the island to almost its present position (Miocene, 10-15 Ma) constitutes the second last tectonic episode.

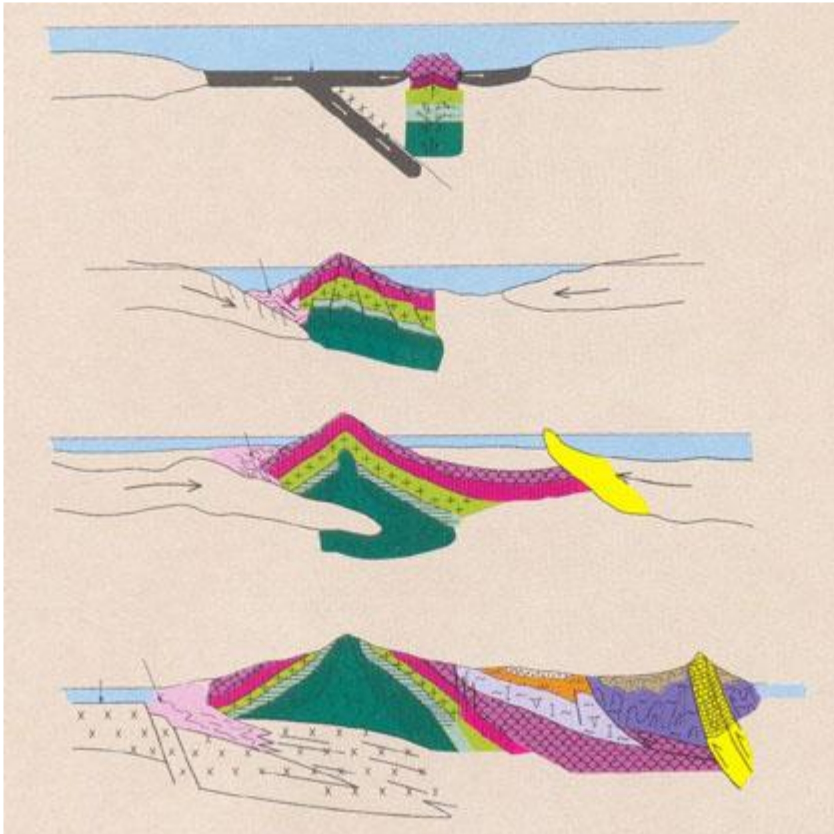


Figure 54: A diagram showing the geological evolution of Cyprus from Upper Cretaceous to recent

With the subduction of the plates and their relevant readjustment, the plates moved northwards so that their southern edges were placed in the area where the Pentadaktylos Range would finally be positioned. Marine sedimentation and relative tectonic inactivity dominated south of that area following the merging of the Troodos and the Mamonia Zones. At the same time the periodic uplift of the Troodos began following its formation, creating the island. At the end of Miocene (6 Ma), in the northern-most part of the region that would constitute Cyprus, a series of allochthonous limestones (Pentadaktylos Zone) were placed over the flanks of the Troodos Zone, folding and displacing all of the younger sediments. East of Cyprus, the Tethys Ocean was closed and the Mediterranean Sea obtained almost its present shape.

The reconnection of the Mediterranean Sea with the Atlantic Ocean (with the opening of the Gibraltar Strait) and the rise of the sea level resulted in the deposition of new sediments, which are today represented by the marls and calcarenites of the Nicosia and Athalassa Formations. An abrupt uplift of the area occurred during the Pleistocene, approximately 2 Ma (last tectonic episode), where the Troodos and Pentadaktylos Ranges were uplifted in elevations higher than today's. The abrupt uplift, combined with heavy rainfall, resulted in extensive erosion of the ranges, particularly that of Troodos, with the transportation of large quantities of erosion material (clastic deposits). These clastic sediments were deposited in large valleys and in the Mesaoria region, forming the Pleistocene Fanglomerates.

3.2.2 The Mineral Resources of Cyprus

Cyprus has both metallic and non-metallic (industrial) mineral resources. The metallic mineral resources are associated with the Troodos Ophiolite Complex and include chromite and sulphide deposits (pyrite and copper ores). These deposits have been formed in different stratigraphic horizons of the ophiolite and emerged on the surface as a result of the uplift of the ophiolite. The surface exposition of the various metallic deposits, especially that of copper, has resulted in its exploitation since antiquity. Cyprus is one of the first places on Earth that the exploitation, treatment and use of copper began. The entire historical, social, cultural and political evolution of the island was closely associated with the exploitation of copper.

Cyprus is a synonym of copper. Cuprum means copper in Latin. Cuprum originates from the word cuprium, which means Cypriot (from Cyprus) and referred to copper from Cyprus (aes cuprium meaning Cypriot copper –aes is an older Latin word for copper).

Cyprus was also known in ancient times for its asbestos and its natural (mineral) pigments such as umbers and ochres. Cyprus also has industrial minerals such as bentonite, gypsum, clay for the production of bricks and tiles, and raw materials for the production of cement and crushed aggregates.

3.2.2.1 Building stone

In Cyprus, building stone was for centuries the main construction material. The type of stone was related to the rocks of each area. In the Troodos Mountains they used rocks from the ophiolite such as gabbro, diabase, harzburgite etc (Figure 55).

Figure 55: The church of Ayios Ioannis Lambadistis was built with ophiolitic rocks

In other areas chalk, limestone and calcarenite were used as building stones. Calcarenite was extensively used in Cyprus for the construction of defensive structures such as the Venetian Walls of Nicosia, castles (Figure 56), as well as public buildings, churches, mosques and mansions. There is a continuing demand for dimension stone for new, and in particular prestigious, buildings and in the repair of old buildings. Also, calcarenite has recently been increasingly used as rock armour for marine works. The main calcarenite quarries are located in Yerolakkos, Ayios Andronikos, Yialousa, Komma tou Yialou, Mammari and Kivides.

Figure 56 The Kolossi Castle in Limassol District was built with calcarenite blocks

Chalks from the Lefkara or Pakhna Formations are also used as rough dimension stones for pavements (external flooring) and as building stones. The silicified chalks from the lowest horizon of the Lefkara Formation occur in persistent thin bands a few centimetres thick and are exploited in the Lymbia and Lefkara regions. The joints are often stained by limonite, which gives an attractive colour and is used as a facing stone. Laminated chalks at other horizons in the Lefkara Formation are extracted and roughly cut for paving. Similar material is also extracted from some chalky layers of the calcarenites of the Pakhna Formation, west of Limassol at Sotira, Kivides and Prastio as well as between the villages of Melousha and Tremetousia.

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3.2.3 The Aquifers of Cyprus

The island of Cyprus has numerous aquifers (Figure 57), which provide water to its inhabitants for domestic use and irrigation through springs, wells and boreholes. The formation of these aquifers has resulted from a combination of geological factors and processes throughout the geological evolution of the island. Permeable formations, which nowadays constitute aquifers, were formed at various geological times from the Permian to the present. However, the most decisive geological events responsible for the present day situation appear to have taken place during the Pleistocene epoch, with the uplift of Cyprus and the formation of the island as we know it today. During this epoch, intense erosion of the uplifted masses of Troodos and Pentadaktylos produced thick accumulations of arenaceous deposits in the Mesaoria region and elsewhere, which now make important aquifers. Many older permeable formations were lifted above sea level and progressively became aquiferous through various geological processes, including serpentinisation, fracturing and solution.

Upper Tertiary sandstones and calcarenites and older limestones have been exploited for hundreds of years. The ancient city of Salamis obtained its water from Kythrea by means of an aqueduct 40 km long. The chains of wells and aqueducts constructed in the seventeenth and eighteenth centuries for the water supply of Nicosia and Larnaca are also quite well known.

The first scientific study of the aquifers of Cyprus was initiated by the British in the late 19th century and the first drilling was carried out at the beginning of the 20th century. Ever since, thousands of boreholes have been drilled and all of the aquifers of Cyprus have been exploited intensively, in particular during the second half of the 20th century. A milestone in the study of the aquifers of Cyprus can be considered in the work carried out by the United Nations Development Programme (UNDP) between 1963 and 1969. Work carried out by the government and in particular by the Geological Survey and Water Development Departments has also been quite significant. Between 1996 and 1999, the General Directorate of the Mineral Research Institute of Turkey worked on the aquifers in the northern part of Cyprus, drilling new boreholes for potable water supply from the Kyrenia Range and the Morphou aquifer and at other regions, which had been studied for determining other additional groundwater resources.

Cyprus has been suffering from water problems due to the irregular rainfall conditions since ancient times. As we know from the "Machera Chronicle", the lack of water caused problems such as inadequate cultivation conditions while long drought periods forced the island's people to immigrate to neighbouring countries. Between 1932–1935, 1940–1948 and especially in the 1970s and beginning of the 1990s, the country suffered terrible periods of drought.

3.2.3.1 General Classifications of the Aquifers in Cyprus

Aquifers in Cyprus have been divided according to their thickness and lateral extent conditions in the report on "Survey of Groundwater and Mineral Resources of Cyprus" by UNDP. According to this classification the aquifers of Cyprus are divided into first-class and second-class, a subdivision which was adopted by later workers.

First-class aquifers are considered to be those that are sufficiently thick and of wide lateral extent and continuity over most of the aquifer area. These are found in Western Mesaoria,

South-eastern Mesaoria and the Akrotiri Peninsula, and lend themselves to regional analysis and management.
Second-class aquifers consist of pervious layers of highly variable thickness and limited lateral extent. They are associated with the fractured and karstic limestones of the Pentadaktylos Range, the reef limestone, gypsum and calcareous rocks of the autochthonous sedimentary succession surrounding the Troodos Massif as well as the coastal plain and river deposits.

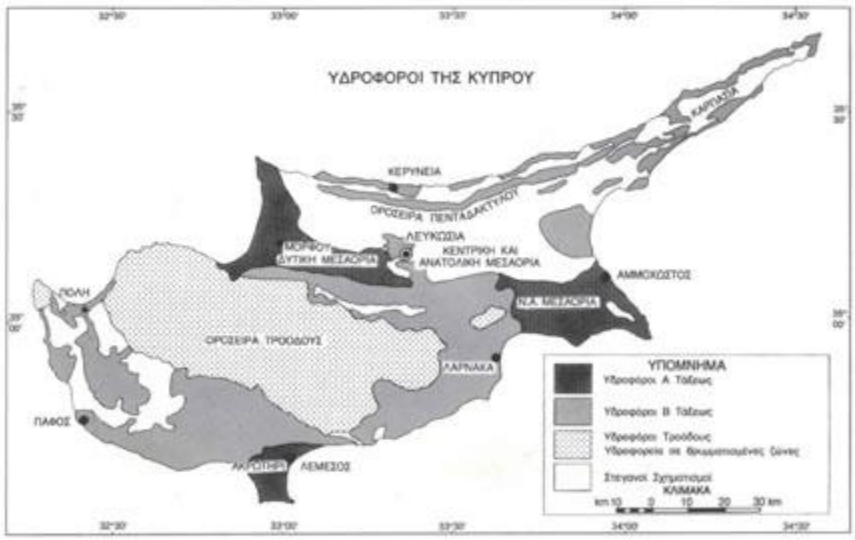

Figure 57: The aquifers of Cyprus

The Troodos Massif was not fully studied during the UNDP project but later work, however, has shown that the igneous formations of Troodos have varying potentials as aquifers depending on lithology, structure and elevation.
The development of aquifers and the presence of water in the subsurface are evidently related to the capacity of rocks to store water in their pores, joints, cavities and fractures and to transmit it to water collection works, such as wells, boreholes galleries etc.

3.2.3.2 The Main Aquifers of Cyprus

Hydrogeologists have mapped and delineated tens of small and large aquifers in Cyprus. Several of these aquifers have well-defined boundaries and are isolated but many others have less well-defined boundaries and are in hydraulic connection with other aquifers. Most of the alluvial aquifers, for example, merge with coastal plain aquifers with which they are hydraulically connected. In a recent study carried out by the Water Development Department (WDD) in co-operation with the United Nations Food and Agriculture Organisation (UNFAO), 66 discrete aquifers have been delineated and examined.
The main groundwater basins in Cyprus according to their geographical location and their hydrogeological properties are as follows:

- Western Mesaoria

- Southeastern Mesaoria
- Akrotiri Peninsula
- Central Mesaoria
- Kyrenia Range (Pentadaktylos)
- Kyrenia Coastal Plain
- Pafos Area
- Chrysochou Basin
- Kiti Area
- Maroni–Anglisides Area
- Pissouri–Paramali Area
- Agia Irini–Kormakitis Area
- Karpas Peninsula
- Troodos Range
- River Bed Aquifers of Marathasa–Lefka–Xeros–Kambos-Limnitis

3.2.4 The Seismicity of Cyprus

Earthquakes are ground tremors that are principally caused by the disturbance of the mechanical equilibrium of the Earth's rocks. It is today known that the Earth's crust is made up of a number of lithospheric plates, which are continuously moving, resulting in the development of forces at their outer limits as well as in their interiors. When the exerted forces exceed the upper limit of elastic deformation of the rocks, then these are ruptured and there is a sudden and violent release of energy that is transmitted in all directions in the form of a wave motion, which in effect constitutes the earthquake. When this wave motion reaches the Earth's surface it can cause damage to buildings and other structures, landslides, land subsidence and fracturing of the ground as well as elevation and hydrographic changes. The point or area of rupture of the rocks is called the focus or hypocentre of the earthquake while the point on the Earth's surface above the focus is called the epicentre.

Special instruments, called seismographs, record the ground tremors of earthquakes and provide seismologists with the necessary information to study the causes, the genesis mechanisms, the transmission of seismic waves, as well as their effect on structures and on Man and the environment.

The graduation of earthquakes is carried out by means of two parameters, the magnitude and the intensity. Magnitude is a measure of the quantity of energy that is released at the focus of an earthquake and is measured on a logarithmic scale that runs from 1 to 10 and is called Richter scale. Intensity is a measure of the fierceness with which an earthquake manifests itself at a particular place and is measured from I to XII on the modified Mercalli scale. Intensity I on this scale is defined as the intensity of an event felt by very few people, whereas intensity XII is that of a catastrophic event that causes total destruction.

3.2.4.1 The Seismicity of the Cyprus Region

Cyprus is situated within the second intensive seismic zone of the earth, that of the Alpine-Himalayan belt. This zone extends from the Atlantic Ocean along the Mediterranean basin through Italy, Greece, Turkey, Iran and India to the Pacific Ocean. The earthquakes occurring in this zone represent about 15% of the world seismic activity.

Cyprus is considered by most workers to be situated on the southern side of the Anatolian Plate, just north of the African Plate. Its seismicity is attributed to the “Cyprus Arc” (Figure 58) which constitutes the tectonic boundary between the African and Eurasian lithospheric plates in the region.

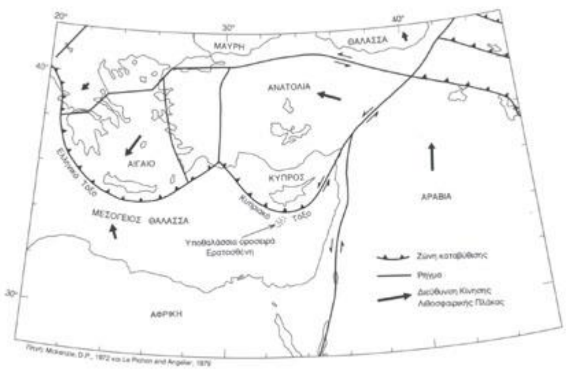

Figure 58: Tectonic Map of the Eastern Mediterranean

The Cyprus Arc starts from the gulf of Antalia, where it joins the Hellenic Arc, passes west and south of Cyprus and extends towards the gulf of Iskenderun in the east where it joins the Eastern Fault of Anatolia. The Cyprus Arc constitutes the zone of subduction of the African Plate under the Eurasian Plate (Figure 59).

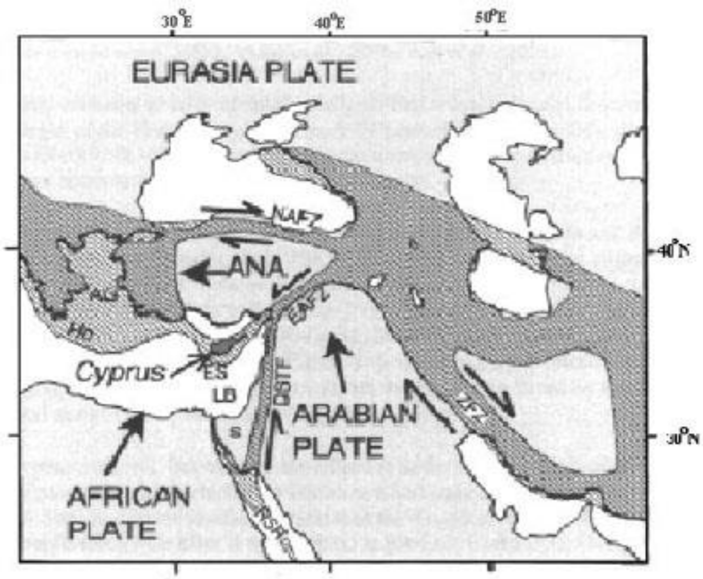

Figure 59: Lithospheric plates in the Cyprus region

Many epicentres are concentrated along the arc, indicating that the tectonic movements along it, are the cause of many earthquakes, several of which are strong. Examples of earthquakes experienced in Cyprus are the one on 23rd February 1995 in the northwest of Pafos and on 9th October 1996 in the southwest of Pafos. Recent neotectonic studies by the Geological Survey Department (GSD) show that Cyprus has several active faults along which earthquakes also occur, like the earthquake of 11th August 1999 which was caused by a movement on the Gerasa fault. It is therefore obvious that the Cyprus Arc takes up only part of the movements of the lithospheric plates and that the remainder is distributed in the rest of Cyprus as far as the Pentadaktylos range.

From the map of epicentres (Figure 60, Figure 61 and Figure 63) of the earthquakes that occurred during the last 100 years, it becomes obvious that the main seismic activity is concentrated in the west and south of the island and along an approximately arcuate zone in the sea, also in the west and south.

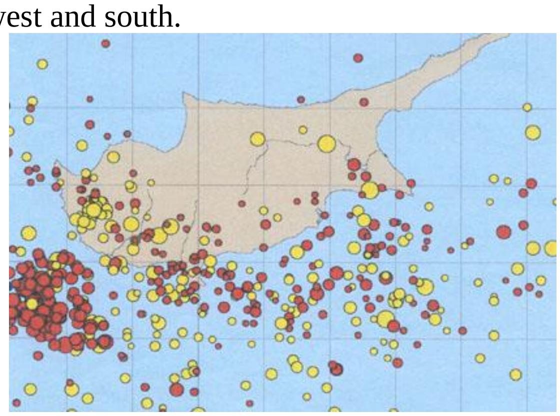

Figure 60: Map of epicentres in the Cyprus region for the period 1905-1996

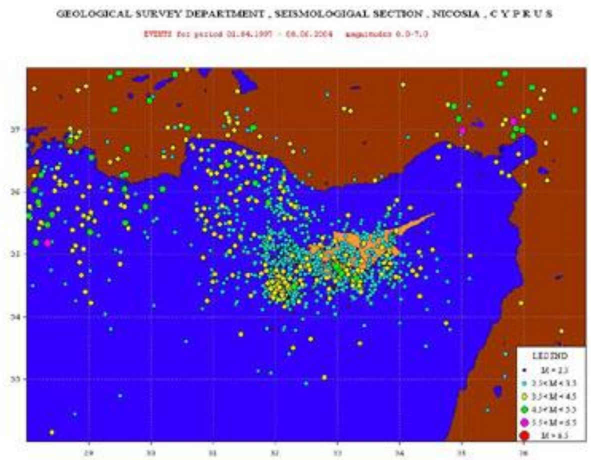

Figure 61: Map of epicentres in the Cyprus region for the period 1997-2004

The largest proportion of seismic activity during the period 1894-1998 is observed to the south of the 35th parallel. There has been seismic quiescence in the southwest of the island during the last 100 years, in contrast with the gulf of Antalia further north where the seismic activity is stronger. A similar but less intense state of quiescence is observed to the northeast of Cyprus towards the gulf of Iskenderun.

3.2.4.2 Historical Records and Instrumental Recordings of Earthquakes

Historical references and recent archaeological findings reveal that Cyprus was struck by strong earthquakes in the past, which on several occasions destroyed its towns and dwellings. Salamis, Kition, Amathus, Kourion, (Figure 62) Pafos and Nicosia as well as several villages suffered damage at different time periods.

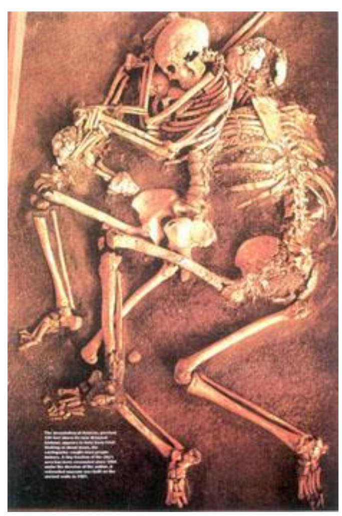

Figure 62: Skeletons of people killed during an earthquake at ancient Kourion

Historical data indicate that 16 destructive earthquakes with intensities of at least VIII on the modified Mercalli scale occurred between 26 BC and 1900 AD. Pafos was levelled in

15 BC while in 76 AD the town was destroyed along with Salamis and Kition. The latter earthquake is considered to be the strongest that ever hit Cyprus. Salamis and Pafos were destroyed again in 332 AD and 342 AD.
The historical data have many inaccuracies and gaps and for some time periods there is complete lack of information. Additionally, several events appear to have been exaggerated by the historians and chroniclers who described them. More accurate data have been collected, regarding the earthquakes occurring in Cyprus and the surrounding offshore area since 1896, when seismological stations started operating in neighbouring countries. The situation regarding the accuracy and completeness of the earthquake recordings improved considerably after 1984, with the establishment of a seismological station in Cyprus and its continual expansion and upgrading. A better picture of the seismicity of the Cyprus region started developing and the areas with higher seismic activity were more clearly recognised. In the time period 1896-2004, more than 400 earthquakes with their epicentres on Cyprus and the surrounding region were felt in several areas of Cyprus. Of these the following 14 earthquakes caused damage and in some of them there were many victims.

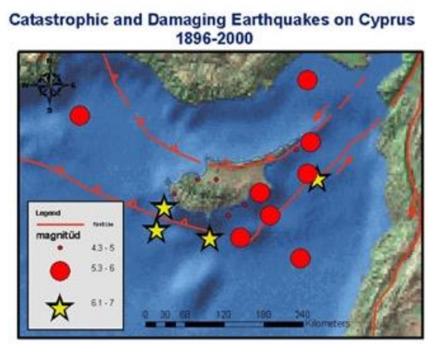

Figure 63: Catastrophic and damaging earthquakes on Cyprus, 1896-2000

Table 2: Catastrophic and Damaging Earthquakes on Cyprus 1896-2000

Date	Magnitude Ms	Description of damage
29/6/1896	6.5	Damage in the area of Limassol, especially at Akrotiri and Episkopi. Many aftershocks followed.
5/1/1900	5.7	Small damage in Mesaoria.
23/2/1906	5.3	Small damage in Limassol and Kolossi. Felt all over the island.
18/2/1924	6.0	Small damage in Famagusta.
13/12/1927	5.0	Small damage in Limassol and in villages to the north (Koilani, Pera Pedi, Monagri).
9/5/1930	5.4	Damage in Pafos town and the surrounding area.
26/6/1937	4.7	Damage in southwest Cyprus (Pachna, Omodos, Platres, Salamiou).
20/1/1941	5.9	Severe damage in the district of Famagusta, especially at Paralimni, where 24 people were injured and many houses collapsed. Limited damage in the districts of Nicosia, Larnaca and Kyrenia.
10/9/1953	6.1	Destructive earthquake in the district of Pafos with 63 dead, 200 injured and 4000 homeless. Many houses were destroyed in 158 villages. The main earthquake was followed by many aftershocks, which caused additional damage.
15/1/1961	5.7	Small damage in Larnaca town and the surrounding area.
28/3/1984	4.5	Small damage in the town and district of Larnaca where it was particularly felt.
23/2/1995	5.7	Destructive earthquake in the Pafos district with two dead. Many houses collapsed in the villages of Pano Arodes and Miliou. There was also damage in the villages of Peristerona, Steni, Gialia, Argaka, Pomos, Pyrgos, Lefka, Neo Chorio, Lachi and Polis.
9/10/1996	6.5	Very strong earthquake in the southwest of Cyprus caused panic to the residents of Pafos and Limassol and to the residents of multi-storey buildings in Nicosia, Larnaca and Paralimni. Twenty people were slightly injured and two lost their lives from indirect causes. Limited damage in Pafos and Limassol.
11/8/1999	5.6	Strong earthquake with the epicentre close to Gerasa caused damage to buildings in Limassol and the villages to the north of the town. Felt all over Cyprus. Forty people were slightly injured mainly because of panic. Many aftershocks followed.

The most catastrophic earthquakes were those of 1941, 1953, 1995, 1996, and 1999.

The study of the historical and recent earthquake recordings shows that the distribution in time of the seismic activity is not regular, but there are periods of intense activity followed by periods of quiescence. Thus, while 28 earthquakes with magnitudes greater than 4.5 were recorded in the period 1918-1937, in the Cyprus region (33.5°-37.0° N, 31.0°-35.5° E), only 11 were recorded in 1960-1990. In the years 1995-1999 there was an increase in seismic activity with strong to very strong earthquakes with magnitudes of 5.6-6.5.

The statistical analysis of the historical data gives a theoretical return period of one catastrophic earthquake every 120 years, while a similar analysis of instrumental recordings of the last 100 years gives the results presented in the Table 3 below.

Table 3: Instrumental recordings of the last 100 years

Magnitude (Ms)	Return period (years)	No. of earthquakes in 100 years
4.6-5.0	8	12.5
5.1-5.5	26	3.8
5.6-6.0	36	2.8
6.1-6.5	75	1.3
6.6-7.0	166	0.6

3.2.4.3 Earthquake Vulnerable Areas

Cyprus lies in a seismic zone and the whole of the island can be considered as an earthquake vulnerable area. Damage from earthquakes that occurred in various times has been reported from almost everywhere. However, both the historical and the contemporary data reveal that the most earthquake prone area of Cyprus (Figure 64) is the coastal zone that extends from Pafos through Limassol and Larnaca to Famagusta. A large part of the Pentadaktylos range and the part of the Troodos range, where the ophiolitic rocks outcrop, constitute the least earthquake prone areas of Cyprus.

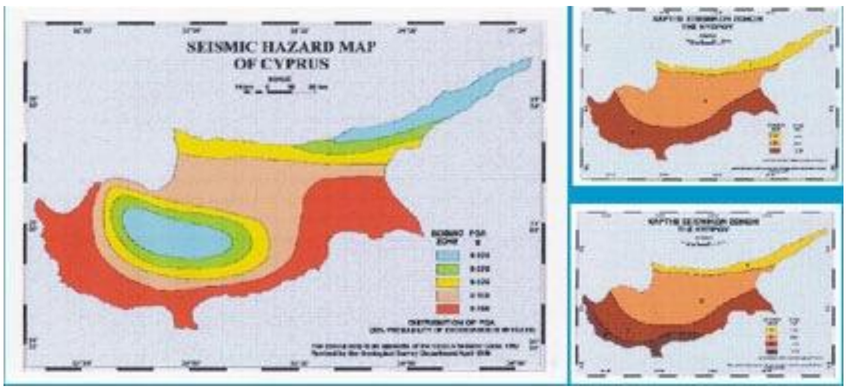

Figure 64: Seismic hazard maps of Cyprus showing that the coastal zone from Pafos to Famagusta is the most earthquake prone area

A large number of medium to strong earthquakes have their epicentres in the sea, several tens of kilometres away from inhabited areas and the damage that may cause is small to negligible, as the intensity with which an area is struck depends on the epicentral distance. As many earthquakes have their epicentres in the west and south, it is obvious that the areas affected more by these are the western and southern coastal zones.

Another important parameter affecting the response of an area towards an earthquake is that of the ground conditions. Areas covered with loose deposits, including most of the coastal areas are more vulnerable to destruction in contrast to areas where the rocks are massive, like the Troodos range which is mostly covered with igneous rocks.

3.2.4.4 Antiseismic Preparedness and Protection

Earthquakes are natural phenomena, which Man cannot avoid. However, Man is in a position to reduce considerably or even obliterate the effects of earthquakes on structures and generally on the environment and in this way offer protection to himself. There are many measures which Man can take within the framework of preparedness in order to face the consequences of earthquakes, most of which revolve around three axes: a) the study and better understanding of the seismicity and seismic behaviour of an area; b) the construction of seismic resistant structures and the anti-seismic shielding of existing structures; and c) the establishment of the necessary infrastructure for the immediate and effective reaction following an earthquake. Coordinated efforts to apply various measures within the framework of the above three axes started in Cyprus at the beginning of the 1980s, mainly by the official authorities but with the support of other institutions and organisations. The measures that have been taken mainly included the following:

a) In the framework of the first axis, i.e. the study and better understanding of the seismicity and seismic hazard, the establishment in 1984 and the operation of a seismological station on Cyprus, the establishment of a network of accelerometers and the carrying out of seismic hazard and neotectonic studies can be included. These measures have been taken by the GSD. The operation of a seismological station allowed for the possibility of the collection of numerous accurate data regarding the earthquakes occurring in the Cyprus region. The processing and analysis of these data has considerably assisted the definition of the seismic sources, and estimation of the expected magnitudes of earthquakes, their recurrence periods and various other parameters that make up the seismicity of the Cyprus region.
The first four accelerometers (Figure 65) were installed by the GSD in the southern part of Cyprus in 1986. By the end of 2003, forty accelerometers were installed in the same part of Cyprus and in particular in the coastal areas, which cover various geological formations.

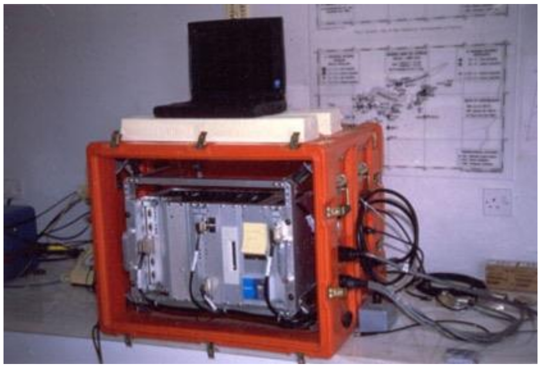

Figure 65: Accelerometer

The accelerometers measure the acceleration with which the ground shakes during an earthquake, a parameter that is necessary for the determination of the dynamic behaviour of soils (i.e. under earthquake conditions). Similarly, six strong motion instruments were installed in the northern part of Cyprus in August 1996 by the Near-East University, in cooperation with Kandilli Observatory and the Earthquake Research Institute,
The neotectonic studies aim at mapping the active faults, i.e. faults along which there is recent movement and can produce earthquakes, and estimating the parameters of these faults. Neotectonic studies were first carried out in Cyprus towards the end of the 1990s. So far they have covered the areas of Limassol, Pafos (Figure 66) and Nicosia and they are continuously extended so that they eventually cover the whole of Cyprus.

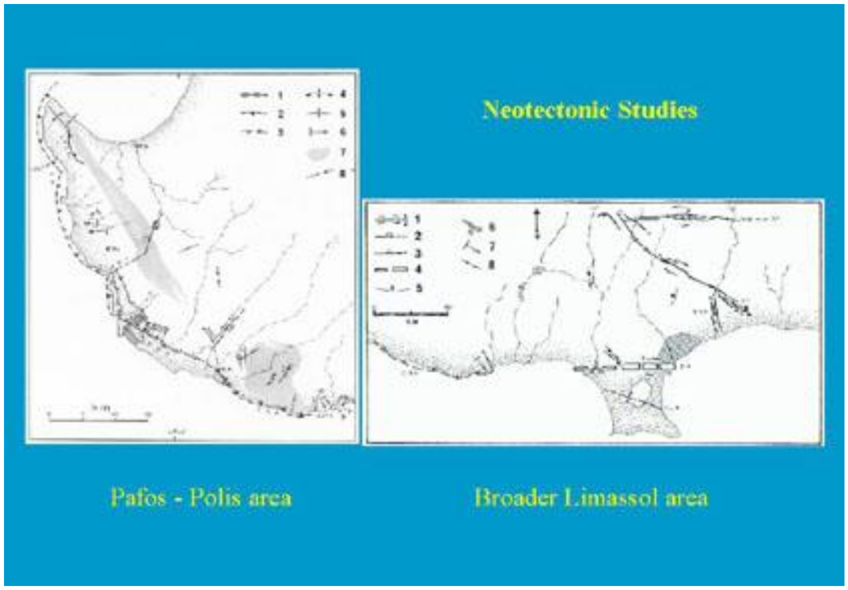

Figure 66: Neotectonic maps of the Pafos and Limassol areas

The seismic hazard or microzonation studies (Figure 67), as they are also known, aim at determining and mapping the response of the ground, i.e. the magnitude and kind of earth movement, and generally its behaviour in the case of an earthquake. In carrying out these studies various data are taken into consideration and co-estimated, like the seismic sources which can affect the area under study, the prevailing geological and geotechnical conditions and the accelerometer recordings. The results of such studies are taken seriously into consideration by civil engineers in the design of structures.

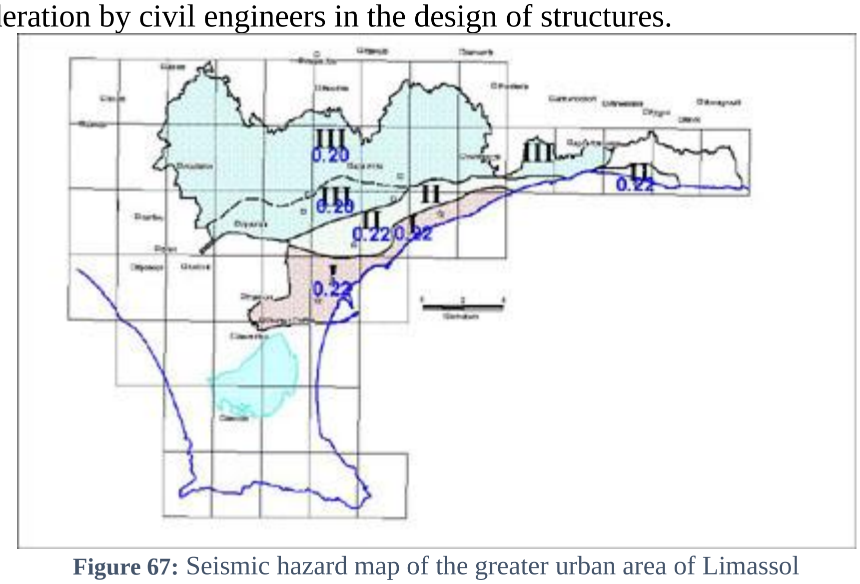

Figure 67: Seismic hazard map of the greater urban area of Limassol

b) In the framework of the second axis, i.e. the construction of seismic resistant structures and the antiseismic shielding of existing structures, the first steps were taken in 1986 with the introduction of the "Brief Antiseismic Measures" which was then followed in 1994 by the introduction of the "Seismic Code", whose application was compulsory for structures with reinforced concrete. These actions were taken by the Seismic Engineering Committee of the Association of Civil Engineers and Architects and the Cyprus Committee of

Antiseismic Measures in cooperation with relevant official services. Efforts are being made today by the Scientific and Technical Chamber of Cyprus to harmonise the Seismic Code of 1994 with Eurocode 8 for the Design of Structures for Earthquake Resistance.

Since 1998, in the northern part of Cyprus, conferences and seminars have been held by the Near-East University, the meteorological authorities, the Chambers of Architects and Civil Engineering as well as the planning and construction authorities. In addition to this, the most important research and study was carried out by the town planning authorities before the approval of the Nicosia Master Plan in 2000.

In the last few years, and in particular after the earthquake of 11th August 1999, studies of the seismic risk of existing structures were initiated. Priority was given to the seismic shielding of school buildings. Within the framework of a project supported by the Bi-communal Development Programme, which is funded by USAID and UNDP and is executed by UNOPS, a seismic risk study of Nicosia was carried out and it is expected that similar studies will be conducted in the future in the other towns.

c) In the framework of the third axis, i.e. the establishment of the necessary infrastructure for the immediate and effective reaction following an earthquake, important steps have been taken in the last few years by the GCC. The most important step appears to have been the legislation and application of the "Civil Defence Law". Other steps refer to the better organisation of the Civil Defence Service, the establishment of the "Damage Restoration Service" and the formation and training of rescue teams. Several other services and organisations, like the district administrations, the technical departments and the Technical and Scientific Chamber of Cyprus have been organised for immediate action in the case of an earthquake.

3.2.5 Environmental Issues

In the last few centuries, and in particular since the Industrial Revolution in the late 18th century, scientific and technological advancements have been considerable. Man has exploited and used mineral resources such as metals, coal, asbestos, oil and many others but all this activity has started to have negative effects on the environment.

Industrialisation caused urbanisation and the expansion of towns and cities to mega-cities, with tens of millions of inhabitants. The extraction of minerals created big scars on the Earth's surface as well as large waste dumps and the use of chemicals such as DDT, has caused serious diseases. The burning of fossil fuels such as coal and oil has caused atmospheric pollution as well as climatic changes, also known as the 'greenhouse effect'.

All these negative effects, which happened in the name of progress and development, were not of much concern until the 1980s. Reaction to the negative effects on the environment started only when it was realised that they were also seriously affecting quality of life. In order to minimise further negative developments, it became necessary to predict and assess the impacts on the environment and propose measures of mitigation of these impacts or even prevent certain activities if the impacts were predicted to be catastrophic. For developments that have already taken place, measures have been taken to alleviate the negative impacts on the environment. According to the Environment Service, the environment can be considered as what includes the waters, the atmosphere and the soil, together with the organisms living in or on them. Our environment consists of natural systems, which have operated in a delicate balance for a long period of time. Although we can manipulate many natural systems, there are often many unforeseen consequences. Natural systems adjust to artificial changes in ways that cannot always be anticipated. The basis of our entire environment is the geological system. It is a complex system that includes soils, rocks and minerals, surface waters and groundwaters. Early civilised Man's impact on the geological system or environment was very small and could normally be obliterated through the action of geologic processes. However, as the population increased and scientific and technological advancements were achieved, the need for housing, food, raw materials and other commodities started causing larger and more permanent impacts on the geological environment to the extent that geological processes could not restore it.

3.2.6 Geotechnical Hazards

Since ancient times, Man has taken into serious consideration the soil or ground that is to be used for the construction of various works such as roads, bridges (Figure 68), buildings, water dams (Figure 69), ports and mines. Building work was carried out as soon as it was decided what effect the ground would have on the stability and safety of his structures. This relationship between the ground and any structure that is built on it constitutes the cornerstone on which the foundation of any structure is based upon. The scientific branch that studies this relationship is Engineering Geology, and its ultimate objective is the study and understanding of the mechanical behaviour of all geological formations and the interaction of these formations to any type of civil engineering structure. Engineering Geology ensures the stability and safety of a structure under static and dynamic conditions in the foundation level. The ground (soil and rock) is often a heterogeneous mass that may change vertically or horizontally. These changes are often unpredictable due to a number of reasons including the way and conditions in which it was formed, the local geological conditions, the tectonic effects and the seismic strain. Thus, the knowledge of the characteristics of the material on which a structure is to be constructed constitutes the basic presumption for the stability of the structure.

Figure 68: Construction of a bridge along the Limassol-Paphos highway

Figure 69: Aerial view of a water dam

The knowledge of the characteristics of the ground is achieved through a geotechnical investigation, which is divided into site and laboratory investigations. During the site investigation, knowledge is gained on matters such as the type, composition and structure of the geological formations, their thickness and side variations, the main mechanical properties of the ground and the hydrogeology of the area. These characteristics of the ground are obtained through geological mapping, geophysical surveys, exploratory boreholes, pits and trenches. The laboratory investigations include a number of tests and analyses on samples collected during the site investigation to obtain the physical and mechanical properties of the ground as well as its chemical and hydraulic characteristics.

3.2.7 Geotechnical hazards

The main geotechnical problems that occur in Cyprus are:

a) slope failures and landslides (Figure 70),

Figure 70: Landslide in the Paphos district

b) rock falls (Figure 71)

Figure 71: Dealing with a rock fall in the field

c) foundation settlements (Figure 72).

Figure 72: Collapse of the surface (left part of the photograph) due to the formation of a sinkhole

Slope failures and landslides: This term includes phenomena of partial or total instability or failure of natural or manmade slopes. Landslides may occur due to:

a) the mineralogical composition of the ground (presence of clay minerals),

b) the presence of faults, especially when their dip is parallel to that of the slope,

c) the dip of the sedimentary layers (parallel to the dip of the slope),

d) frequent and heavy rainfall resulting in erosion and mechanical weakness of the soil or abrupt increase of the water table,

e) intensive groundwater pumping resulting in lowering the water table, internal erosion and reduction of the soil cohesion, and

f) earthquakes and manmade intervention.

In Cyprus, relatively large and active slope failures and landslides occur in the western part of the island (Paphos District), where rocks of the Mamonia Complex and the Kannaviou Formation are exposed. Characteristic examples of landslides are observed in the villages of Mamonia, Kannaviou, Statos, Pentalia, Kritou Marottou, and Anadiou. In the southern part of the island (Limassol District), landslides relate chiefly to the Lower Marls of the Lefkara Formation as well as the Moni Formation (bentonite). Examples can be seen in the areas of the villages of Kilani, Silikou, Doros, Korfi, Trimiklini as well as Moni and Pentakomo. Also, in northwest Cyprus, landslides can be observed along the roads from Morphou to Skylloura and from Myrtou to Panagra. The long mining history of Cyprus has resulted in extensive waste dumps in many areas such as Kalavasos in the south, Limni in the northwest, Mitsero and Mathiatis in central Cyprus and Troulli in the east. In all these examples the waste dumps have been deposited without a proper design. They are characterised by high porosity and high compressibility, low density and limited strength. Thus, under certain conditions the slopes of these dumps may develop landslide phenomena. A number of measures can be taken either separately or in conjunction with one another to face the problem of slope failures and landslides. Such measures include the decrease of the dip of the slope, the unloading of the land-slit mass, the construction of berms or terraces, the controlled pumping of ground water to maintain a stable water table, the construction of drainage system and retaining walls etc.

Rock Falls: Rock falls are observed mainly in the mountainous areas of Cyprus and in natural and manmade slopes. They are mainly related to one or more causes according to the geological, topographical and rainfall conditions. Faults and fractures play an important role, especially their density and network. Earthquakes often contribute to the fracturing of the rock mass and eventually to rock falls. Rock falls directly affect the safety of the people. Examples of rock falls have been observed in Lemithou, Akrounta, Pelentri, Prodromos and along the road from Nicosia to Kyrenia.

Depending on the characteristics of each case of rock fall, different measures can be taken to resolve the problem. The most frequently used method for facing the problem is the installation of anchors and rockbolts.

Foundation settlements: Settlement is the subsidence of a civil structure that is caused by its weight and the relative compressibility and deformation of the underlying soil. Thus, foundation settlements are highly related to the geological conditions and the mechanical properties of the ground. Marls, clays and gypsum are the main soil types in Cyprus that are related to foundation settlements.

In Cyprus, marls are found in different types according to their geological age and lithological characteristics. Marls are found either as thin interlayers in the Lefkara and Pakhna Formations or as thick layers in the Athalassa and Nicosia Formations. The most extensive and significant type of marl, from the geotechnical point of view, is that of the Nicosia Formation. The mechanical behaviour of marl depends significantly on its moisture and clay content. Thus, the mechanical behaviour of marl is very sensitive to the effects of water, which gives rise to swelling and shrinkage phenomena leading to cracks in buildings. Some clayey geological formations that contain the mineral montmorillonite, and thus belonging to the bentonitic soils, are characterised by high plasticity and swelling as well as shrinkage under certain water-content conditions. In summer, for example, they shrink due to dryness and cause volume reduction leading again to the development of cracks in civil structures. In winter, on the other hand, they expand (swelling effect) due to the absorption of water and become more plastic which reduces their strength and increases their compressibility. The most characteristic swelling clays in Cyprus belong to the Kannaviou and Moni Formations (bentonitic clays), although the Lower Marls of the Lefkara Formation also exhibit significant swelling properties. The problems that are related to swelling clays are mainly seasonal movements of buildings (subsidence and lifting) and other linear civil structures such as roads and drainage systems. Swelling clay effects are observed in areas around the villages of Pentakomo, Moni, Kannaviou, Kritou Marottou, Pentalia, Marathounta, Nata, Kythrea, Myrtou, Gastria and Kornokipos. Also, landslides are observed in areas that are composed of bentonitic clays.

The solution to the problems relating to foundation settlements due to the presence of marls or bentonitic clays is difficult, expensive and often of limited effectiveness. The main remedy includes measures to ensure stable moisture content on the foundation level. Raft foundation is also designed as well as pilling.

Foundation settlements or subsidence of civil structures can also be caused by the development of void spaces or caves in the ground called sinkholes. In Cyprus, sinkholes are formed in lithological units that contain either gypsum or limestone and they are the products of the dissolution of these two lithologies by water. Sinkholes in gypsum occur all over the island, in particular in the areas of Pissouri, Maroni, Aradippou, Kathikas, Kalavasos, Nisou, Pergamos and between Lefka and Galinoporni. The sinkholes are rather

small in size, may have an irregular shape and constitute foundation “traps”. When their roof collapses due to the weight of the civil structure on top, sinkholes may cause subsidence problems. Remedial measures are often very difficult and include filling up the sinkhole with grout.
Limestone is another rock type that sinkholes or caves can be developed in due to its dissolution by water. In Cyprus, the dissolution of limestones appears to be rather limited, forming small, irregular surface caves or complex underground voids and drainage systems leading to the development of karstic springs (karst is a term derived from the Carso area in the Dalmatian Alps in Yugoslavia relating to rock dissolution). Such karstic springs are found in the northern part of the island along the Pentadaktylos Range. Underground dissolution voids are difficult to identify from the surface and constitute a serious potential problem in the stability of civil structures.

3.2.8 Geoforms

Geoforms are specific geological forms or features, which have aesthetic, scientific, cultural or instructive value and should be protected and preserved for present and future generations. They are natural monuments, which were formed throughout geological time by means of a variety of geologic processes, including denudation (erosion, weathering and transport), deposition, earth movements, metamorphism and igneous activity. Some of them were revealed by the action of man in relation to activities such as road construction, mining and quarrying. Although the value of geoforms has been known to geologists and naturalists for some time now, it was only recently that systematic and coordinated efforts were made to record them and include them in “National Catalogues of Natural Monuments” and the UNESCO “Catalogue of World Natural Heritage”. Geoforms are gradually becoming better known to the public and are being more and more appreciated.

3.2.8.1 Geoforms in Cyprus

In Cyprus, a number of geoforms have been identified, recorded and described, and several of them have already been included in official catalogues. The following list includes some of the better known examples:

1. **Flat topped, steep sided hills called “mesa”,** (Figure 73) characteristic of the Mesaoria Plain. The upper surfaces of these hills are covered by hard rocks, usually calcareous sandstone or cemented gravel and their sides by softer marl. Their formation is due to the differential weathering of these rocks in conjunction with the uplifting movements in Cyprus.

Figure 73: Flat topped, steep sided hills called “mesa”, characteristic of the Mesaoria Plain

- **Aronas hill** (Figure 74), on the Athalassa-Geri road, is a typical example, because it is capped by a flat lying bed of hard calcarenite, which overlies softer marls. The rocks belong to the Nicosia-Athalassa Formation of Pliocene age. The hill is bounded towards the top by a steep cliff, which has developed in the mechanically strong layer of calcarenite, but the sides of the hill become much gentler in the underlying marls and provide a marked contrast. The hill is isolated and forms an erosional remnant of the Mesaoria plain that persisted because of its protective cover of more resistant sedimentary rock of calcarenite.

Figure 74: Aronas hill is a typical example of “mesa” type topography

2. **Gorges.** (Figure 75) They occur in several parts of Cyprus and have formed due to the down cutting action of rivers through chemically resistant and mechanically strong rocks in areas that have been raised high above sea-level.

Figure 75: Gorges have formed due to the downcutting action of rivers through chemically resistant and mechanically strong rocks

- Androlykou, Limnati and Avakas (scan photo from pamphlet of Env Serv) are typical examples. Avakas is one of the deepest, steepest and narrowest gorges of the island. It has taken its name from the river of Avakas or Avgas, which through the centuries has cut through the calcareous rocks of the area to form this explicit natural monument. The rocks belong to the Lefkara and Pakhna Formations. The gorge is 6 km long, starting from Pegeia forest to the east and ending at Toxeftra coast to the west. The most impressive part of the gorge, however, is limited to a length of 2 km. In this part, vertical calcareous rocks rise some 30 m above the river bed. Here the gorge is also very narrow with a width of about 2 m, which can exceed 6 m in other places. The gorge has a rich flora and its walls are usually moist. The ecosystem that has developed there is very fragile and this unique geoform must be protected and preserved.
- Khali or Lefkoniko Pass on the eastern extension of Kyrenia Range to the north of Lefkoniko;
- Panagra to the north of Myrtou.

3. **Important fossil sites.** Fossils of mammals and in particular of pygmy hippopotami and pygmy elephant were found in caves and other natural cavities that formed in the terrestrial Pleistocene formations of Cyprus. These mammals appear to have come to Cyprus 100,000 to 250,000 years ago and adapted to the new environment of an island. The most important adaptation was dwarfishness. The pygmy

hippopotamus of Cyprus (Phanourios minutus) (Figure 76) had a length of 1.5 m and a height of 0.75 m while the pygmy elephant (Elephas cypriotes) had a height of about 1 m. They became extinct about 10,000 years ago. Reese (1995) has recorded 40 sites from all over Cyprus where mammal fossils were found.

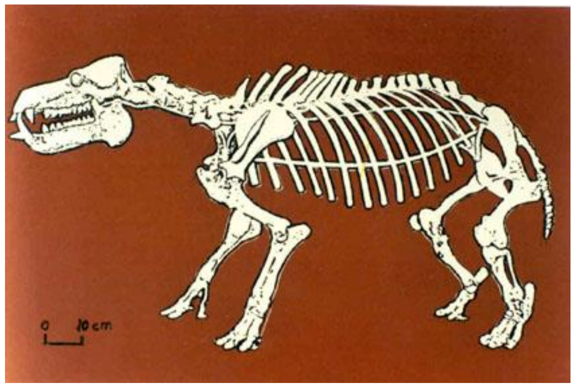

Figure 76: A restored cypriot pygmy hippopotamus skeleton

- **Kakkaristra site** (Figure 77) near Latsia. The Kakkaristra fossil site is situated within the Kakkaristra gorge (Figure 78), which lies to the southwest of Latsia. The gorge is about 1 km long and a maximum of 10 m deep. It developed during the Upper Pleistocene after the emergence of the area above the sea and the action of denudation on the resistant beds of the newly formed land. The rocks, through which the gorge has cut, include sandy marls, greywackes, calcarenite, limestone and conglomerate. The fossils of the Kakkaristra fossil site occur in sandy marls of the Nicosia Formation of Pliocene age. They are made up almost entirely of Ostrea edulis but other species including Pecten and Balanus are also found. They are mostly concentrated in a layer.

Figure 77: *Fossil shells at Kakkaristra*

Figure 78: *View of the Kakkaristra gorge to the southwest of Latsia*

- Potami site - remains of Conifers; these are found in Pliocene marls and are quite well preserved. They provide the oldest evidence for the presence of conifers in Cyprus.
- Empa site – Bones and teeth of pygmy hippopotamus and elephant; pygmy hippopotamus and elephant fossil sites are also found at:
    - Agia Napa
    - Akrotiri-Aetokremmos;
    - Agia Irini;
    - Agios Georgios town to the west of Kyrenia, on the coast;
    - North of Akanthou village;
    - NNE of Kato Dhikomo.

4. **Caves.** They have formed in rocks of limestone and gypsum and their formation is due to the solution of the rock mass by rainwater charged with carbon dioxide. Stalactites grow downward from the roof and stalagmites upward from the floor. In Cyprus, caves are usually small because of the limited thickness and extent of the limestone and gypsum formations.

- Xylofagou caves (Figure 79) in Koronia Limestone.

Figure 79: Caves in limestone at Xylophagou (Cape Pyla). Fossil bones of mammals are found in some of these

- Kyrenia Range caves in Mesozoic limestones. They occur in particular on the southern flanks of the Kyrenia Range immediately to the north of Aghirda village and Ay. Khariton.
- Man-made caves from the ancient times. These caves were excavated in the sandy marls of the Nicosia Formation and are found at Galinoporni and Korovia villages. It is thought that these caves belong to the early Byzantine times. Similar caves were found at the eastern part of Koma tou Yialou village; they were excavated into calcarenite.

- Gypsum cave at Platani village. This is described in greater detail below.

5. ***Important rock outcrops.***

- Koronia Hill on the Astromeritis – Troodos road to the southwest of Koutrafas. It is a good example of locality for the Koronia Limestone Formation of Upper Miocene age as it provides a complete section. It is a reef limestone with fossils of corals and molluscs including Pecten, Cardium and Venus. It rests directly on Upper Pillow Lavas and due to its toughness, the limestone has resisted erosion and forms a capping on the hill. Similar rocs occur at Armenochori. (Figure 80)

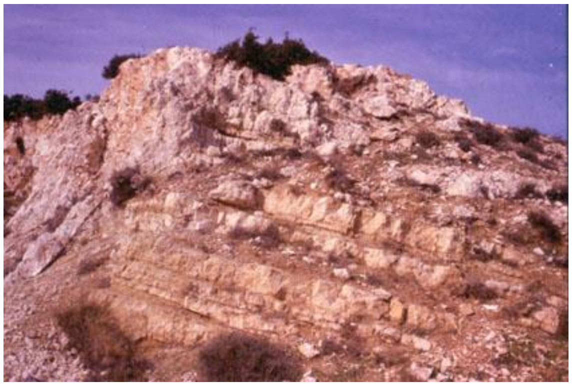

Figure 80: Koronia reef limestone at the top of the hill at Armenochori

- Kathikas Melange (Figure 81). Typical outcrops of this Upper Cretaceous Formation occur to the west of Kathikas and on the Koilineia – Vretsia road. This spectacular series of debris-flows (olistostromes) form the Kathikas Formation of Upper Cretaceous age. The melange comprises clasts of nearly all of the rocks of the Mamonia terrane (chert, sandstone, lava) in a matrix of reddish-purple argillaceous sediment.

Figure 81: Typical outcrop of Kathikas melange

- Picrite basalt – Upper Pillow Lavas at Margi. The site lies 500 m to the southwest of Margi village and has long been of interest to the geo-scientists. Good examples of picritic and glassy olivine basalts are found here and certain horizons contain fresh volcanic glass. Such lavas are relatively rare elsewhere.

- Pillow Lavas – Maroullena- Akaki River at Klirou (Figure 82); Panagra gorge on the Myrtou–Kyrenia main road; and Platanisso village in the Karpas Peninsula.

Figure 82: Horizon of Lower Pillow Lavas showing typical pillows and dykes

- These pillow lavas are spherical or ellipsoidal structures, usually composed of basalt lava 30-70 cm in diameter. They are the result of rapid cooling of hot, fluid magma that came into contact with seawater. The Troodos pillow lavas are cut by steeply dipping dykes composed of the same basaltic material. Many of these dykes represent the feeders of later lava flows.
- Travertine terraces at Chiklos site on the Kyrenia – Nicosia main road and in the town centre and southern portion of Lapithos village in the Kyrenia district.
- Pinnacles (tall pyramidal stacks in Mesozoic limestone of the Kyrenia Range close to the road from Vasilia to Larnaca tis Lapithou and on the road between Karmi and Phtreykha.

6. *Important mineral exposures.*

- Zeolites (Figure 83) – near Avdellero. The most common zeolite minerals found at Avdellero are analcite and natrolite and they occur in Upper Pillow Lavas. Analcite is normally found in the form of trapezohedron crystals, milk-white in colour but quite often colourless, several millimetres across. Natrolite occurs in the form of fibrous or radiating crystals sometimes 3-4 cm long.

Figure 83: Zeolite crystals of analcite and natrolite from Avdellero

- Rare nodular chromite – Limassol and Akapnou forests. This form of chromite consists of closely packed, rounded and elongated nodules in a serpentinite matrix. Individual nodules vary in diameter from a few millimetres to 2-3 cm and are often perfectly rounded. This nodular texture is known as leopard ore.

- Twin gypsum crystals (Figure 84) – Eledio-Amargeti road and Kathikas-Stroumpi road; near the road junction between Pano Dhikomo and Vouno.

Figure 84: Twin gypsum crystals

- In the Eledio-Amargeti and Kathikas-Stroumpi areas the gypsiferous deposits accumulated in a small basin bounded by higher areas, represented by the Troodos ophiolite to the east and the Akamas peninsula to the west. In this area the gypsum is of two types: a) fine-grained alabastrine sugary gypsum and b) elongate swallow-tail gypsum. The latter form is the most impressive with individual crystals attaining lengths of 3 m.

- Chromite sands are found at various beach sites in the northern part of Cyprus, like Monarga (Bogaz) and to the east of Agios Epiktitos village in the Kyrenia District.

- Secondary copper mineralisation occurrence in the oxidation zone to the west of Platanisso.

- Some Barite occurrences around Kilanemos village in the Karpas Peninsula.

7. **Prominent rock blocks** (Figure 85). They are usually large, detached blocks of limestone or sandstone of the Mamonia Complex and other formations.

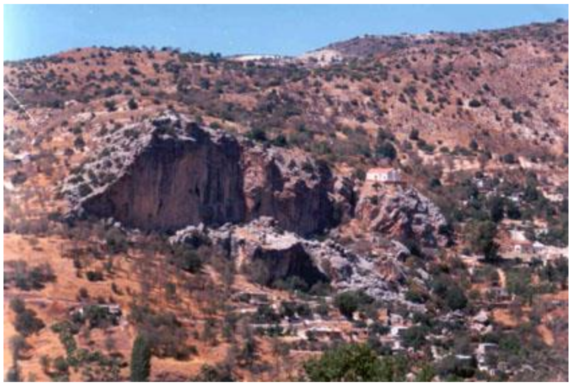

Figure 85: Recrystallized limestone block at Episkopi, Pafos

- Hasampoulia (Figure 86) – recrystallised limestone on the Nikoklia - Agios Nikolaos road near Prastio, Pafos. The rock rises 30 m above the ground and in combination with the rusty and dark colours of its surface presents an impressive picture.

Figure 86: Hasamboulia: Impressive limestone blocks on the Nikoklia-Ayios Nikolaos road near Prastio, Pafos

- Inia rocks (scan photo from pamphlet of Env. Serv.) – large, detached rocks of Akamas Sandstone near Inia.

3.2.9 Risk From Tsunami in Cyprus

Destructive tsunami has hit Cyprus in its history, have caused loss of human life and have destroyed its then coastal cities and ports, as confirmed by historical testimonies of people who have survived through the centuries. Each tsunami, however, leaves behind geological evidence: 'When it hits the shores, it carries with it various materials from the seabed, which it deposits on land and later constitute the geological evidence of the phenomenon.
The map below shows the recorded and confirmed tsunami sources worldwide from 1610 BC. by 2014. These sources include earthquakes, volcanic eruptions, submarine landslides and other unknown causes. The Pacific Fiery Zone has the highest tsunami activity, while the Mediterranean region accounts for 16% of global activity.

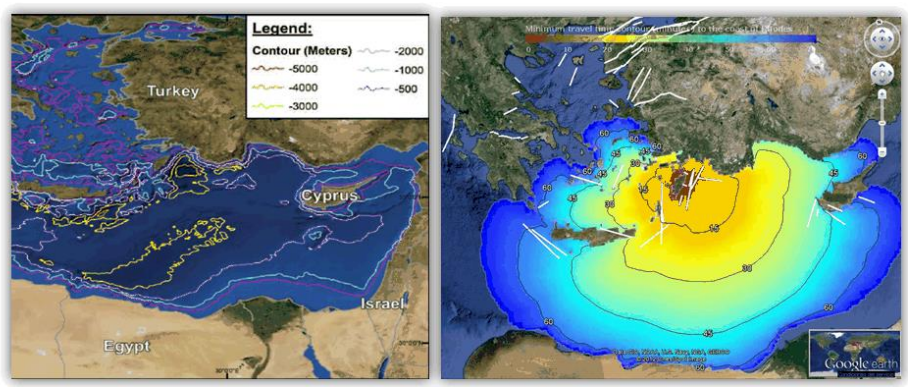

Figure 87: Recorded tsunamis in Cyprus area

The depth of the Mediterranean Sea in the region of Cyprus reaches up to 3 km, with the result that the speed of tsunami propagation, which depends directly on the depth, is about 500-600km / h in the open sea, in contrast to Pacific Ocean where speeds are up to double. However, because the coasts of Cyprus are very close to tsunami sources, the warning time is very short and ranges from a few seconds to an hour and a half for the most remote sources, unlike other parts of the world, where the warning time is of the order of several hours.

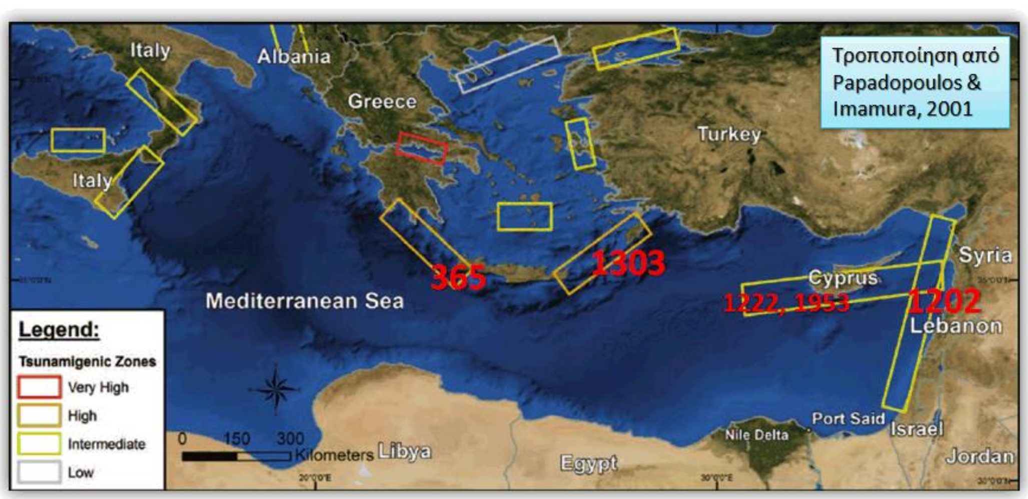

Figure 88: Tsunami zones of the eastern Mediterranean

The above map shows the tsunami zones of the eastern Mediterranean with a categorization in relation to the intensity of the tsunamis that they can cause. The zones that affect Cyprus in the Cyprus Seismic Arc and on the Levantine coast are classified as moderate intensity zones, while the zones in the Greek Seismic Arc are classified as high intensity zones.
In Cyprus, the tsunami risk comes from three different sources:

- Local, strong, submarine and surface earthquakes in the central part of the Cyprus Arc (such as the earthquakes of 1222 and 1953),
- submarine landslides on the Levantine coast which are caused by strong earthquakes in the Dead Sea fault (such as the earthquake of 1202)
- regional, strong, submarine and surface earthquakes in the Greek Arc (such as its earthquakes 1303 and 365). The following is a brief description of the above important events.

3.2.9.1 Historical Tsunamis

On May 11, 1222, a very strong submarine earthquake in the Cyprus Arc, which is today considered to be of the magnitude of 7.0-7.5 on the Richter Scale, caused one of the most devastating tsunamis to hit Cyprus in its history. The earthquake and tsunami caused severe loss of life and extensive damage in Paphos and Limassol. The city and the fortress of Paphos were leveled, while its port was left without water as the coastline moved to the sea.
Ogerius Panis and Marchisius Scriba (1294) experienced the tsunami and described:"Κύπ .in Cyprus the sea rose from the vibration and rushed to land. Huge masses of sea water as big as mountains flooded the land, demolishing buildings and filling villages with fish. "Paphos suffered the most, its port dried up and the city was flooded by the sea."
Researchers' simulation of this tsunami (Yolsal et. Al, 2007) showed that after the earthquake, Paphos was hit in about 20 seconds, Limassol in 4 minutes, Famagusta in 25 minutes, the rest of the coast of Cyprus within one hour.
On May 20, 1202, a very strong land earthquake in the Dead Sea Rift, which is now considered to be of magnitude 8.0 on the Richter Scale, caused a submarine landslide off the coast of Syria, which in a chain caused a catastrophic the eastern Mediterranean. Arab historians have vividly described the devastation of the tsunami: "The sea between Cyprus and the Levantine was divided and waves as high as mountains gathered, sending ships ashore and flooding the eastern regions of Cyprus." Researchers' simulation of this tsunami (Salamon et. Al) showed that the Levantine coast was hit within the first 30 minutes after the landslide, eastern Cyprus in 20 minutes, western Cyprus in 40 minutes and Northern Cyprus within one hour.
On August 8, 1303, a very strong submarine earthquake in the eastern part of the Greek Arc, which is now considered to be of the magnitude of 8.0 on the Richter Scale, caused one of the most devastating and documented tsunami events in the Mediterranean.
The earthquake and tsunami caused extensive damage in Crete and Egypt with severe loss of life. The tsunami hit Turkey, Cyprus and the Levantine coast to a lesser extent. Researchers' simulations of this tsunami (Yolsal et. Al, 2007) showed that after the

earthquake, Cyprus was hit in 70 minutes and the entire eastern Mediterranean within an hour and a half.
On July 21, 365 AD, in the western Greek Arc, perhaps the strongest earthquake that has ever hit the Mediterranean occurred. Today it is believed that it was of the order of 8.5 degrees on the Richter Scale, and that it was associated with a fault area of 200x50km and a vertical displacement of 15 meters. The earthquake shook the entire Eastern Mediterranean, flattening the whole of Crete and causing extensive damage. Today it is believed that it caused the elevation of Crete by 10 meters. The quake was followed by a devastating tsunami that struck the Eastern Mediterranean - killing 50,000 people in Alexandria alone. A Roman historian experienced the tsunami and described: "θάλασσα, the sea receded and the waters were drawn to such an extent that its seabed and marine life were revealed. Huge amounts of water killed, on their return, many thousands of people. Some large ships were blown up by the waves on the roofs of houses, as happened in Alexandria, and others up to two miles from land."
It is worth mentioning that recent earthquakes in Cyprus caused small, non-destructive tsunamis. In 1941, a 6.5 magnitude earthquake in Famagusta caused a small tsunami that was observed off the coast of Israel. In 1953, a magnitude 6.5 earthquake in Paphos caused a small tsunami off the coast of Paphos.
Along the southwest coast of Cyprus, which starts north of Paphos and extends for about 40 km to the southern part of the Akamas Peninsula, there are chaotic deposits of boulders with sandy loam coastline environment. These boulders weigh several tons, have angular edges and relatively fresh peeling surfaces, suggesting that they have been deposited where they are today by strong thrusts such as tsunamis. Similar deposits exist on almost all coasts of Cyprus, such as Kormakitis, Karpasia, Cape Greco and Pyla, while in Ayia Napa there are areas from which the soil is absent.

4 Local Legislations and Financial Recourses

4.1 The city of Milano, Italy

The Local Government Plan approved in 2019 (PGT Milano 2030) subdivides the city at an administrative level into 9 municipalities and at a more detailed level into 88 neighbourhoods (NIL - Nuclei di Identità Locale). The area selected for the study is part of Municipio 1 “Centro” and NIL 01 “Duomo”. The area of NIL 01 is about 2,3km^2 and is densely urbanized (96,7% of the surface is urbanized), with 49,3% of the soil ocupied by buildings and only 9,2 of the surfaces dedicated to green. Due to the high concentration of public buildings and services, the population density is not so high with respect to other neighborhoods (7,289 inhabitants/km^2). Cultural services represent 25% of the services in the area, being 92 out of 373 identified services.

4.1.1 Heritage Protection Legislative Framework

The cultural value of the area is clearly expressed in the legislative system. The entire historic centre (the area defined by the Spanish walls) is subject to landscape protection (Legislative Decree 22-01-2004 n.42, Part III - Title I, as amended). The urban fabric is identified as a "complex of immovable assets that constitute a characteristic aspect of aesthetic and traditional value" (Art. 136.1.c). Some specific buildings are also subject to architectural protection (Legislative Decree 22-01-2004 n.42, Part II - Title I, as amended)

and are protected by direct (Art.10 and 11) or indirect (Art.45, 46 and 47) protection prescriptions.
Legislative Decree 42/2004 deals with the complex system of landscape protection, with reference to the Unique Text of Legislative Provisions on Cultural and Environmental Heritage 490/1999. The legislative framework of reference is the European Landscape Convention adopted on 19 July 2000, which has been applied in Italy since 1 September 2006. In particular, the Convention aims to commit public authorities to implement, at local, regional, national and international level, policies and measures to safeguard, manage and plan Europe's landscapes, in order to preserve and improve their quality and ensure that populations, institutions and territorial bodies recognise their value and interest and participate in public decisions on them. There is a new concept of the landscape dimension of the territory. In fact, the principle of the uniqueness of the landscape is established, and its protection must no longer be exercised over individual portions of the territory, but rather in a total perspective.
In art.1, a., the Convention establishes that "landscape designates a determined part of the territory, as it is perceived by the populations, whose character derives from the action of natural and/or human factors and from their interrelationships". The introduction of the art. 9 in the Italian Constitution has produced the reception of the term landscape in its current meaning at that time, as a result of a value judgement and intended as a peculiar aspect of the national identity to this meaning has been added, especially after the introduction of the law n. 431/1985, the further reference to other territorial areas by virtue of their morphological or location characteristics.
Article 134 of the Code identifies the following categories of landscape heritage:

1. the properties and areas of public interest referred to in Article 136 which, due to their intrinsic landscape value, are the subject of measures declaring significant public interest in accordance with the procedures established by the Code (Articles 138 -141).
2. the areas referred to in article 142 are in any case of landscape interest. These are, with minor modifications, the categories of assets already introduced by the Galasso law (Law no. 431 of 8 August 1985)
3. further properties and areas specifically identified in terms of article 136 and subject to protection by the landscape plans provided for by articles 143 and 156.

The landscape authorisation is regulated by art. 146 of the Code, which states that owners, possessors or holders in any capacity of buildings or areas of landscape interest, protected by law, cannot destroy them or introduce modifications that jeopardise the landscape values protected (art. 146, c. 1).
Therefore, in the case of interventions in areas subject to landscape protection, there is an obligation to submit the projects of the works to be carried out to the competent body (delegated by the region, generally the municipalities) so that their landscape compatibility can be ascertained, and authorisation issued. The interlocutor of the proposing subject in landscape matters is therefore the municipality, which is responsible for issuing the landscape authorisation.
This legal framework can be considered effective in recognising and protecting the existing cultural heritage from anthropogenic changes; however it does not include the assessment

of environmental concerns and the potential impact of climate change. The existing legislation is therefore ineffective in protecting heritage from a range of threats that are difficult to quantify. It is in this gap that the aim of the YADES project fits.

4.2 The archaeological area of Pafos, Cyprus

Paphos is protected and managed according to the provisions of the highly effective national Antiquities Law and the international treaties signed by the Republic of Cyprus. In accordance with the Antiquities Law, Ancient Monuments are categorized as being of the First Schedule (governmental ownership) or of the Second Schedule (private ownership). Paphos (both the town of Kato Paphos and the village of Kouklia) is for the most part under government ownership, due to the policy by the Department of Antiquities to gradually acquire land within the sites and their vicinity. Listed Ancient Monuments of the Second Schedule are gradually being acquired according to the provisions of Section 8 of the Antiquities Law. Furthermore, the Law provides for the establishment of "Controlled Areas" within the vicinity around the sites to control the height and architectural style of any proposed building; such areas are in place for both the town of Kato Paphos and the village of Kouklia. Paphos was given "enhanced protection" status in November 2010 by UNESCO's Committee for the Protection of Cultural Property in the Event of Armed Conflict.

4.2.1 Legislation[6]

1. Convention for the Protection of Cultural Property in the Event of Armed Conflict with Regulations for the Execution of the Convention, The Hague, 14 May 1954
2. First Protocol to the Hague Convention of 1954 for the Protection of Cultural Property in the Event of Armed Conflict, The Hague, 14 May 1954
3. Second Protocol to the Hague Convention of 1954 for the Protection of Cultural Property in the Event of Armed Conflict, The Hague, 26 March 1999
4. European Cultural Convention, Paris, 19 December 1954
5. Statutes of the International Centre for the Study of the Preservation and Restoration of Cultural Property, as amended on 24 April 1963 (ICCROM), New Delhi, 5 December 1956
6. Statutes of the ICCROM, as revised by the XXIII session of the General Assembly, Rome, 21 November 2003
7. Convention on the Means of Prohibiting and Preventing the Illicit Import, Export and Transfer of Ownership of Cultural Property, Paris, 14 November 1970
8. Convention for the Protection of the World Cultural and Natural Heritage, Paris, 16 November 1972
9. Convention for the Protection of the Architectural Heritage of Europe, Granada, 3 October 1985

[6] http://www.mcw.gov.cy/mcw/da/da.nsf/DMLlaw_en/DMLlaw_en?OpenDocument

10. European Convention on the Protection of the Archaeological Heritage (Revised), Valletta, 16 January 1992
11. Unidroit Convention on Stolen or Illegally Exported Cultural Objects, Rome, 24 June 1995
12. Convention for the Safeguarding of the Intangible Cultural Heritage, Paris, 17 October 2003
13. Charter for the protection and management of the archaeological heritage, Lausanne 1990
14. Charter for the conservation of historic towns and urban areas, Washington 1987
15. Recommendation concerning the Protection and Promotion of Museums and Collections, their Diversity and their Role in Society, Paris 2015

4.2.2 Antiquities Laws

- The Antiquities (Amendment) Law 2012
- The Return of Cultural Goods Law, 2016 (in Greek)
- Designation of areas where the use of metal detectors is permitted
- Designation of areas where the use of metal detectors is permitted-MAPS
- Export of Cultural Goods Law, No 182 (1) of 2002
- Memorandum of Understanding between USA and Cyprus, 2002
- Regulation (EU) 2019/880 on the introduction and the import of cultural goods
- Memorandum of Understanding Between USA and Cyprus, as extended, 2006
- Memorandum of Understanding between USA and Cyprus, as extended, 2007
- Memorandum of Understanding between USA and Cyprus, 2012
- Memorandum of Understanding between USA and Cyprus, as extended, 2017

5 Current Practices & Needs

5.1 The city of Milano, Italy

5.1.1 Precipitation, droughts, floods

As far as precipitation is concerned, statistically insignificant variations are noted, suggesting a decrease in the annual cumulative value and an increase in the number of extreme events and a trend indicating an increase in consecutive days without precipitation during the summer season. This data, when compared with the analysis of temperatures, shows that the increase in droughts has probably contributed to the increase in temperatures, which is due to the reduction in soil moisture levels and, therefore, the failure to remove thermal energy from the environment through evapotranspiration.

As mentioned in the previous section, the scenario resulting from the climate data projection shows an increase in seasonal minimum and maximum temperatures of between 1 and 2.3°C and an increase in the number and duration of heat waves and tropical nights. In addition, droughts are expected to increase, resulting in a decrease in the cumulative summer value and an increase in the number of consecutive days without precipitation, with a consequent worsening of the thermo-hygrometric comfort level.

With regard to precipitation, the indicators taken into account are:

- *Consecutive days without precipitation*: average monthly percentage of the maximum number of consecutive days without rain (i.e. with less than 1 mm of rain).

- *Heavy rainfall*: number of days with very heavy rainfall (equal to or more than 20 mm)

- *Maximum precipitation*: the maximum amount of precipitation in a day.

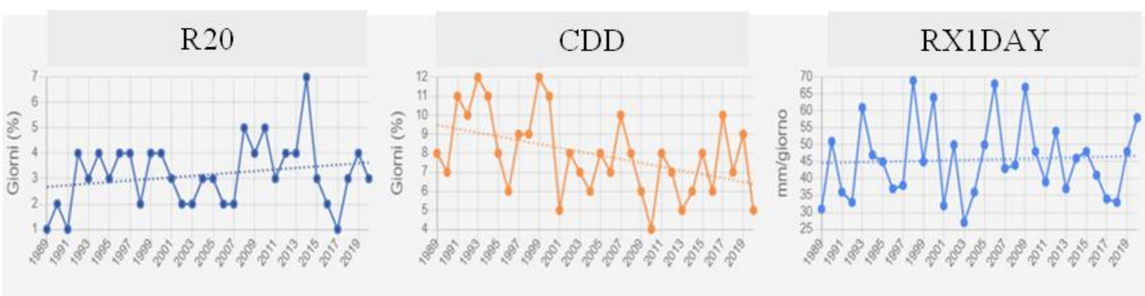

Figure 89: Annual evolution of the indicators for heavy rainfall (R20) maximum number of consecutive days without rain (CDD), both calculated in terms of percentage of days per month, and maximum daily values (RX1DAY), over the period 1989-2020. the trend over the 1989-2020. the trend over the period is not statistically significant for the R20 indicator, while the CDD and RX1DAY indicators are both characterised by a statistically significant decreasing trend over the period.

From the graphs (Figure 89) showing the annual trends of the indicators over the period under study, it can be seen that the consecutive days without precipitation (CDD) and the daily maximum precipitation (RX1DAY) are characterised by a statistically significant decreasing trend over the period 1989-2020.

Several literatures work report that the length of rain-free periods can also have important impacts in urban areas on the functionality of some components, such as water supply, wastewater management, management of urban green areas, population, health infrastructure.

Moreover, the impacts of extreme precipitation events on urban water management should be considered. Milan, as already mentioned in the historical section, is a city with a very rich hydrographic system consisting of both natural watercourses and a large number of secondary natural and artificial canals. This system is the result of a centuries-old human activity functional to supply water to the city that, from Roman times until the period of early industrialization, has become increasingly water-demanding due to the progressive development of settlement. The development of civil and industrial settlements has produced new sewage networks and, together with the changed conditions of land use, an increase in the volume of water poured into rivers and streams and a reduction in the time of runoff, thus giving rise to significant increases in volumes and floods. This situation, further aggravated by the development over time of interfering works inadequate to the flow, has led to large and frequent floods of the main waterways and consequent flooding of heavily urbanized areas, which have often resulted in serious damage.

Figure 90: Areas flooded by a precipitation event with duration equal to 1 hr and return time equal to 100 years (detail on the city center) according to the Safer_RAIN algorithm (Source: Report Milano - CMCC - map contained in: Mercogliano, P, Rianna, G, Reder, A, Raffa, M, Padulano, R, Essenfelder, A, Mazzoli, P, and Bagli, S, 2021: Flood indicators for European cities from 1989 to 2018. Copernicus Climate Change Service, Climate Data Store).

The presence of an urban hydrographic network has always made the City of Milan particularly exposed to urban flooding phenomena, especially during extreme events of intense precipitation. Since the second half of the last century, up to the most recent years, structural interventions have been implemented in order to reduce the volume of water flowing into the urban area; however, these works have had only partial effectiveness, while they have led to a significant alteration of the natural catchment area, making particularly complex the analysis of the impacts of meteoric events. In the last 140 years, almost 150 flooding events have affected, in particular, the North area of the City; of these, one of the most recent and catastrophic, occurred in September 2010, caused huge disruptions and damages to infrastructures for a total of about 20 million euros.

Specifically, flash-floodings are considered more and more a relevant issue for the city of Milan. Flash floodings consist of a quick flooding of "low-lying" areas, potentially occurring due to strong heavy rain and extreme weather events, combined with inefficient and inadequate urban drainage systems and mainly impervious urban surfaces. Timescale is the main difference with standard floodings, as flash floodings can occur in less than 5/6 hours from the precipitation, making really hard and dangerous the facing of this issue. As a consequence, flash floods are currently a significant hazard at urban level.

5.2 The archaeological area of Cyprus

Paphos is authentic in terms of its locations and settings, forms and designs, as well as materials and substances. The key elements of the property, such as the archaeological remains associated with the cult of Aphrodite, the rare mosaics, and the remains of civil, military, and funerary architecture, retain a high degree of authenticity with regard to the built fabric. Management of the property is under the direct supervision of the Curator of Ancient Monuments and the Director of the Department of Antiquities. The District Archaeological Officer of Paphos is responsible for supervising the property, under the direction of the Curator of Ancient Monuments. The property has sufficient funding, which is provided by the Department of Antiquities from the yearly government budget. A Master Plan for Kato Paphos (Site I) was implemented from 1991 onwards. The second phase of this Master Plan, concerning the creation of shelters for the mosaic floors, is in progress. A Master Plan for Palaepaphos (Site II) has also been prepared and is under progressive implementation. The creation of a management plan for Paphos that addresses the conservation, promotion, and preservation needs of the property is one of the objectives set by the Department of Antiquities for all listed Cypriot World Heritage properties.

Sustaining the Outstanding Universal Value of the property over time will require completing, approving, and implementing a management plan for Paphos, aiming at the conservation, promotion, and preservation of the property's unique values for future generations. It will also reinforce efforts undertaken within the framework of the national legislation to minimise dangers of encroachment and the erection of inappropriate buildings in this favoured tourist area.

5.2.1 The Seismological Station networks

The basic targets and pursuits of the operation of the seismological stations are the following:

a) The collection of trustworthy data for the study of the seismicity of Cyprus. Until the end of the 19th century, data on seismicity were derived from historical records and archaeological findings and cannot be considered as reliable. They do not contribute substantially to the study of the seismicity of Cyprus. From the end of the 19th century until 1984 there is data from the stations of neighbouring countries, which undoubtedly improve considerably the previous situation, but they are considered as insufficient both quantitatively and qualitatively for providing answers to many questions that arise in the effort to provide protection to the built environment. These data refer mainly to moderate to strong earthquakes which are limited in number, while the accuracy of the determinations of the epicentral distances is 50 km. The Seismological Stations in Cyprus now offer the possibility to record numerous earthquakes while the accuracy in the determination of epicentres has improved to a few kilometres. As it has already been mentioned above the better knowledge and understanding of the seismicity of Cyprus contributes significantly to the study of the seismic hazard in various parts of Cyprus.

b) Immediate and accurate analysis of the earthquake recordings and communication of the results to international and regional seismological centres. The immediate exchange of information between seismological centres contributes significantly to the improvement of the accuracy in the computation of the parameters of an earthquake, to the better understanding of the phenomenon and consequently to the understanding of the necessary measures for facing the consequences from the continuation of seismic activity.

c) Immediate informing of the relevant authorities and the public for all felt earthquakes. In the case of destructive earthquakes, providing consultative services to the relative authorities with regard to the development of the seismic activity.

5.2.2 Tsunami risk

Regarding the tsunami risk from historical data, Greek researchers (Fokaefs & Papadopoulos, 2007) have calculated the following statistics for the wider region of Cyprus and Levantine:

A very strong tsunami (wave height on the coast 4m) is expected every 375 years, a strong tsunami (wave height on the coast> 1m) is expected every 120 years and a moderate tsunami (with a wave height <1m) is expected every 30 years. The incomplete historical data, however, do not fully represent the tsunami risk of Cyprus. For a more accurate assessment of the tsunami risk of Cyprus, the geomorphological data that are believed to be related to tsunami action on its coasts should be dated. Since 1965, the Intergovernmental Oceanographic Commission (IOC) of UNESCO is responsible for coordinating the warning system for tsunamis in the Pacific Ocean (PTWS). In June 2005, after the tsunami of 26 th December 2004 in the Indian Ocean, it was decided to create three similar warning systems in the Indian Ocean, the Caribbean and the North Atlantic and the Mediterranean region. On November 25, 2016, the Council of Ministers approved the establishment of the Cyprus National Tsunami Warning System Committee in the Mediterranean and North Atlantic (NEAMTWS).) coordinated by the Department of Geological Survey and members the Civil Defense and the Oceanographic Center. On October 9, 2018, the Council of Ministers decided to modify the composition of the Cyprus National System Committee NEAMTWS by appointing the Director of the Department of Lands and Surveys or its representative as a member of the Committee, and by appointing the Director of the University Oceanography Center or as an observer of the Commission. There are four certified tsunami alert and warning centers in the North Atlantic and Mediterranean region, most notably in Italy, France, Turkey and Greece. In the event of a tsunami being detected by these centers, automatic warnings are sent to the Member States of the system. These alerts are received from local tsunami alerts, i.e., Civil

Defense services, which activate national disaster response plans. In the operation of the NEAMTWS System (YouTube), the Seismological Network of Geological Survey Department provides real-time continuous seismic data in the National Warning Center for marine seismic waves Geodynamic Institute of the National Observatory of Athens (GEIN-NOA) and the National Italian Center for Geophysics and Volcanology (INGV)

6 Conclusion

To sum up, Deliverable D7.1 “End Users requirements” documents the work performed in Task 7.1. This deliverable includes the description of the sites and the regions that Cultural Heritage buildings are located as well as the available equipment of each site. Moreover, a brief description of each climatic hazards (geological, environmental, and geotechnical), for each demo site, are descripted in detail. In addition, all the local legislations and financial resources of each city and region are presented. Lastly, all the current practices and needs for the areas of study are also identified and presented. The deliverable is mainly intended for internal use, in particular by the partners involved in the specification of the system requirements, the use cases and the overall system architecture.

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ANNEXES