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Εθνικόν και Καποδιστριακόν Πανεπιστήμιον Αθηνών
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Τμήμα Γεωλογίας και Γεωπεριβάλλοντος

Πρόγραμμα Μεταπτυχιακών Σπουδών
Επιστήμες Γης και Περιβάλλον

ΕΛΙΣΑΒΕΤ ΝΙΚΟΛΗ
Α.Μ.: 22008

Ανάδειξη της Γεωποικιλότητας σε Ηφαιστειακά Περιβάλλοντα: Η Μελέτη Περίπτωσης του Υποψήφιου Γεωπάρκου UNESCO Νισύρου

Ειδίκευση:
Κλιματικές Μεταβολές & Επιπτώσεις στο Περιβάλλον

Τριμελής Εξεταστική Επιτροπή

Παρασκευή Νομικού (Επιβλέπουσα)
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Promoting the Geodiversity of Volcanic Environments: The Case Study of Nisyros Aspiring UNESCO Global Geopark

Specialization:
Climatic Variations & Impacts on the Environment

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ΔΗΛΩΣΗ ΠΕΡΙ ΜΗ ΠΡΟΣΒΟΛΗΣ ΠΝΕΥΜΑΤΙΚΗΣ ΙΔΙΟΚΤΗΣΙΑΣ

Προσβολή πνευματικής ιδιοκτησίας θεωρείται η ολική ή η μερική αναπαραγωγή του έργου άλλου προσώπου ή η παρουσίαση του έργου κάποιου άλλου ως προσωπικού του γράφοντος. Το Τμήμα Γεωλογίας και Γεωπεριβάλλοντος λαμβάνει πολύ σοβαρά υπόψη και καταδικάζει την προσφυγή σε τέτοιου είδους πρακτικές από τους Μεταπτυχιακούς Φοιτητές. Σε περιπτώσεις πρόδηλης ή εκ προθέσεως προσβολής πνευματικής ιδιοκτησίας, τα αρμόδια όργανα του Τμήματος δύνανται να επιβάλουν ως κύρωση έως και την οριστική διαγραφή από το ΠΜΣ. Κατά την εκπόνηση, υποβολή, εξέταση και δημοσίευση της Διπλωματικής Εργασίας Ειδίκευσης οι Μεταπτυχιακοί Φοιτητές οφείλουν να τηρούν τις ακόλουθες κατευθυντήριες οδηγίες:

1. Η Διπλωματική Εργασία Ειδίκευσης πρέπει να αποτελεί έργο του υποβάλλοντος αυτήν φοιτητή.
2. Η αντιγραφή ή η παράφραση έργου τρίτου προσώπου αποτελεί προσβολή πνευματικής ιδιοκτησίας και συνιστά σοβαρό αδίκημα. Στο αδίκημα αυτό περιλαμβάνεται τόσο η προσβολή πνευματικής ιδιοκτησίας άλλου φοιτητή όσο και η αντιγραφή από δημοσιευμένες πηγές, όπως βιβλία, εισηγήσεις ή επιστημονικά άρθρα. Το υλικό που συνιστά αντικείμενο λογοκλοπής μπορεί να προέρχεται από οποιαδήποτε πηγή. Η αντιγραφή ή χρήση υλικού προερχόμενου από το διαδίκτυο ή από ηλεκτρονική εγκυκλοπαίδεια είναι εξίσου σοβαρή με τη χρήση υλικού προερχόμενου από τυπωμένη πηγή ή βάση δεδομένων.
3. Η χρήση αποσπασμάτων από το έργο τρίτων είναι αποδεκτή εφόσον, αναφέρεται η πηγή του σχετικού αποσπάσματος. Σε περίπτωση αυτολεξί μεταφοράς αποσπάσματος από το έργο άλλου, η χρήση εισαγωγικών ή σχετικής υποσημείωσης είναι απαραίτητη, ούτως ώστε η πηγή του αποσπάσματος να αναγνωρίζεται.
4. Η παράφραση κειμένου, αποτελεί προσβολή πνευματικής ιδιοκτησίας.
5. Οι πηγές των αποσπασμάτων που χρησιμοποιούνται θα πρέπει να καταγράφονται πλήρως σε πίνακα βιβλιογραφίας στο τέλος της εργασίας.
6. Η προσβολή πνευματικής ιδιοκτησίας επισύρει την επιβολή κυρώσεων. Κατά την απόφαση επί των ενδεδειγμένων κυρώσεων, τα αρμόδια όργανα του Τμήματος θα λαμβάνουν υπόψη παράγοντες όπως το εύρος και το μέγεθος του τμήματος της εργασίας που οφείλεται σε προσβολή πνευματικής ιδιοκτησίας. Οι κυρώσεις θα επιβάλλονται σύμφωναμε το Άρθρο 7 Παράγραφος 7 του Κανονισμού Σπουδών.

Βεβαιώνω ότι η Διπλωματική Εργασία Ειδίκευσης, την οποία υποβάλλω, δεν περιλαμβάνειστοιχεία προσβολής πνευματικής ιδιοκτησίας, όπως αυτά προσδιορίζονται από την παραπάνω δήλωση, τους όρους της οποίας διάβασα και αποδέχομαι.
Παρέχω τη συναίνεσή μου, ώστε ένα ηλεκτρονικό αντίγραφο της διπλωματικής εργασίας μου ναυποβληθεί σε ηλεκτρονικό έλεγχο για τον εντοπισμό τυχόν στοιχείων προσβολής πνευματικής ιδιοκτησίας.

Ημερομηνία

20/05/2024

Υπογραφή Υποψηφίου

ΕΥΧΑΡΙΣΤΙΕΣ

Ολοκληρώνοντας τις μεταπτυχιακές μου σπουδές με την παρούσα διπλωματική μελέτη, θα ήθελα να ευχαριστήσω όλους τους ακαδημαϊκούς του Τμήματος Γεωλογίας και Γεωπεριβάλλοντος του Εθνικού και Καποδιστριακού Πανεπιστημίου Αθηνών για τις πολύτιμες γνώσεις που μου παρείχαν καθ’ όλη τη διάρκεια της φοίτησης μου σε αυτό. Θα ήθελα να ευχαριστήσω ιδιαίτερα την Αναπλ. Καθηγήτρια και επιβλέπουσα της παρούσας εργασίας, κα Νομικού Παρασκευή, για την καθοδήγηση και την εμπιστοσύνη που μου έδειξε προσφέροντας μου την πολύτιμη ευκαιρία να μελετήσω μια τόσο ενδιαφέρουσα και μοναδική περιοχή όπως είναι η Νίσυρος και να συμβάλλω στην προσπάθεια ανάδειξης της ως Παγκόσμιο Γεωπάρκο της UNESCO. Τέλος, θα ήθελα να ευχαριστήσω ολόψυχα την οικογένεια μου και όλα τα αγαπημένα μου πρόσωπα που με στήριξαν καθ’ όλη την πορεία των σπουδών μου αυτά τα χρόνια.

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ΠΕΡΙΛΗΨΗ

Η παρούσα έρευνα αποσκοπεί στην ολοκληρωμένη καταγραφή και εξέταση της γεω-πολιτιστικής κληρονομιάς του Υποψήφιου Παγκόσμιου Γεωπάρκου UNESCO Νισύρου, με στόχο να συμβάλει στην ανάδειξη του ως Παγκόσμιο Γεωπάρκο της UNESCO. Μέσω μιας λεπτομερούς ανάλυσης των γεωλογικών σχηματισμών, της εξέλιξης του ηφαιστείου της Νισύρου και της πολιτιστικής του αξίας, η παρούσα μελέτη τονίζει τη σημασία της διατήρησης της γεωκληρονομιάς στο πλαίσιο των γεωπάρκων, ρίχνοντας φως στα μοναδικά χαρακτηριστικά του νησιού και στις πρακτικές ανάδειξης τους, προσφέροντας παράλληλα συστάσεις για τη βιώσιμη διαχείριση και διατήρηση του ηφαιστειακού αυτού τοπίου. Επιπλέον στόχο της εργασίας αποτελεί η εξερεύνηση των πολιτιστικών και ιστορικών πτυχών που σχετίζονται με τη γεωκληρονομιά της Νισύρου καθώς και της οικολογικής ποικιλομορφίας και της περιβαλλοντικής σημασίας του Γεωπάρκου Νισύρου, που περιλαμβάνει τη χλωρίδας και της πανίδα που ευδοκιμεί στην περιοχή. Μέσω της μελέτης περίπτωσης του Γεωπάρκου Νισύρου, η παρούσα έρευνα επιδιώκει να συμβάλει στην ευρύτερη κατανόηση της διατήρησης της γεωκληρονομιάς στα γεωπάρκα. Τα ευρήματα αναμένεται να παράσχουν πολύτιμες γνώσεις τόσο για τον ακαδημαϊκό διάλογο όσο και για τις πρακτικές στρατηγικές διαχείρισης, προωθώντας μια ολιστική προσέγγιση για τη διατήρηση του γεωλογικού, οικολογικού και πολιτιστικού πλούτου του γεωπάρκου Νισύρου.

Λέξεις κλειδιά: Νίσυρος, Γεωπάρκο, Ηφαίστειο, Γεώτοποι, Γεωκληρονομιά, UNESCO

ABSTRACT

The present study aims at the comprehensive documentation and examination of the geo-cultural heritage of the Nisyros Aspiring UNESCO Global Geopark, in order to contribute to its designation as a UNESCO Global Geopark. Through a detailed analysis of the geological formations, the evolution of the volcano of Nisyros and its cultural value, this study highlights the importance of geoheritage conservation in the context of geoparks, shedding light on the unique features of the island and their promoting practices, while offering recommendations for the sustainable management and conservation of this volcanic landscape. In addition, this work aims to explore the cultural and historical aspects related to the geoheritage of Nisyros as well as the ecological diversity and environmental significance of the geopark, including the flora and fauna that thrive in the area. Through the case study of Nisyros Geopark, this research seeks to contribute to a broader understanding of geoheritage conservation in geoparks. The findings are expected to provide valuable insights for both academic debate and practical management strategies, promoting a holistic approach to the conservation of the geological, ecological and cultural wealth of the Nisyros Geopark.

Key words: Nisyros, Geopark, Volcano, Geosites, Geoheritage, UNESCO

1. Introduction

1.1 Background and Context of the Study

The concept of geoparks, designated areas recognized for their geological significance, has gained increasing prominence as a means of preserving and showcasing Earth's unique heritage. Geoparks serve as invaluable platforms for scientific research, environmental education, and sustainable tourism. Defined by their outstanding geological features, these areas not only contribute to our understanding of Earth's dynamic processes but also offer cultural and historical insights. Within the broader framework of geoparks, the focus of this study lies on Nisyros Geopark, a region of particular geological interest situated in the southeastern part of the active Hellenic Volcanic Arc. Nisyros Geopark stands as evidence of the complex interaction between geological forces, forming a variety of landscapes that bear witness to the Earth's evolutionary history.

Geoparks play a multifaceted role in the conservation of geoheritage. Geoheritage encompasses not only geological formations but also the ecological and cultural treasures associated with these landscapes. By studying Nisyros Geopark, we aim to unravel the geological narratives embedded in its rocks and formations, examine the ecological diversity it sustains and explore the cultural significance that has evolved over centuries. Understanding the geological heritage of Nisyros Geopark serves both scientific and practical purposes. As the world becomes more conscious of environmental conservation, the importance of geoparks in advocating for sustainable actions and cultivating a sense of responsibility becomes even more vital. The preservation of Nisyros Geopark's geoheritage holds the potential to contribute to both local and global initiatives aimed at balancing the preservation of natural wonders with responsible tourism and community engagement.

1.2 The UNESCO Global Geopark Network

The UNESCO Global Geopark Network comprises a collection of geographically diverse regions recognized for their outstanding geological heritage, cultural significance, and sustainable development initiatives. Geoparks, conceived as areas of international geological significance, represent a holistic approach to conservation that transcends the boundaries of traditional nature reserves. Defined by UNESCO as "areas with a geological heritage of international value," geoparks are not merely landscapes etched with geological wonders; they are living laboratories that weave together the Earth's narrative. The evolution of the geopark concept can be traced through decades of global collaboration, culminating in a recognition that extends beyond geological importance to encompass ecological diversity and cultural richness.

UNESCO Gloval Geoparks serve as living laboratories, where visitors can explore and learn about Earth's dynamic processes, ancient landscapes, and the interactions between geology, ecosystems, and human societies (UNESCO, n.d). Established in 2004, the UNESCO Global Geopark Network aims to promote geotourism, education, and conservation while fostering local economic development and community engagement. Geoparks within the network adhere to stringent criteria, ensuring the preservation of geological sites, promotion of scientific research, and integration of geology into educational and recreational activities (Gray, 2013).

By connecting geoparks worldwide, the UNESCO Global Geopark Network promotes collaboration, knowledge exchange, and best practices in geotourism and sustainable development. Through education and outreach programs, these geoparks inspire visitors to appreciate Earth's geological heritage and recognize the importance of preserving natural landscapes for future generations (Newsome et al., 2012). Currently, there are 213 UNESCO Global Geoparks recognized in 48 countries worldwide, spanning continents and showcasing the planet's geological diversity and cultural heritage (Figure 1.2.1).

Fig. 1.2.1: Worldwide distribution of the designated UNESCO Global Geoparks.
(https://unesdoc.unesco.org/ark:/48223/pf0000385482.locale=en)

Greece boasts a total of 8 UNESCO Global Geoparks, each offering a unique insight into the country's rich geological history and cultural heritage. These geoparks are recognized for their outstanding geological features, biodiversity, and sustainable development initiatives.

One notable Greek UNESCO Global Geopark is the Lesvos Petrified Forest Geopark, located on the island of Lesvos. This geopark is renowned for its extensive petrified forest, which dates back millions of years and provides valuable insights into ancient ecosystems and climate change. Visitors to the Lesvos Petrified Forest Geopark can explore fossilized tree trunks, volcanic formations, and geological landscapes, while also learning about the island's cultural heritage and traditional way of life.

Another prominent Greek UNESCO Global Geopark is the Psiloritis Natural Park Geopark, situated on the island of Crete. This geopark encompasses the majestic Mount Psiloritis, the highest peak in Crete, as well as diverse geological formations, limestone caves, and traditional villages. Visitors to the Psiloritis Natural Park Geopark can embark on hiking trails, guided tours, and educational programs to discover the region's geological wonders and cultural treasures.

Furthermore, the Chelmos-Vouraikos UNESCO Global Geopark, located in the Peloponnese region of Greece, offers visitors the opportunity to explore rugged mountain landscapes, deep gorges, and pristine rivers. This geopark is characterized by its unique geological formations, including limestone cliffs, karstic caves, and fossil-rich deposits. Visitors to the Chelmos-Vouraikos Geopark can engage in outdoor activities such as hiking, rock climbing, and river rafting, while also learning about the region's cultural heritage and environmental conservation efforts.

1.3 Significance of Promoting Geodiversity of Volcanic Environments

Promoting geodiversity in volcanic environments holds significant importance due to its role in raising awareness about sustainable resource usage and controlling geological hazards such as volcanic eruptions and earthquakes. It also involves celebrating the unique geological features and processes that have shaped these landscapes over millennia. By highlighting the diverse range of volcanic formations, geological phenomena, and associated ecosystems, geoparks offer visitors an opportunity to explore and understand Earth's dynamic history.

Volcanic landscapes exhibit a wide range of geological formations, including volcanic cones, calderas, lava flows, and hot springs, each contributing to the overall geodiversity of the region. The dynamic nature of volcanic processes adds a layer of complexity to geodiversity management, requiring a nuanced understanding of the interactions between geological, ecological, and cultural elements.

One key aspect of promoting geodiversity in volcanic geoparks is through interpretation and education. Geoparks provide informative signage, guided tours, and educational programs that explain the formation of volcanic landforms such as craters, lava flows, and calderas. Through interactive exhibits and multimedia presentations, visitors learn about the geological processes that have sculpted these landscapes and the role of volcanism in shaping the Earth's surface (Gordon, 2016).

Furthermore, geoparks emphasize the importance of conservation and preservation of geological sites. By implementing sustainable management practices, geoparks protect fragile volcanic features from erosion, human impact, and climate change. This ensures that future generations can continue to appreciate and study these unique geological wonders (Gray, 2013). Geodiversity promotion also involves fostering scientific research and collaboration. Volcanic geoparks provide opportunities for geologists, researchers, and educators to conduct fieldwork, collect data, and study volcanic processes. By sharing knowledge and findings with the broader scientific community, geoparks contribute to our understanding of volcanic activity and its implications for hazard mitigation and land management Newsome et al., 2012). Moreover, volcanic geoparks celebrate the cultural heritage and indigenous knowledge associated with volcanic landscapes. Through cultural events, traditional ceremonies, and storytelling, geoparks engage local communities and visitors in the rich cultural history of volcanic regions. This fosters a deeper appreciation for the connectedness between geology, culture, and society (Farsani, et al., 2017).

Among the UNESCO Global Geoparks are several notable examples showcasing volcanic landscapes and geological phenomena. One such geopark is the Jeju Island Geopark in South Korea, located on Jeju Island. Here, visitors can explore shield volcanoes, lava tubes, and volcanic cones, gaining insights into the island's unique geological history and biodiversity. Another renowned geopark is the Azores Geopark in Portugal, comprising several volcanic islands characterized by volcanic calderas, hot springs, and coastal cliffs. This geopark offers opportunities to study volcanic processes and the interaction between geology and ecosystems.

Fig. 1.3.1: Jezu Geopark
(http://www.globalgeopark.org/GeoparkMap/geoparks/Korea/12575.htm)

In Iceland, the Reykjanes UNESCO Global Geopark on the Reykjanes Peninsula features diverse volcanic landscapes, including lava fields, geothermal areas, and volcanic craters. Visitors can learn about the geological forces that have shaped the region and experience its unique natural beauty. Similarly, the Harz Geopark in Germany showcases volcanic formations such as extinct volcanoes, lava flows, and volcanic lakes. Here, visitors can explore the region's volcanic history, mineralogy, and geological evolution.

Fig. 1.3.2: Mud pools and steam vents in south-west Reykjanes, Iceland.
(https://reykjanesgeopark.is/)

These UNESCO Global Geoparks provide valuable insights into volcanic landscapes, geological processes, and the cultural significance of volcanic regions. Through education, conservation, and sustainable tourism initiatives, they inspire appreciation for Earth's geological heritage and promote the preservation of natural landscapes for future generations.

1.4 Purpose of the Research

This research seeks to comprehensively examine and document the extensive geological and cultural richness of Nisyros Geopark, aiming contribute to its designation as a UNESCO Global Geopark. By doing so, we hope to contribute to the broader discourse on the importance of geoheritage preservation in the context of geoparks, shedding light on the unique attributes of Nisyros and offering recommendations for sustainable management and conservation. Through a detailed analysis of its geological formations, cultural significance, and ecological diversity, this study aims to achieve several overarching objectives:

-Geological Documentation: Undertake a detailed survey and documentation of the geological features within Nisyros Geopark. This includes the identification, characterization, and mapping of key rock formations, landforms, and geological processes that have shaped the landscape.

-Cultural and Historical Exploration: Explore the cultural and historical aspects associated with the geoheritage of Nisyros. Investigate any cultural artifacts, historical sites, or indigenous knowledge linked to the geological formations, uncovering the human dimension of the geopark's history.

-Ecological Assessment: Evaluate the ecological diversity and environmental significance of Nisyros Geopark. This involves studying the flora and fauna that inhabit the region, understanding their ecological roles, and assessing the overall biodiversity of the geopark.

By addressing these objectives, this research seeks to contribute to the broader understanding of geoheritage conservation within geoparks. The findings are expected to provide valuable insights for both academic discourse and practical management strategies, fostering a holistic approach to preserving the geological, ecological, and cultural richness of Nisyros Geopark but also to provide practical recommendations for sustainable conservation, responsible tourism, and community engagement.

1.5 Nisyros Geopark

Nisyros Geopark, a geological masterpiece, integrates together scientific, cultural, and environmental significance, making its study profoundly important for various reasons. The geopark boasts a diverse range of geological formations, including volcanic craters, lava flows and other unique volcanic landforms, providing a window into Earth's dynamic processes and contributing to our broader understanding of geological evolution. The scientific exploration of Nisyros reveals an intriguing geological puzzle that captivates scientists and researchers. Delving into the geological history encoded in its rocks and landforms unravels clues about past volcanic activity, tectonic processes, and environmental changes, offering valuable insights into the Earth's geological narrative.

Beyond its geological uniqueness, Nisyros Geopark is deeply connected to its rich cultural and historical heritage. Exploring the connection between local communities and the geological features offers a unique perspective on how humans have interacted with and interpreted the landscape throughout history. Nisyros Geopark is not merely a geological showcase; it thrives as an ecosystem supporting a diverse range of flora and fauna. Understanding and documenting this biodiversity are crucial for conservation efforts, ensuring the preservation of both geological heritage and the ecological balance that sustains life within the geopark.

The geoheritage of Nisyros holds immense potential for sustainable tourism development. By studying and promoting responsible tourism practices, a balance can be struck between showcasing the natural beauty of the geopark and preserving its integrity for future generations.
As a microcosm of geological, ecological, and cultural interplay, Nisyros Geopark offers lessons with broader implications. Insights gained from this study can contribute to global discussions on the importance of geoheritage preservation, sustainable geopark management, and the role of local communities in safeguarding natural and cultural resources.

2. Study Area

The Nisyros aUGGp is a group of islands situated between Kos and Tilos islands in the Dodecanese prefecture of Greece. This island complex is located at the southeastern part of the Aegean Sea. Within the geopark is Nisyros (42 km^2), the youngest and still active volcano in the Southeastern Aegean Volcanic Arc, along with the volcanic islets of Strongyli, Pachia, Pergousa, and the non-volcanic islet of Kandeliousa. In total, the Nisyros aUGGp covers an area of 481 km^2, including the island as well as the marine area between them. The geopark is run by the Municipality of Nisyros Corporation for Public Benefit (DIKEN) and hosts a total of 24 unique geosites, along with numerous sites of cultural interest and biodiversity significance.

Fig. 2.1: Nisyros Geopark map.

The whole territory of the Nisyros aUGGp is included administratively into the Municipality of Nisyros, which belongs to the Regional Unit of Kos that is part of the Administrative Region of South Aegean. The present condition of the volcanic island of Nisyros is the result of habitation during the past 200 years. According to the last census (2001), 1008 residents were recorded living in Nisyros island, while the surrounding islets of the geopark are not inhabited. Mandraki settlement, the capital of Nisyros island, is the largest one among the total four villages (Emborios, Pali, Nikia) and it hosts 681 residents of the total population. All the settlements are built with an eastward direction, to be shielded from the western wind and they are all considered as historically preserved areas.
After the end of the 19th century the population of Nisyros was about 5.000 when it began to have a very sharp decline as the inhabitants turned to immigration, first to Alexandria, Izmir, Constantinople and later to America. After 1930, many also began to flock to Athens. The evolution of the population based on the censuses 1951-2011 indicates a continuous decrease of the population until 1981, where the population stabilizes at the current levels with a small upward trend.

2.1 Natural Environment

Nisyros Geopark, located in the southeastern Aegean Sea, is an active volcanic field that forms part of the South Aegean Volcanic Arc. Situated between the islands of Kos and Tilos, Nisyros is within a prehistoric volcanic field that experienced a massive volcanic eruption around 161.000 years ago, known as the Kos Plateau Tuff. The island itself has an almost circular shape, with a diameter of 8.5 km, a coastal circumference of approximately 25 km, and covering an area of 42 km^2. Its topography resembles a cone, with lava and pyroclastic deposits forming its flanks, interrupted by canyons, volcanic domes, lava necks, plain surfaces (Lakki), faults, and scree. The offshore region of the Geopark consists mainly of basins and ridges, as well as hummocks, canyons, and various underwater features such as domes, craters, and fractures.

The highest peaks on the island of Nisyros are Prophitis Ilias (698m), Saint George (519m), and Saint John (588m). These peaks are all volcanic domes. Within the peaks of Nisyros, there is a large collapse crater, known as its iconic caldera, which extends in a NE-SW direction. The caldera is approximately 2.5km long, 1km wide, and sits at an altitude of around 100m. It is divided into two parts: the northeastern part called Lakki, which has abundant vegetation, and the southwestern part called Ramos, known for its intense steam emissions. At the bottom of the caldera, there are hydrothermal craters, including Stefanos, Andreas, Alexander (Flegethron), Logothetis, Mikros, and Megalos Polyvotis, as well as the Kaminakia craters. The most recent volcanic eruption occurred over 24.000 years ago, but the hydrothermal system within the caldera remains active to this day.

Fig. 2.1.1: The active hydrothermal field of Nisyros.

2.2 Geodynamic Setting

The Hellenic Volcanic Arc (Fig. 2.2.1) has emerged in the rear section of the Hellenic subduction zone, running parallel to and roughly 150 km north of the Hellenic Arc (McKenzie, 1970; Le Pichon & Angelier, 1979). It resulted from the subduction of the East Mediterranean oceanic lithosphere beneath the European continental plate, a process ongoing for at least the past 45 million years (Papanikolaou, 1993). The geodynamic framework of the Hellenic Arc encompasses the Hellenic Trench, a curving series of troughs extending approximately 1.500 kilometers from the Ionian Sea in Western Greece to the Lybian Sea, situated south of Crete and terminating southeast of Rhodes Island. Additionally, it comprises the Island Arc, represented by the Peloponnese, Crete, and the Dodecanese Archipelago, along with the back-arc extensional basin of the Cretan Sea. The Hellenic Volcanic Arc has formed in parallel with and behind the Island Arc.

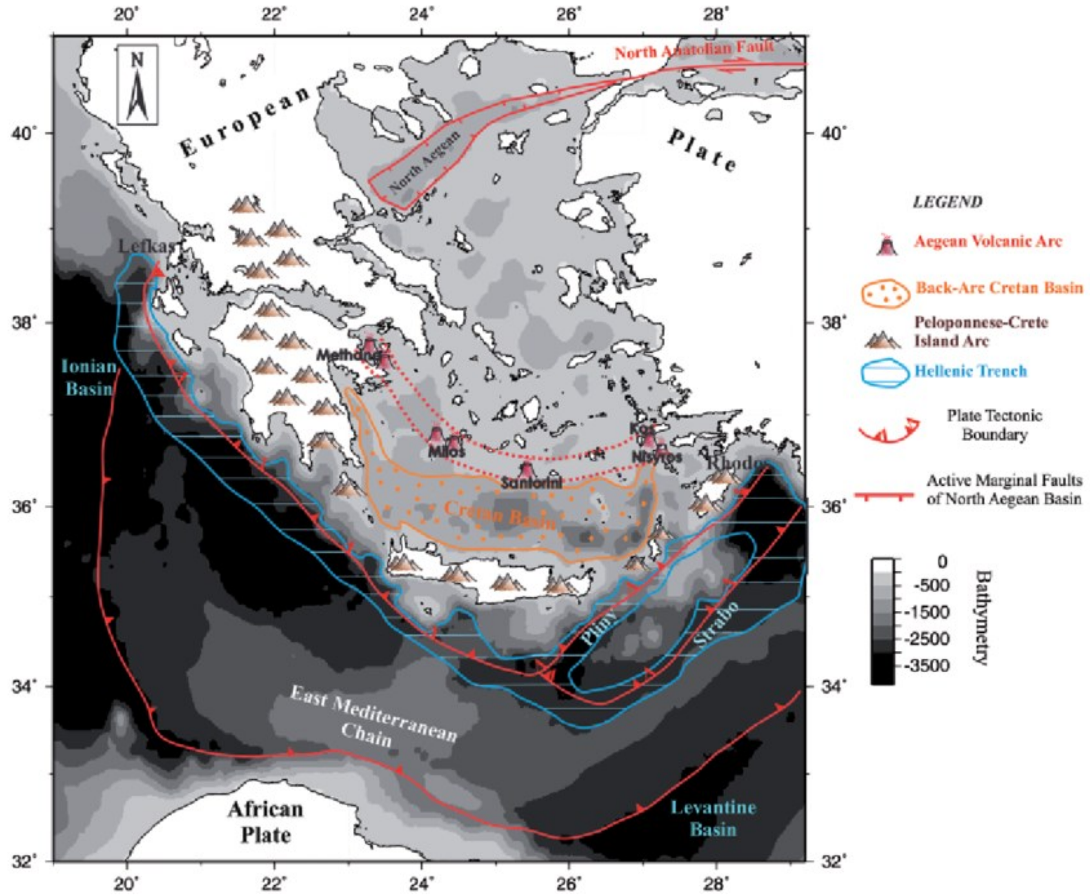


Fig. 2.2.1: Simplified map depicting the current geodynamic structure of the Hellenic arc, illustrating the contemporary South Aegean Volcanic Arc formed beyond the Hellenic trench, the Peloponnese-Crete Island arc, and the Cretan back-arc basin (Nomikou et a., 2013).

Recent volcanic activity is evident on Soussaki, Methana, Aegina, and Poros to the west, on Milos and Santorini in the central region, and on Kos and Nisyros to the east. Additionally, submarine volcanoes have been discovered in the Epidauros Basin in the western Saronikos Gulf (Pavlakis et al., 1990), the Anydros Basin northeast of Santorini (Perissoratis, 1995; Alexandri et al., 2003), and in the submarine area surrounding Nisyros (Nomikou et al., 2004). The volcanoes of the Hellenic Arc exhibited intense activity during the Late Pleistocene to Holocene periods, with documented eruptions occurring in historical times (Fytikas et al., 1976; Liritsis et al., 1996).

The eastern part of the Hellenic Volcanic Arc (Fig. 2.2.2), encompassing the islands of Kos, Yali, and Nisyros, formed due to the northeastward subduction of the Eastern Mediterranean lithosphere beneath the active Hellenic margin of the European plate. This region exhibits high volcanic activity, characterized by the largest volumes of volcanic materials during the Late Pleistocene to Holocene epochs. Significant magmatic events commenced at least 160.000 years ago (Keller et al., 1990), resulting in the most substantial eruption in the Eastern Mediterranean known as the "Kos ignimbrite," which extended over an area exceeding 3.000 square kilometers. Although the precise epicenter of this eruption remains uncertain, it is likely situated in the submarine zone north of the Yali islet, a few kilometers northwest of Nisyros (Nomikou, 2004).

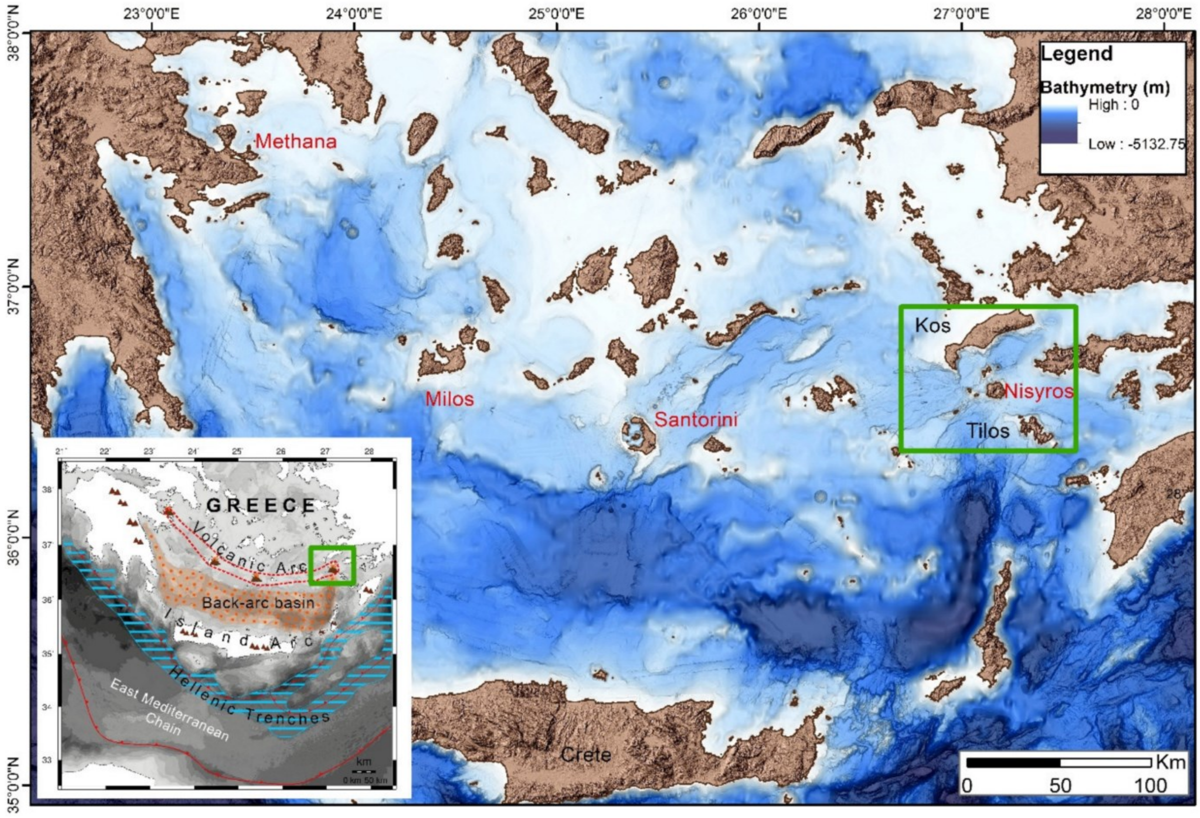


Fig. 2.2.2: The four volcanic groups of the Aegean volcanic arc (in red) and the area of Kos and Tilos islands border the neotectonic graben of the Nisyros volcanic field (in green frame). (Nomikou et al., 2021).

2.3 Geology – Volcanic Evolution

The island of Nisyros is a Stratovolcano that consists entirely of Quaternary volcanic formations, characterized by alternating layers of lava flows, pyroclastic material, and viscous lava domes, ranging from 200 to 25 thousand years old. Nisyros forms the shape of a truncated cone with a diameter of 8 km at its base and features a central caldera measuring 4 km in diameter (Fig. 2.3.1) Basement rocks composed of Mesozoic limestone were encountered at depths of 600 meters in a well situated in the NW section of the caldera and at 1000 m beneath the SE section through geothermal drilling efforts (Geotermica Italiana, 1983, 1984). The caldera's filling above this basement consists of deposits from lakes, rivers, and volcanic ash.

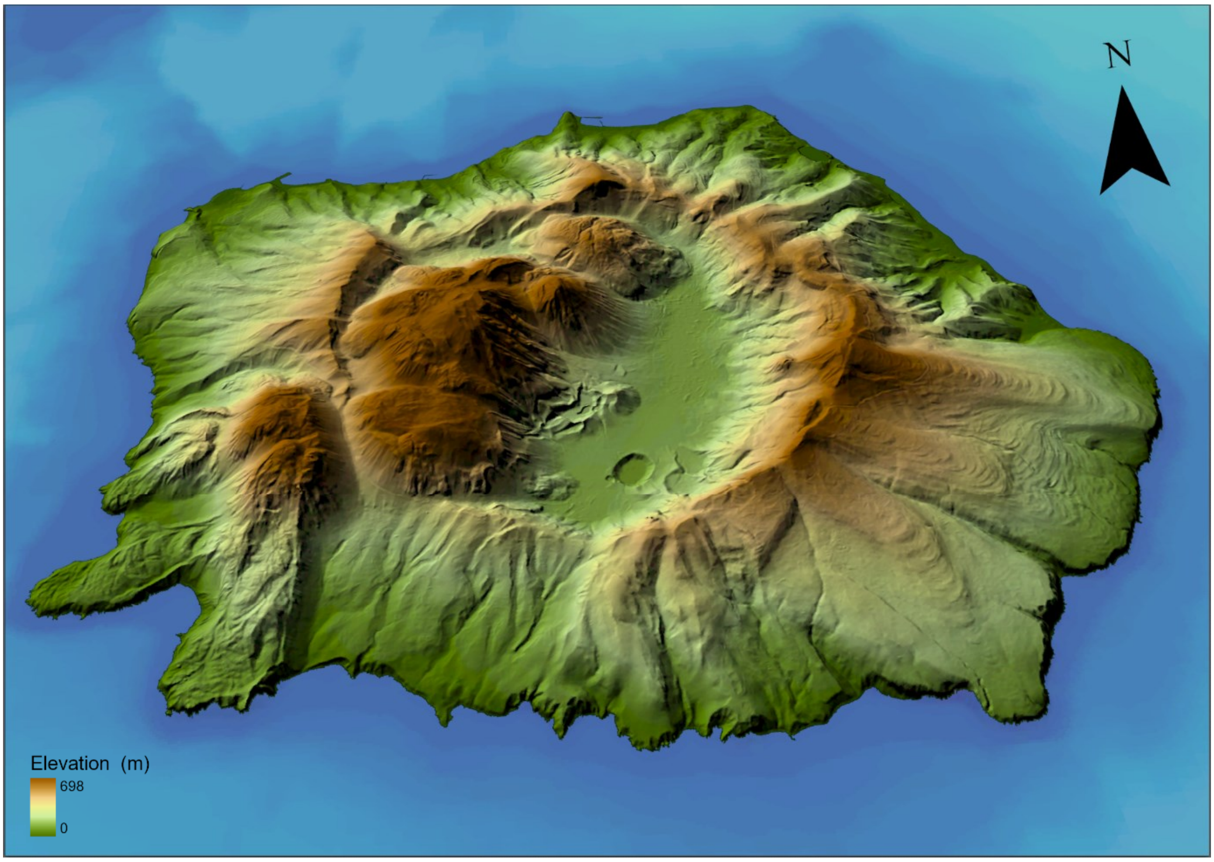


Fig. 2.3.1: Digital Elevation Model (DEM) of Nisyros volcano.

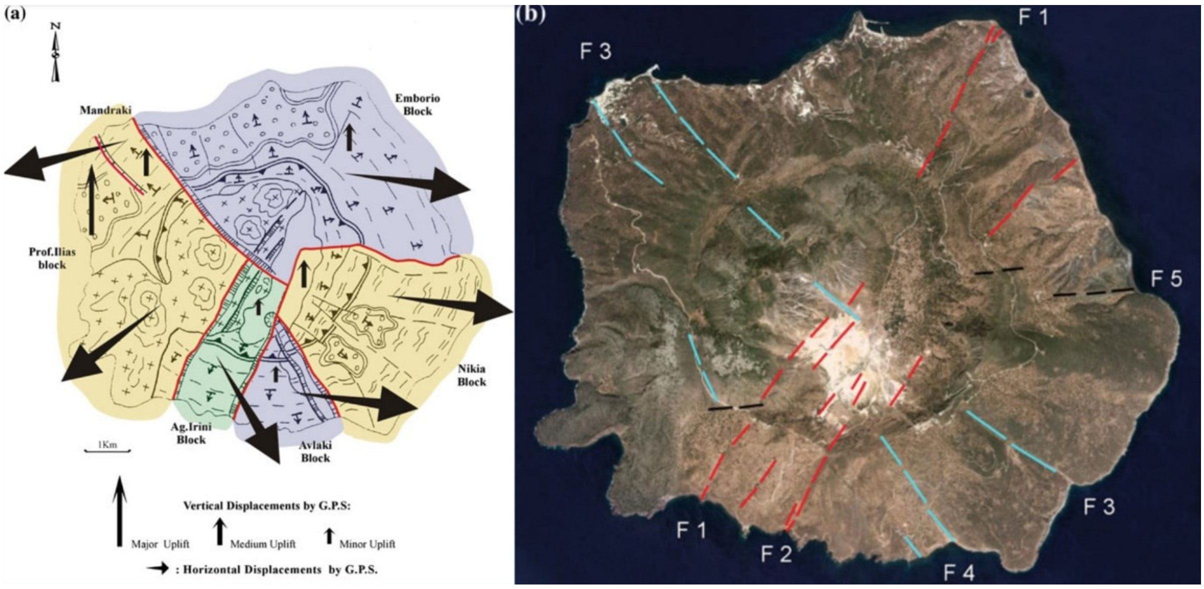
The dominant structural feature of Nisyros volcano is its caldera (Fig. 2.3.2). The assumption of its post-eruptive collapse origin is widely accepted due to its circular shape and steep walls, dropping 300–400 m from the northern and eastern rims to the Lakki plain at 110 m a.s.l., and the filling of the western part with rhyodacitic domes up to 698 m. Following the recognition of two major young plinian eruptive cycles, discussions have centered on caldera formation during one or two collapse episodes, about 25-30 thousand years ago. Two large stratovolcano flank collapses, potentially occurring concurrently with the plinian eruptions, may have influenced the present-day caldera's shape. Three older phreato-magmatic to sub-plinian eruptive phases during the early shield volcano cycles emitted substantial pumice fallout, pyroclastic flows, and surges. The existence of two lacustrine cycles may indicate an early internal lake-stage, possibly expressing a depression in the NE center of the island. Despite alteration effects, no significant hydrothermal deposits or strong hydrothermal alteration have been recognized as possible earlier indications of high-crustal level magma reservoirs accompanied by post-eruptive caldera-forming collapses (Dietrich, 2019).

2.3.2: Aerial image of the Lakki plain inside the caldera.

2.3.1 Fault Systems

The caldera is crosscut by two conjugate major and three minor fault systems (Fig. 2.3.3):

- (F1, 2) N30E 1st order faults with local changes to NE directions
- (F3, 4) N30W 1st order faults with changes between N0° and N40°W
- (F5) E–W 2nd order faults
- (F6) N–S 2nd order faults
- (F7) WNW–ESE 2nd order faults (approx. 120°)



2.3.3: a. Schematic geological map of Nisyros Island showing the major neotectonic blocks (Profitis Ilias & Nikia blocks in yellow, Ag. Irini block in green, Avlaki & Emborio blocks in blue) resulting from the four major fault zones F1, F2, F3, F4, and F5; b. F1–F5 fault zones (Dietrich, 2019)

1st order fault system - NE–SW (F1, 2)

The F1 Fault Zone extends in a NE–SW direction within the central region of the caldera. It consists of two or three parallel fault surfaces with a strike oriented N30°E and a dip ranging between 70° and 80° to the southeast. With a throw exceeding 100 meters, this fault zone separates the Profitis Ilias lavas and domes to the northwest from the caldera deposits to the southeast (Fig. 2.3.4) Its morphological impact is notably significant within the caldera, but less pronounced outside of it. Towards the northeast, its prominence diminishes, and there is no abrupt discontinuity along the caldera rim in the vicinity of Emborios village. The F2 fault zone is parallel to F1 and runs along the southern caldera wall roughly 1.5 km southeast of F1. It strikes N30°E and dips 70–80° to the WNW forming a tectonic graben with the opposite facing F1. This graben structure comprises the remnant of the 160.000 years Kos caldera plain with lacustrine and alluvial deposits, known as Lakki plain (Dietrich, 2019).

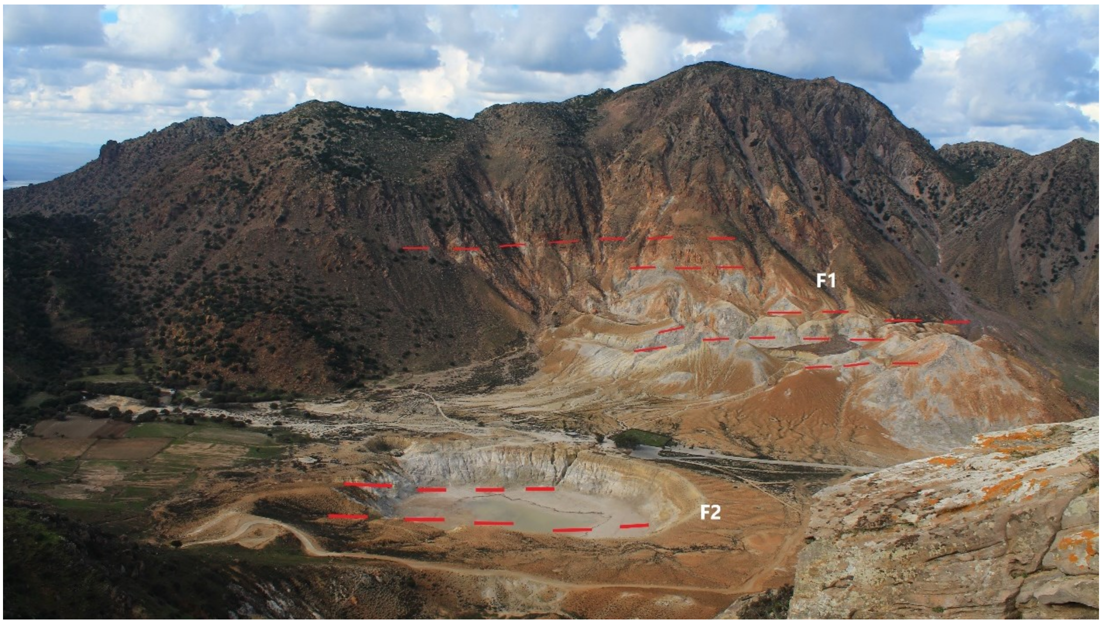
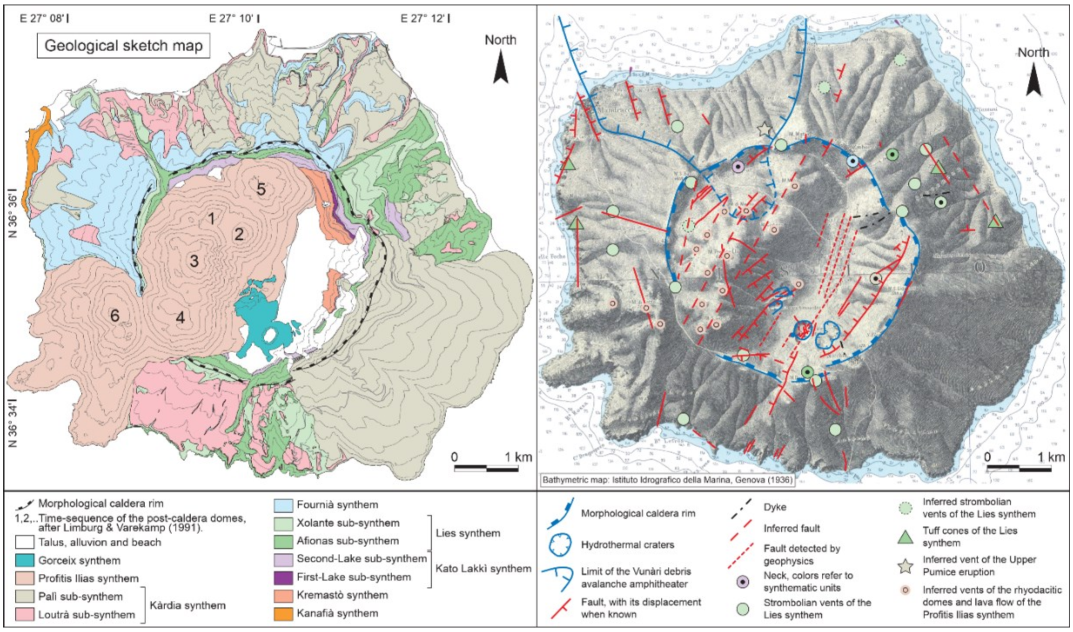


Fig. 2.3.4: Recent fault systems inside the caldera linked to the hydrothermal explosion craters with faults F1 and F2 (View from Nikia).

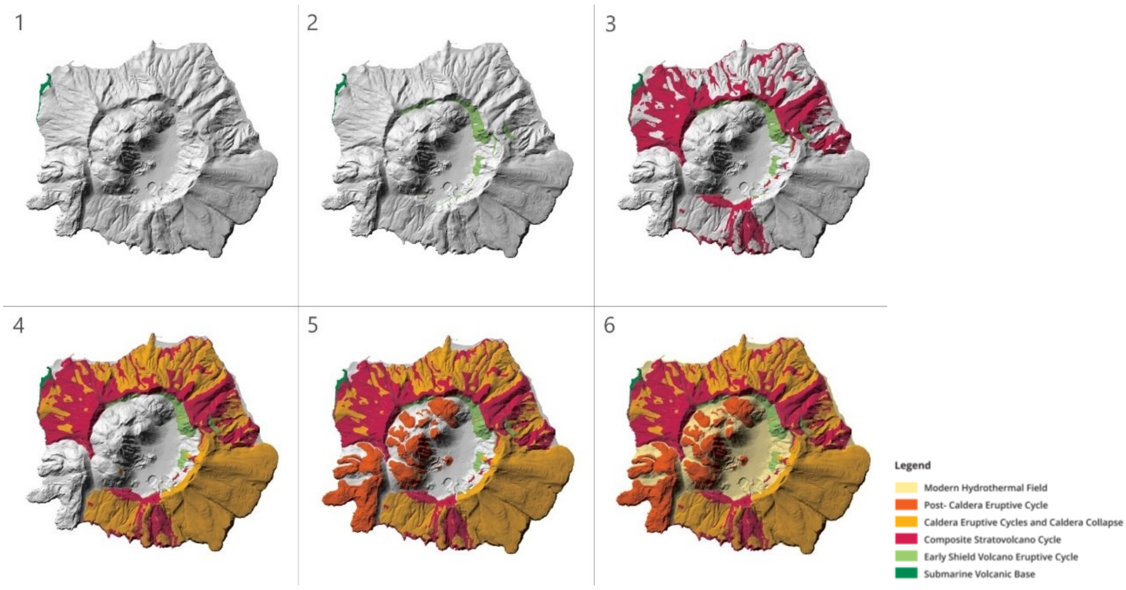


2.3.5: Geological sketch map of Nisyros volcano (Volentik et al., 2005).

2nd order fault system - NW–SE (F3, 4)
The NW-SE major fault system that consists of the F3 and F4 faults, features steep inclinations of 70-80o, trends N30oW and the direction of the dip changes between NE and SW, due to different geomechanical properties of the rocks it cuts through. Downfaulting is up to 70m. F3 fault zone dips 70-80o to the NE, with a throw of more than 100m and juxtaposes different formations: Inside the caldera, it separates the lava domes of Profitis Ilias from the smaller domes to the NE, while outside, it separates the outcrops of white pumice of the downfaulted block from the pillow-lavas of the uplifted block. This fault zone is related to another famous fault of Nisyros, the Mandraki fault that runs parallel to F3 at a distance of about 1km to the SE, with a throw of 100m. Mandraki fault‘s blocks host an ancient castle and a monastery (western block), as well as the entire town of Mandraki (eastern block). F4 fault zone trends N20ºW, consists of two conjugate faults with opposing dips and its throw is about 40-50m (Dietrich, 2019).

2.3.2 Volcanic Evolution

Due to the scarcity of potassium-bearing minerals, like sanidine and biotite, as well as other petrologic and chemical factors, accurate geochronological data are still unavailable. Consequently, the eruptive history of Nisyros Island can only be inferred from the relative ages derived from a detailed lithostratigraphy of thirty-two mappable eruptive units. This stratigraphy has led to the identification of six volcanic cycles based on eruptive successions, contact relationships, epiclastic deposits, and intercalated paleosols (Dietrich, 2018).



2.3.6: The 6 eruptive phases of Nisyros volcano.

The entire island bears witness to a wide array of explosive and effusive volcanic activity, resulting in the formation of calc-alkaline pyroclastic deposits and lavas of varying compositions including basaltic andesitic, dacitic, rhyodacitic, and rhyolitic. Initially, an underwater volcano, characterized by erupting basaltic and andesitic pillow lavas, formed the lower volcanic rocks visible along the northern coast near Mandraki. Over a span of more than 100.000 years, a stratovolcano towering 500–700 meters high developed atop these partly submerged lavas. Following numerous eruptive episodes involving gas and steam explosions, two significant rhyodacitic plinian eruptions blanketed the entire island with pyroclastic flows and pumice falls.

Subsequently, a substantial central collapse of the volcano formed a large caldera approximately <20.000 years ago (Limburg & Varekamp,1991), and during prehistoric times, the western section of the caldera depression was filled with a succession of rhyodacitic domes. The tallest among them, Profitis Ilias, reaches an elevation of 698 meters above sea level. No volcanic activity has been recorded on the island since the formation of these domes, spanning at least 25.000 years. The sole reported historical eruptions are associated with the creation of several phreatic craters within the caldera, including Alexandros, Polyvotis, Stephanos, Phlegethon, and Achelous, which continue to emit fumaroles. Violent earthquakes, gas detonations, steam blasts, and mudflows accompanied the most recent hydrothermal eruptions in 1871–1873 and 1887 AD, resulting in minor injuries and damages to local residences (Marini et al., 1993).

1. Submarine Volcanic Base

The volcanic activity commenced with the emergence of shallow submarine basaltic-andesitic lavas during the "Submarine Volcanic Base" cycle, transitioning into a subaerial environment featuring local lacustrine lakes. The oldest occurrence of volcanic activity on the island is represented by a shallow submarine to subaerial formation of hyaloclastites, pillow breccia and pillow lavas of up to 50 m thickness. They outcrop in the north-western part of Mandraki and at Cape Kanoni (Fig. 2.3.7). The autobrecciation of these atypical pillow lavas and pillow breccias can lead to an interpretation either of water intrusion into the vents at shallow aquatic levels, or the intrusion of lava into muddy tuffaceous sediments (Dietrich, 2019).

2.3.7: Pillow lava formations at Hohlaki Beach (Mandraki).

2. Early Shield Volcano

The volcanic activity that followed led to the development of a shield volcano that underwent three major eruptive cycles (early shield volcano cycles) with short time intervals between them, as implied by the absence of erosional contacts or paleosols. Their exposure is limited to the north-eastern inner walls of the caldera. In this part of the internal caldera cliffs, two volcanoclastic, lacustrine sedimentary successions have been identified (Fig. 2.3.8). These layers indicate the presence of a shallow internal lake, characterizing the internal lake stage and associated volcanic cycles, within a period of minor volcanic activity. The restricted thickness of the beds indicates a short lifetime span of a few hundred years for the two lacustrine systems. Above these layers, a 70m thick of basaltic andesitic lava flows were effused, terminating the lake stage(Dietrich, 2019).

2.3.8: Volcanoclastic lacustrine sedimentary successions
exposed in the internal caldera cliffs.

3. Composite Stratovolcano Cycle

Over time, a composite stratovolcano took shape, where volcanic centers were active both at the north and south parts of the island with the latter witnessing the effusion of rhyolitic lava. Along the eastern coast, predominantly explosive eruptions gave rise to two larger tuff cones composed of andesitic and dacitic materials. To the south, the cycle starts with a 30m thick basaltic andesitic pyroclastic succession followed by pyroclastic flows. The rocks feature strong hydrothermal alteration, something that requires a larger magma reservoir at higher crustal depth as well as heat supply by a hydrothermal system. The cycle ends with the effusion of up to 40m thick partly glassy and perlitic rhyolitic lava flows (Fig. 2.3.9) (Dietrich, 2019).

Fig. 2.3.9: i) Rhyolitic lava flow west of Avlaki, ii) Western part of the southern coast (Lefkos Bay); red scoria fallout cover on top of rhyolitic lava.

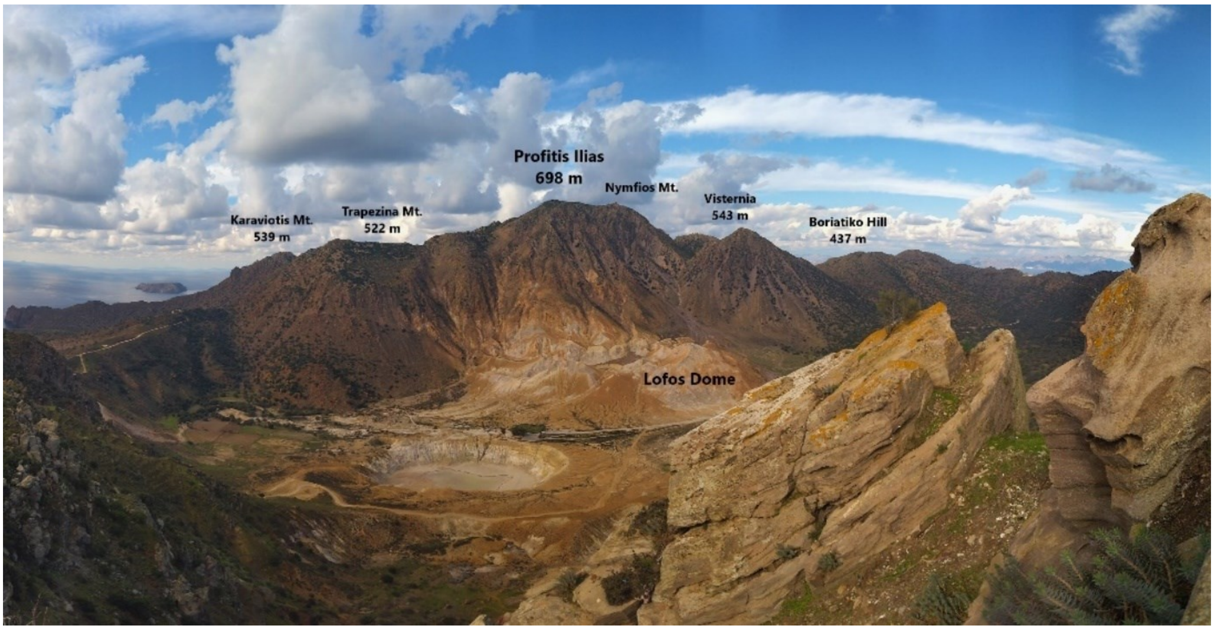
4. Caldera Eruptive Cycles & Caldera Collapse

Following an indeterminate hiatus, extensive eruptions of rhyolitic pyroclastics commenced from both northern and southern eruptive centers, marking the "Caldera Eruptive Cycles." During that period, two vast successions of rhyolitic pumice derived from plinian eruptive cycles, designated as "lower and upper pumice" (Fig. 2.3.10), were deposited and divided by epiclastic deposits, the effusion of voluminous rhyolitic lava flows and the breakdown of a large caldera to the present-day dimensions. The duration of volcanic activity for each cycle, as well as the overall timespan, remains uncertain, despite the presence of two extensive paleosols delineating these periods. These paleosols are prominently displayed at Cape Katsouni. Following this, there was a primary caldera collapse, followed by extensive rhyolitic lava flows spreading southeastward. The latest significant explosive rhyolitic eruption, emerging from a northern center after an indeterminate period, deposited substantial pumice on the northern and eastern slopes, resulting in a subsequent stage of caldera collapse (Dietrich, 2019).

2.3.10: Lower and Upper pumice deposits at Cape Katsouni.

5. Post-Caldera Eruptive Cycles

During the "Post Caldera Eruptive Cycle," significant outpourings of rhyodacitic magma created expansive domes and flows in the western section of the caldera (2.3.11), the highest of which, Profitis Ilias, rises 698 m a.s.l. Since then, Nisyros Volcano has been dormant. Magmatic elements, including gabbroic and dioritic intrusions, as well as mafic cumulates, have contributed to the development of an extensive hydrothermal system at depth, which continues to be highly active today (Dietrich, 2019).



2.3.11: The Nisyros caldera with the hydrothermal explosion crater field surrounded by rhyodacitic domes.

6. Modern Hydrothermal Field

The recent cycle of several hydrothermal explosions took place on the SW sector of the Nisyros caldera in the Lakki plain and is not related to any volcanic activity. Presently, the geodynamic activity is evident through ongoing seismic tremors, steam emissions, and hydrothermal explosions. These phenomena are a consequence of groundwater interacting with magma deep below the surface, causing it to erupt vigorously and giving rise to the hydrothermal craters situated within the caldera. Notable craters include Stephanos, Alexander (Flegethron), Logothetis, Mikros (Small), and Megalos (Big) Polyvotis, as well as the Kaminakia craters (Gorceix, 1873). The most recent hydrothermal explosion, forming the Mikros Polyvotis crater, occurred in 1887 (Martelli, 1917). Since then, the entire system has remained relatively dormant and poses a low risk (Dietrich, 2019).

2.3.3 Thermal Springs

Among the notable hot springs on Nisyros are the Mandraki Baths, situated in Loutra of Mandraki, the Thermiani spring located east of Pali near the church of Panagia Thermiani, and the springs of Avlaki (Fig. 2.3.12):

- The Public Baths of Mandraki, established since 1872 along the island's north coast, feature hot water rich in chlorine, sodium, and sulfur, with temperatures ranging from 46-47°C. Emerging through tuffs and pumice, this hot spring is renowned for its therapeutic effects on various ailments including rheumatism, arthritis, dermatological conditions, and cardiovascular diseases.

- In the village of Pali, hot water from the Thermiani spring flows from alluvial deposits over a coastal

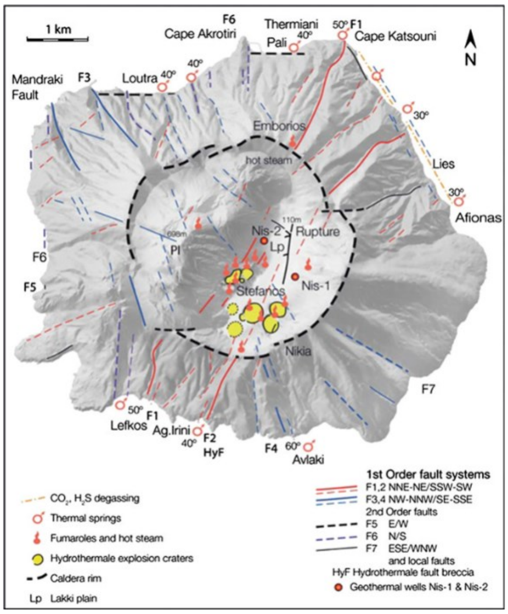


Fig. 2.3.12: Sites of surface emissions hydrothermal explosion craters, fumarolic and steam emissions, thermal springs (Dietrich, 2019).

zone spanning 100 meters, with an average temperature of 39-40°C. The historical Pandelidis Thermal Baths operated here from 1895 until the early 1930s. Although these old baths have been reconstructed, they are not yet operational.

- The hottest spring of significant outflow is located on the south coast of the island, at Avlaki, within andesitic lavas. A third thermal bath was located at this point and benefited from the presence of hot thermal waters measuring 60°C. It was constructed adjacent to a lava flow that extended into the sea, facilitating the establishment of a small harbor in the early 20th century. While the location offers protection from strong northerly winds, it is fully exposed to the open Aegean Sea and occasional southerly gales, which subject the lava cliffs to damage from waves as large as houses.

2.3.4 Offshore Geomorphology

In addition to the features on land, the seabed within the Nisyros Geopark area plays a crucial role in understanding the evolution, dynamics, and potential natural hazards of the volcano. Numerous research projects conducted in the marine environment of the Nisyros complex have generated detailed high-resolution swath bathymetric maps, revealing the extension of the volcanic structure offshore. Within the regional geotectonic basin of Nisyros, which encompasses volcanic domes, calderas, craters, and fractures, volcanosedimentary formations exceeding 700 meters in thickness have been identified through seismic profiling. The Nisyros volcano is built up from a base level of −242 m up to +698 m, with an overall volcanic relief of 940 m. The boundary of the geopark encompasses various areas, including (Fig. 2.3.13):

- Parts of the Kondeliousa Basin, which is bordered by the Kondeliousa intermediate horst structure to the south and the Kefalos platform of Kos island to the north. Northeast of Kondeliousa islet, submarine domes orientedNE-SW, have been identified, with underwater dives confirming the presence of sub-vertical massive lava walls and thick dikes (Nomikou et. al., 2010). These submarine volcanic features exhibit a volcanic relief of 360 meters, ranging from a water depth of 451 meters at the seabed to a summit depth of 91 meters.

- Distinctive morphological features indicative of volcanic debris avalanche deposits are also observed on the submarine slopes southeast and southwest of the Nisyros volcanic structure. These deposits form clusters at various depths, ranging from 196 meters to 769 meters, and extend up to 20 kilometers away from the Nisyros coast. The shape of these hummocks varies, ranging from circular to elongated and asymmetrical blocks with different orientations, with an average axial length of 350 meters for the larger ones. A particular debris avalanche deposit has been extensively studied on the southeast flank of Nisyros (Tibaldi et al., 2008; Nomikou et al., 2009; Livanos et al., 2013; Anagnostopoulos & Anastasakis, 2020). The blocks exhibit elongation parallel to the flow direction of the debris avalanches originating from the Nikia rhyolites exposed at southeast Nisyros Island. The volcanic debris avalanche consists of numerous hills rising up to 60 meters above the sea bottom, along with longitudinal ridges, forming a horse-shoe-shaped structure.

- The Avyssos caldera, the largest underwater volcanic crater situated northeast of the Strongyli islet, derives its name from its considerable depth, ranging from 600 to 700 meters. This location is thought to possibly correspond to a vent, from which the significant volume of the "Kos Plateau Tuff" (or Kos Ignimbrite) erupted approximately 161.000 years ago (Keller et al., 1990; All, 2001; Dalabakis, 1987). The caldera exhibits an elliptical shape, measuring 3 kilometers in the NW-SE direction and 4 kilometers in the NE-SW direction. At the center of Avyssos, there is a hill roughly 1 kilometer in length with a relief of about 60-70 meters, which likely represents later intrusions of volcanic rocks within the nearly flat base of this offshore caldera. Exploration of Avyssos has revealed that it is covered with fine-grained sediment of low thickness, characterized by bioturbation holes and mounds, and lacks any evidence of hydrothermal activity (Nomikou, 2021).

- The intra-volcanic smaller-scale basins include the Pachia-Pergoussa basin, characterized by a maximum depth of 345 meters and a basinal morphology marked by volcanic intrusions, and the Yali-Nisyros basin, with a maximum depth of 290 meters and bordered by faults. The western marginal fault of the Yali-Nisyros basin is the offshore extension of the active Mandraki fault, which caused the destructive earthquake that struck the island's capital in 1996. The Pachia-Pergoussa Basin is bordered by Yali to the north, and Nisyros to the west. The basin's morphology exhibits fluctuations due to volcanic intrusions and is separated from the Western Kos Basin and the Yali-Nisyros Basin by small submarine ridges (Nomikou, 2004).
- Finally, the Yali-Nisyros Basin (275 m of depth) is bordered by Nisyros to the south and Yali to the north. It is divided to two even smaller sub-basins, separated by a N-S ridge. The western sub-basin‘s western margin is controlled by the active fault zone that gave the Mandraki earthquake of 1996, which has a throw of approximately 100m and a length of 5 km (Nomikou et al., 2018; Nomikou & Papanikolaou, 2011).

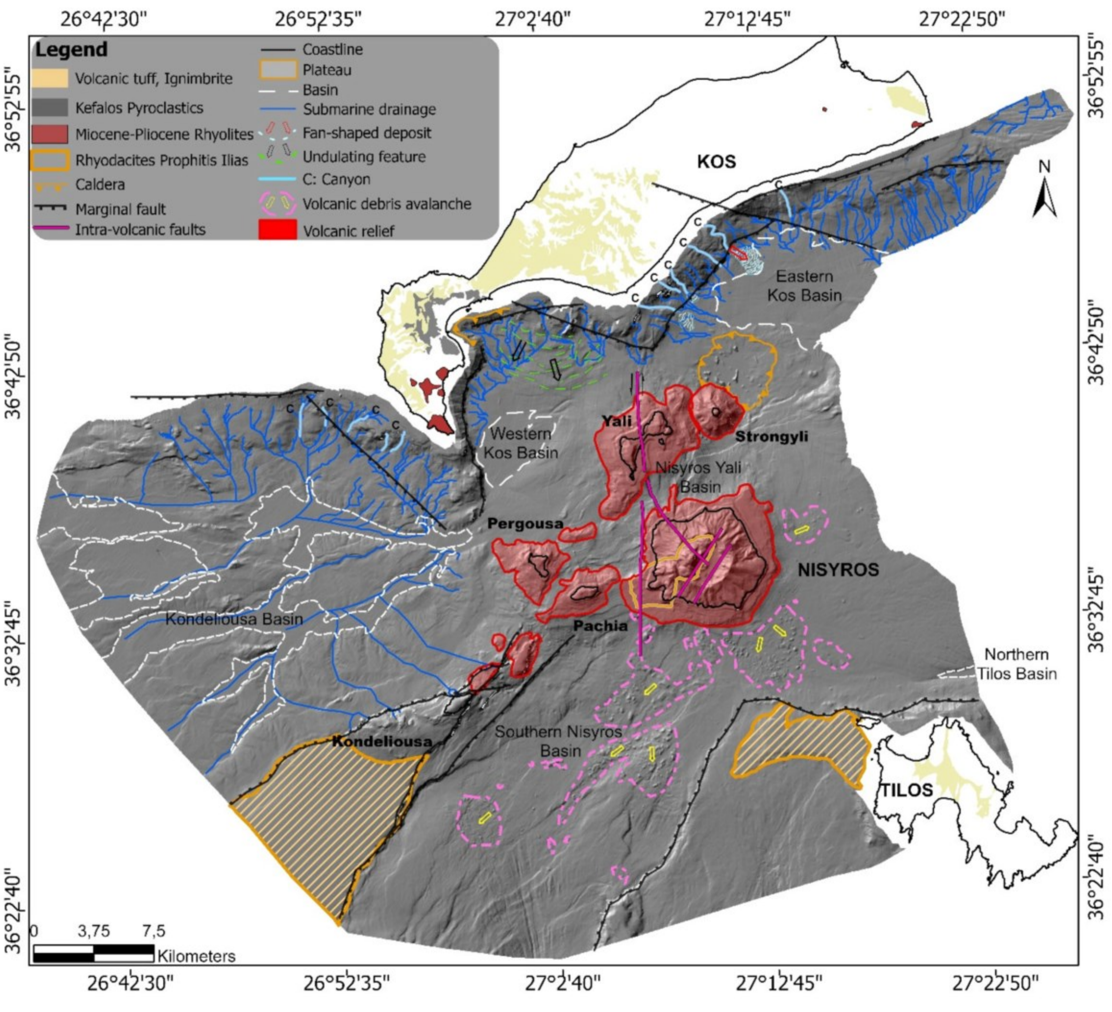


Fig. 2.3.13: Integrated offshore morphotectonic map of Kos-Nisyros volcanic field. The submarine volcanic relief is shown in red polygons. The volcanic edifice comprises also the two submarine calderas and the Nisyros volcanic debris avalanches (Nomikou et al., 2021).

2.4 Cultural and Historical Significance

According to Greek mythology and Apollodorus, the island was created by the god Poseidon, during the Gigantomachy, the war between gods and giants. While Poseidon was chasing Polyvotis giant, he came to Kos Island, and to eliminate him, he grabbed a huge piece of the island and threw it on the giant, thus engraving him. This piece of land is believed to be Nisyros, and the periodical tremors due to volcanic activity are caused by the never resting Polyvotis giant, who is trying to escape from the land that imprisoned him (Fig. 3.4.1).

Fig. 2.4.1: Poseidon crushing Polybotis under a huge rock; black-figure amphora from the 5th century BC. Photo Yorgos Fafalis, © Athens, Museum of Cycladic Art, inv. no. SP 98

The long history of this island, found at the crossroads between occidental and oriental cultures, lies back to the prehistoric times. During Antiquity the island was known as Porphyris (the Red Island), according to geographers Plinius Presviterus (11th century) and Stephanos Vyzantinus (6^{th} century), probably due to the red dye production or the abundant porphyry (red volcanic rock. As far as the modern name of the island is considered, there are many interpretations. Some believe that Nisyros is a phoenix word and means supervision, clipping or fragment, while others believe that it comes from 'neo'(new) and 'syro'(drag), thus reflecting the original myth for the creation of the island. DionisosPyrrosThessalos mention the first name to be Kisiris (pumice) or Kisiros, due to the vast amounts of pumice, which is mentioned as 'akisira' from the locals, and as 'kisiris' from geologists (pumice). Later on, they replaced the first letter K with letter N.

Despite its explosive past, Nisyros has been inhabited since prehistoric times, when the first inhabitants of this island came from the west Anatolian coast and Asia Minor. These were the pre-Hellenic Pelasgians, followed by the Kares, the Kos people, the Thessalians and the Rhodes people. Early trading is indicated by the findings of obsidian from Yali in the first center of obsidian fabrication on the island of Saliagos between Paros and Antiparos islands. Nisyros must have reached a certain economic importance during archaic times, proven by the archaeological finds such as steles and vessels from the cemetery of the 8th–5th centuries B.C and displayed in the Archaeological Museum at Mandraki.

During the 4th century BC the island thrived and it evolved into an autonomous 'city-state', cutting its own coin.The island was also known at those times for its thermal springs as is evident from an inscription in the Roman thermal bath at Pali. Several watchtowers ('fryktories') from this period have been found on the islet of Pergousa, on the southwest side of Nisyros, at Drakospilia on Cape Lefkos and at Pyrgoi near Kateros. Paleokastro (Fig. 2.4.2), the capital's fortress castle, dates back to the same period. It was built by using large blocks of volcanic black rock at the west side of the island. and it was protecting one of the most impressive villages.

Fig. 2.4.2 The ancient wall of Paleokastro (left) and the Castle of Mandraki (right).

The villages of Nisyros (Fig. 2.4.3) retain their charm on the principle of space saving, according to the Nisyrian proverb. The four main villages of Nisyros are Mandraki, Emborios, Pali and Nikia. They are all built with an eastward direction, in order to be shielded from the western wind and they are all considered as historically preserved areas.

Fig. 3.4.3: i) Pali, ii) Nikia, iii) Emborios & iv) Mandraki.

● Mandraki: It is located in the northwestern coast of the island, and it is the capital, the main port and the most extensive village. It is a very picturesque village, built amphitheatrically on the hill on which the Venetian Castle (Mandraki Castle) looms, as well as the Monastery of Panagia Spiliani (Fig. 2.4.4). The double houses are east-faced, built right next to each other and they include white walls and window frames in vivid colours.

Fig. 2.4.4: Panagia Spiliani Monastery

● Emborios: A small mountainous village in the northeastern part of the island, built at an altitude of 350m, hence offering a breathtaking view to the caldera. There the Pantoniki castle and the Taxiarchis church can be found. At the entrance of the village there is a cave that is considered a natural sauna, due to heat caused by the volcanic activity. The village has been abandoned since the 1933 earthquake, and nowadays few people dwell there.

Fig. 2.4.5: Traditional Nisyrian buildings, houses and pebbled floors.

● Pali: A seaside village situated at the northern part of the island, at a distance of 4km from Mandraki, Paloi is home to Panagia Thermiani (Thermal Virgin) and the Pantelidis thermal springs. A private marina for vessels is in operation in this village.

● Nikia: Located in the Southeastern part of the island and built right on the edge of the caldera, Nikia offers a panoramic view of both the crater and the Aegean sea. It‘s architecture is of great importance, with an impressive ellipsoid stony square named ‘Porta’ (door).

Fig. 2.4.6: Nisyrian settlements reflecting the typical characteristics of Dodecanese architecture.

The architecture of the Nisyrian settlements reflects the morphological and typological characteristics of the Dodecanese ‘s architecture (Figs. 2.4.5 & 2.4.6). The typology of the domestic environment varies as well, from the classic small house to the spaced urban one, according to neoclassical reports.The Nisyrian houses are usually double-decked, with differences regarding the chimney, the gutter, the stairs, the windows and the colors of the wooden balconies. At the ground floor there is the ‘Katoi‘, which is used for cooking, weaving, kneading and baking, as well as for storage. On the first floor the hall and the boudoir can be found, along with a wooden platform that is used as a bed, isolated with hanging embroidery.

Below this platform there is space left for storage. The house yards and the village squares are decorated with fabulous stone floors that depict a wide variety of patterns with spirals, waves and nature scenes. They are constructed by local craftsmen or craftsmen from the neighboring islands. The traditional villages of the island retain the classical characteristics of the Dodecanese: they are densely structured and include interesting squares, plateaus, and small street widenings, which take advantage of the narrow space and are a continuation of the everyday life of locals.

During its long history, Nisyros became a spiritual and religious region. This is proven by the numerous places of worship (ancient temple remains, numerous Byzantine and post-Byzantine temples, chapels, monasteries, objects of unparalleled religious craft, like Byzantine glyphs, wooden temples, rock crafts etc). These compose a mosaic of rare beauty and contribute to the enhancement of the island‘s cultural heritage (Fig. 2.4.7).

Fig. 2.4.7: i) Prof. Ilias (Nikia), ii) Kimisi Theotokou (Emborios), iii) Panagia Diavatini (Prof. Ilias Mt.) & iv) Prof. Ilias (Diavatis Mt.).

2.5 Biodiversity

Due to its volcanic origin and location, the island plays a significant role in the migration of various Asiatic species towards Greece and Southern Europe. The entire island, along with the surrounding islets, is included in the Natura 2000 network (GR4210032 NISOS NISYROS KAI NISIDES), covering a total area of 4.730,83 hectares. The southern part of the island, Strongyli, and the coastal zone (GR4210007) also fall under this designation, spanning an area of 17.823,80 hectares. Additionally, it is recognized as a Place of Significant Natural Good. A wildlife refuge encompassing approximately 16.100 hectares extends from the northern to the central parts of the island.

Fig. 3.5.1: Flora of Nisyros

Nisyros boasts a diverse flora (Fig. 2.5.1), with 450 recorded species, making it the only green active volcano in the Aegean region. Adequate moisture is held within the nutrient-rich volcanic soil, ashes, and pumice, ensuring the required humidity levels. While the prevailing north winds can escalate to stormy conditions, even during summer, the southern winds typically remain calm or escalate to gale force during winter. The island's vegetation primarily comprises Mediterranean evergreen shrubs and phrygana communities, interspersed with sporadic terebinth and oak trees (Petanidou et al., 2008). The volcanic activity between 1873 and 1877 completely devastated the crater's vegetation, but today, thriving plant life has emerged from the soil formed by caldera-fill deposits. The region is also home to 85 bird species, 7 reptile species, and the Monachus-monachus seal along the island's coasts (Fig. 2.5.2).

Fig. 2.5.2: Fauna of Nisyros.

3. Geoheritage Inventory

3.1 Geosites Mapping

In this section, the focus shifts to the heart of the thesis, delving into the comprehensive inventory and assessment of the geoheritage of Nisyros. The unique geological features and formations of the island hold invaluable scientific, educational, and aesthetic significance, making it a prime candidate for recognition as a UNESCO Global Geopark. Through systematic inventory and rigorous assessment, this section aims to unearth the diverse geological assets of Nisyros, shedding light on its volcanic landscapes, mineralogy, and geological processes. By cataloging and evaluating these geological treasures, this study endeavors to lay the groundwork for effective conservation, sustainable management, and the establishment of educational programs aimed at promoting the geodiversity of Nisyros on a global scale.

The mapping and cataloguing process of the 24 geosites of Nisyros Geopark involved a meticulous approach to capturing the geological and geoenvironmental features of each site. The process began with comprehensive data collection field trips aimed at precisely locating and documenting each geosite. Detailed information, including bibliographic data, topographic maps, and geological structures, was homogenized, organized, and transformed into a geodatabase using GIS tools. Additionally, ArcGIS Collector was utilized during fieldwork to ensure the accuracy of geographic location data collection. The collected data were combined for the creation of the final geotouristic map using ArcGIS Pro, representing all the points of interest, providing valuable information for visitors exploring the geosites of Nisyros Geopark. The resulting geotouristic map (Fig. 3.1.1) showcases the location of each geosite and georoute, offering an interactive and comprehensive guide to the geological heritage of the geopark.

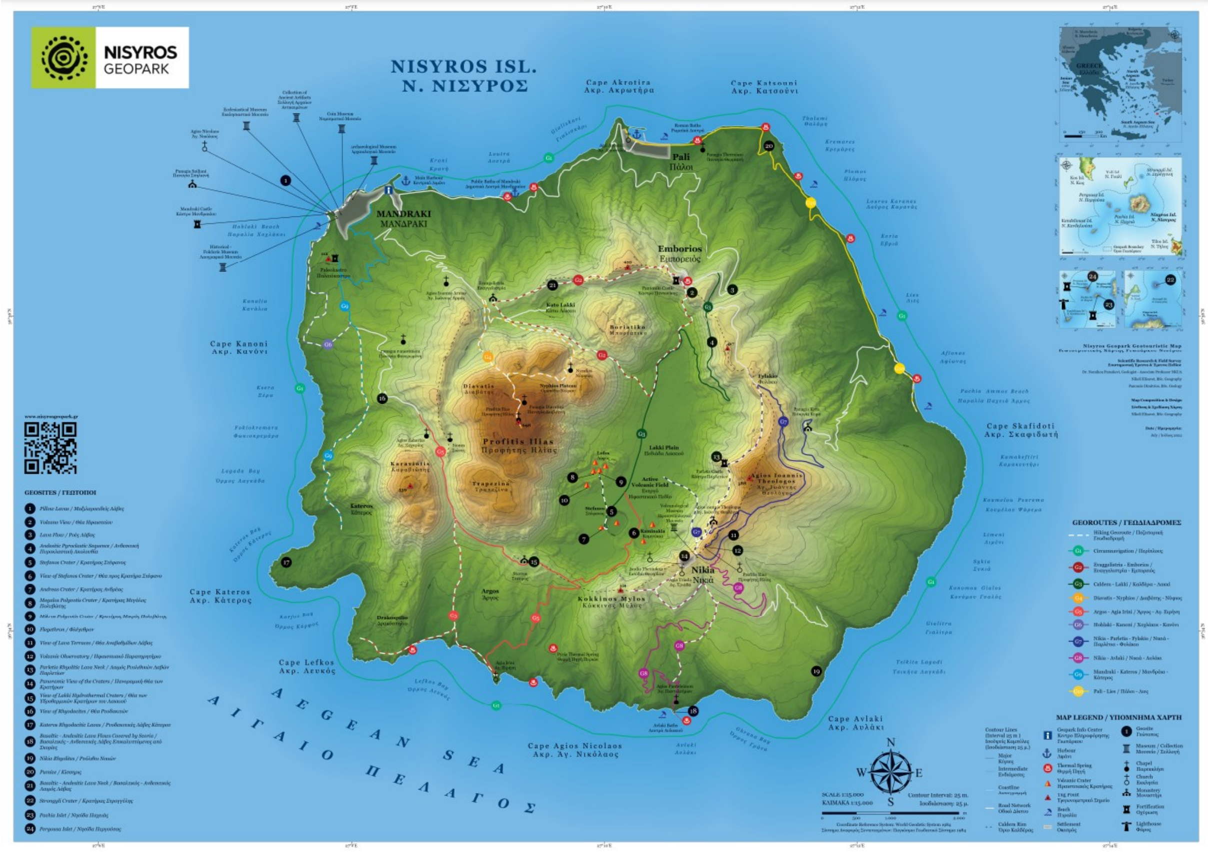


Fig. 3.1.1: The official Geotouristic Map of Nisyros aspiring UNESCO Global Geopark (see Appendix).

The 24 geosites of the Nisyros aUGGp are registered in a database (Fig. 3.1.2) which is created, managed and constantly updated, together with all the necessary descriptive information concerning the geological value and the location of each one of them.

No	Longitude	Latitude	Name	Category
1	27.130379	36.611186	Pillow Lavas	Geological/Geomorphological Interest
2	27.178195	36.6025038	Volcano View	Educational, Aesthetic Value
3	27.1836147	36.6028175	Lava Flow	Geological/Geomorphological Interest
4	27.1809213	36.5973001	Andesitic Pyroclastic Sequence	Geological/Geomorphological Interest
5	27.1676069	36.5794055	Stefanos Crater	Geological/Geomorphological Interest, Educational
6	27.1705672	36.5770473	View of Stefanos Crater	Aesthetic Value
7	27.1663651	36.5774998	Andreas Crater	Geological/Geomorphological Interest, Educational
8	27.1648976	36.5831679	Megalos Polyvotis Crater	Geological/Geomorphological Interest, Educational
9	27.1660571	36.5833716	Mikros Polyvotis Crater	Geological/Geomorphological Interest, Educational
10	27.1637942	36.5819376	Flegethron	Geological/Geomorphological Interest, Educational
11	27.1837574	36.5768332	View of Lava Terraces	Geological/Geomorphological Interest
12	27.1800022	36.5757291	Volcanic Observatory	Aesthetic Value
13	27.1815201	36.5851	Parletia Rhyolitic Lava Neck	Geological/Geomorphological Interest, Archaeological Interest
14	27.1771858	36.574659	Panoramic View of the Craters	Aesthetic Value
15	27.1574076	36.574042	View of Lakki Hydrothermal Craters	Aesthetic Value
16	27.1374829	36.5912784	View of Rhyodacites	Geological/Geomorphological Interest
17	27.1247321	36.5739788	Kateros Rhyodacitic Lavas	Geological/Geomorphological Interest
18	27.176827	36.5587434	Basaltic - Andesitic Lava Flows Covered by Scoria	Geological/Geomorphological Interest
19	27.1946551	36.5624413	Nikia Rhyolite	Geological/Geomorphological Interest
20	27.18841	36.6180027	Pumice	Geological/Geomorphological Interest
21	27.1598638	36.6032808	Basaltic - Andesitic Lava Neck	Geological/Geomorphological Interest
22	27.179361	36.680523	Strongyli Crater	Geological/Geomorphological Interest
23	27.0720586	36.569765	Pachia Islet	Geological/Geomorphological Interest
24	27.0384296	36.5867204	Pergousa Iset	Geological/Geomorphological Interest

Fig. 3.1.2: GIS attribute table regarding the geosites. The table consists of the number, coordinates of the geosites in WGS'84 GeographicCoordinate System, the name of each geosite and its category.

Fig. 3.1.3: The Geopark's Map panel installed in the port of Mandraki.

3.2 Geosites Documentation

Geosite 01 | Pillow lavas

The northeastern coastline of Nisyros Island is characterized by the presence of basaltic andesitic pillow lavas. These lavas were formed during the "Submarine Volcanic Base" eruptive cycle, which marked the initial volcanic activity on Nisyros. The pillow lavas found in this area are shallow and range in thickness up to 50 meters. This formation consists of hyaloclastites, pillow breccia, and pillow lavas. Unlike the closely packed pillow lavas typically found in ophiolite complexes, these lavas suggest that they were not extruded from submarine fissures. Within the formation of the pillow lavas, there are intermittent lava lenses of varying thicknesses, some of which are mixed with hydrothermally altered tuffs and tuffites (Skilling et al. 2002; de Goerde Herve 2008).

Fig. 3.2.1: Impressive pillow lavas at Mandraki.

Fig. 3.2.2: Basaltic andesite "pillow-hyaloclastite" formation at Hohlaki beach. The horizontal hatched lines represent erosional levels of different stages of uplift (Dietrich, 2019).

Based solely on the outcrops of these formations, it is possible to reconstruct a paleogeographic model that resembles a subaerial shield volcanic structure. The vents from which the lavas were emitted align in a northeast to southwest direction. This early volcanic structure is known as the submarine volcanic base of Nisyros. Hohlaki cove, also known as Mandraki Beach, boasts impressive black pebbles that shine under the sun. These pebbles are a result of coastal erosion of the underwater lavas from the aforementioned cycle. The name "Hohlaki" comes from the Greek Hohlos, which describes the sound that the pebbles make when they encounter the sea.

The charming village of Mandraki on the island of Nisyros showcases its rich architectural history. The settlement also offers visitors a unique opportunity to immerse themselves in its cultural heritage. Serving as the island's capital, Mandraki is nestled amphitheatrically on a hill, providing an ideal setting for the imposing Knight's Fortress and the exceptional Panagia Spiliani monastery which adds a spiritual dimension to Mandraki. Nearby, the impressive ancient wall of Nisyros, known as Paleokastro, stands as one of the best-preserved fortifications in the Aegean region and indicates the island's historical significance and defensive strategies.

Fig. 3.2.3: i) The majestic monastery of Panagia Spiliani, ii & iii) Paleokastro, iv) Mandraki Settlement

Geosite 2 | Volcano View

This viewpoint provides a magnificent panorama of the flat expanse of the Lakki caldera, showcasing the distinct Stefanos crater, as well as the Lofos hill, housing the post-caldera craters of Alexander (Flegethron), Mikros and Megalos Polyvotis, and Logothetis. The caldera itself is nearly circular in shape, with steep walls that drop 300-400 m between the northern and eastern rims. It spans approximately 3.6 km in diameter. Inside the caldera, to the east, lies the Lakki plain, situated 110 m above sea level. To the west, the landscape is dominated by towering rhyodacitic domes reaching heights of up to 698m. These domes were formed through the island's most recent magmatic activity. They are a result of two significant plinian-type eruptions that took place during the Caldera Eruptive cycles of Nisyros over 24.000 years ago. These eruptions occurred due to a lack of magma within the magmatic chambers that produced them.

In Lakki area, there is constant geodynamic activity manifested through high seismic restlessness, fumarolic activity, and hydrothermal explosions. Presently, steam and fumarolic activity can be observed in the hydrothermal craters along faults, as well as from various minor fractures in the Profitis Ilias dome. A Volcanological Observatory is situated in the renovated premises of the former Municipal School of Emborios, which has been restored. The building's strategic location on the caldera's edge allows for clear observation of the caldera's base and the hydrothermal craters.

Fig. 3.2.4: i) View of the caldera Spiliani, ii) Apyria thermal spring iii) Emborios Settlement, iv) The Volcanological Observatory at Emborios

Geosite 03 | Lava Flow

During the initial stages of the Composite Stratovolcano cycles, a series of eruptive occurrences occurred that signified the shift from the earliest shield volcano to stratovolcano. This period of transition is characterized by three primary lava flows originating from eruptive centers in the northern and eastern central regions. These flows constitute the upper sections of the caldera walls in the northern, northeastern, and eastern segments, while also covering the north-western slopes extending from the Monastery of Evagelistria and the eastern slopes between Linevrochia and Kremasto. The first flow, measuring 40 meters in thickness and composed of andesitic lava, emanated from a central vent, spreading across the upper caldera walls except for the southwest portion where it is likely overlaid by the younger Profitis Ilias rhyodacitic lava flows. Within the same geological unit, there are two additional satellite eruptive centers represented by an andesitic neck and a small scoria cone situated on the upper eastern slopes near the present-day caldera rim.

Due to its volcanic origin and advantageous location, Nisyros plays a significant role in the growth of plant and animal life. It serves as a crucial migration hub for Asiatic species heading towards Greece and Southern Europe. The island boasts an impressive array of documented biodiversity, including 450 species of plants, 85 species of birds, and 7 species of reptiles. This abundance of diverse life showcases the importance of Nisyros and calls for its special protection and exploration. As a result, two specific areas within the Nisyros Geopark have been included in the Natura 2000 Network, while an additional 3 areas have been designated as Wildlife Refuges.

Fig. 3.2.5: i) Andesitic Lava Flow, ii) Coracias garrulus - European roller, iii) Crocus longiflorus - Yellow-throated Crocus, iv) Panoramic view of the lava flow

Geosite 04 | Andesitic Pyroclastic Sequence

Within the inner rim of the Northeastern caldera, as you travel along the road to Lakki, there is an intriguing sequence of volcanic activity to be enjoyed. During the initial eruptive cycle of the Shield Volcano, three distinct eruptions occurred in relatively quick succession. These eruptions resulted in the formation of pyroclastic materials and lavas with a composition of basaltic andesite, albeit with slight variations in their eruption characteristics. Additionally, two sets of volcanoclastic, lacustrine sedimentary deposits can be observed. These deposits span five hundred meters and are separated by subaerial basaltic andesite lava layers that are a few meters thick. This arrangement suggests the presence of an "internal lake" during a period of minor volcanic activity.

Fig. 3.2.6: Panoramic view of the sedimentary deposits.

The layered deposits found in the two lakes within the caldera, along with the volcanic activity, suggest that volcanic ash and small, grainy particles were deposited in a watery environment. The presence of sandy layers indicates a mixture of sediments. The duration of these cycles in the lakes was relatively short, likely lasting only a few hundred to a thousand years. This is because the layered deposits are not thick, indicating a limited timespan for their formation.

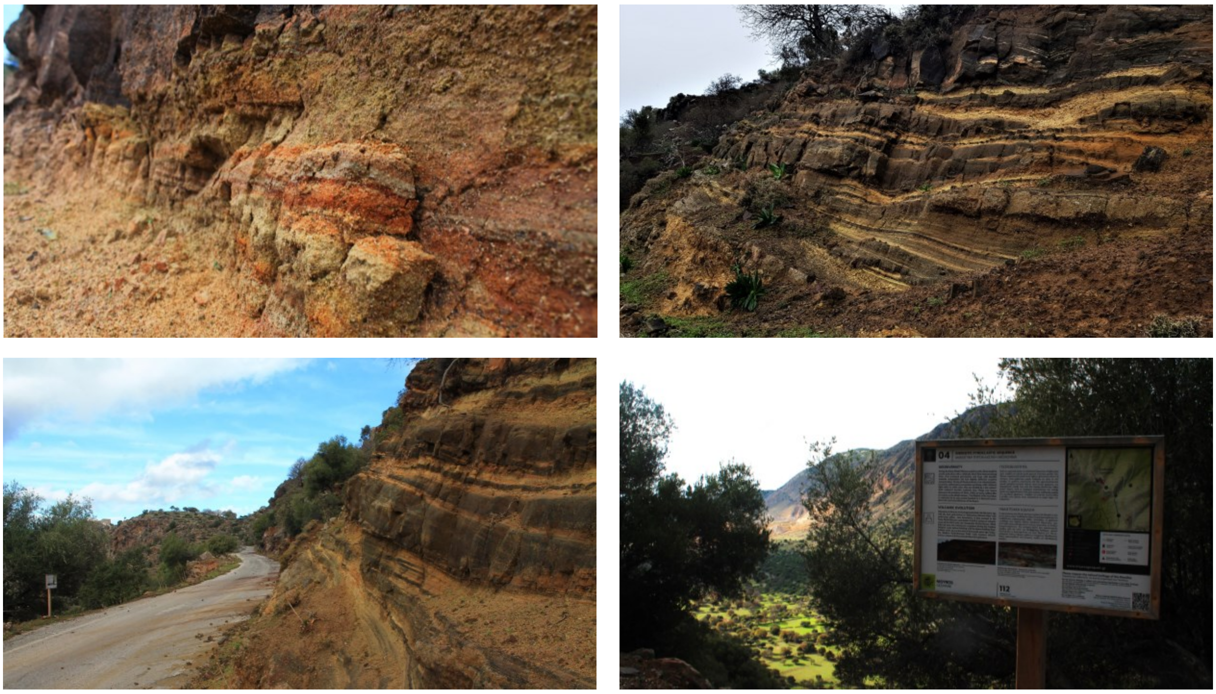


Fig. 3.2.7: Sedimentary Succesions - Distinctive light yellow-white color volcanoclastic, lacustrine strata interrupted by a layer of basaltic andesite lava.

Geosite 05 | Stefanos Crater

The elliptical Stefanos Crater stands as one of the largest phreatic craters worldwide, boasting dimensions measuring 260x330m. Its maximum depth reaches an impressive 27m, and its peculiar shape appears to have formed due to the presence of two significant NE trending active faults, indicated by a series of fumarolic vents positioned in alignment. As for its age, it remains shrouded in mystery. On the eastern walls of Stefanos, where optimal exposure occurs, experts have identified a total of seven stratigraphic layers. These layers include talus comprised of magmatic lithics, epiclastics, and fine argillitic layers, followed by fine-grained lacustrine deposits and compact deposits originating from the eruption products that shaped the Kaminakia craters. Additionally, there are deposits resulting from the eruption of Stefanos itself, as well as a thin layer of explosive products originating from Polyvotis.

Fig. 3.2.8: Panoramic view of the massive Stefanos crater

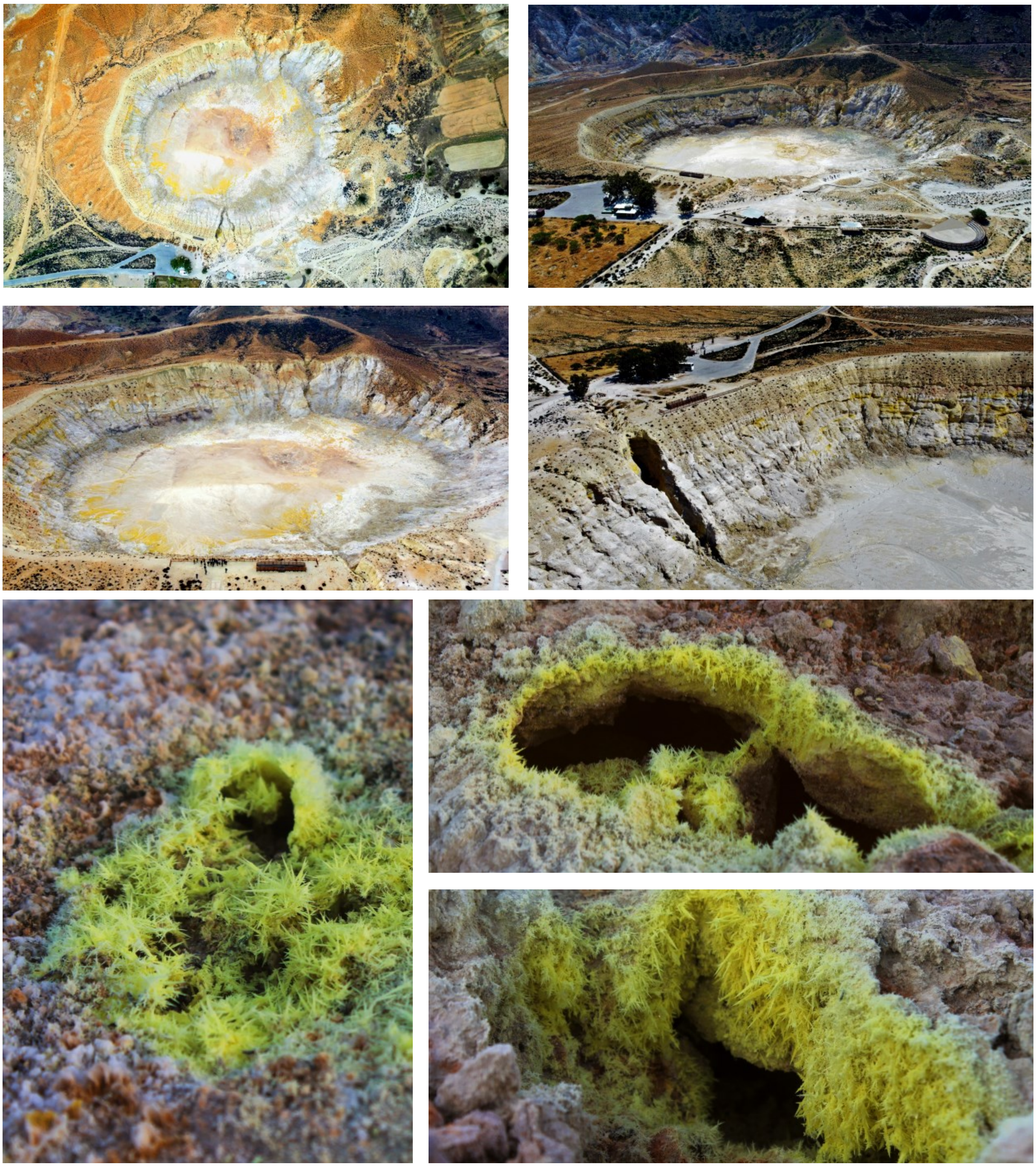


Fig. 3.2.9: The enormous Stefanos crater featuring fumaroles covered by fresh sulfur crystals.

Geosite 06 | View of Stefanos Crater

The view of Stefanos from the Kaminakia area is truly impressive. These two hydrothermal craters have a unique crescent shape and are located on the southeastern walls of the caldera. Stefanos Crater is a massive phreatic crater, ranking among the largest in the world. It measures 260x330m and reaches a maximum depth of 27m. Its distinctive shape appears to be a result of two major active faults that trend northeast, as indicated by the alignment of fumarolic vents. The exact age of Stefanos Crater remains unknown. On the other hand, Kaminakia are two craters with a diameter of 150m each. They are partially filled with debris from the caldera slopes and materials erupted from Stefanos. These hydrothermal craters are unique because they are the only ones to form on the southeastern slopes of the caldera. Furthermore, they are much younger than Stefanos. This site also provides a vantage point for observing the Parletia lava neck (Geosite 13), an lava mound situated atop the caldera rim.

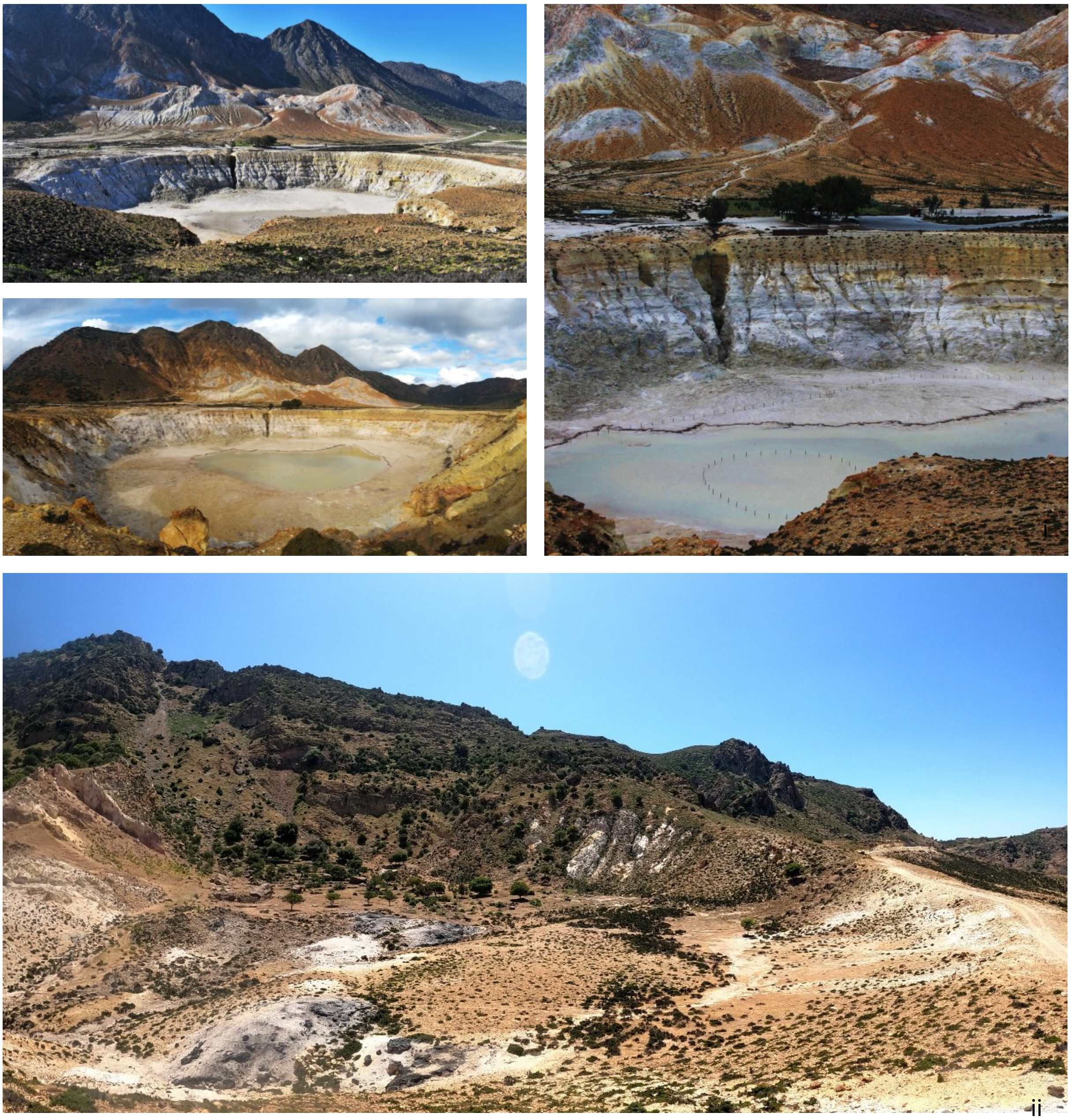


Fig. 3.2.10: Panoramic view of the massive Stefanos hydrothermal crater along with the rhyodacitic domes partially filled with water after heavy rainfall (i) and Kaminakia craters (ii).

Geosite 07 | Andreas Crater

While descending the hiking trail towards Stefanos crater, one can observe Andreas, a small hydrothermal crater, situated at the southwestern rim. The presence of deposits that unconformably overlay those of Stefanos provides evidence of Andreas' brief phreatic explosion. This indicates that Andreas is a more recent geological feature compared to its larger neighbor, hence it is also known as Mikros (Small) Stefanos. Historical records indicate that the intense hydrothermal activity of the volcano between 1873 and 1877 had a significant impact on the local vegetation surrounding the craters, resulting in its complete destruction. Andreas stands out for its floor vegetation, presenting a stark contrast to Stefanos. Unlike Stefanos, Andreas lacks active fumaroles, thermal emissions, and sulfur deposits, creating a more favorable environment for the growth of low vegetation.

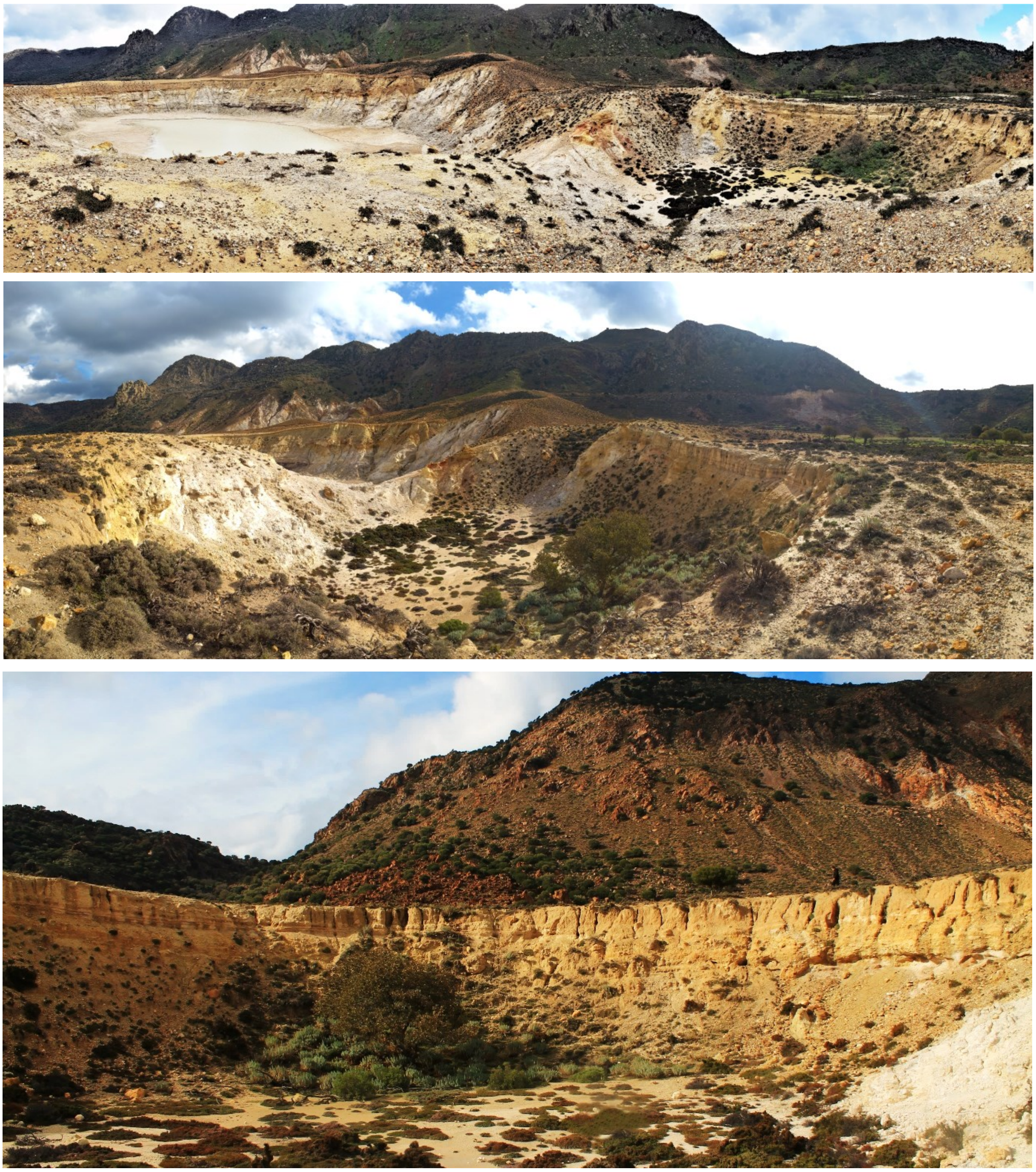


Fig. 3.2.11: Panoramic view of Andreas crater, cutting Stefanos' crater rim.

Geosite 08 | Megalos Polyvotis Crater

Megalos Polyvotis was formed as a result of an early and intense hydrothermal explosion in the Lofos area. This crater has an elliptical shape, measuring 180x350 meters, and its ejecta, which are 3-5 meters thick, are partially covered by Flegethron products from a later event. The crater is composed of altered fragments of lava and rhyodacitic blocks embedded in a clayey to sandy matrix. The lava blocks are surrounded by brown-reddish oxide coatings and intersected by veins of anhydrite.

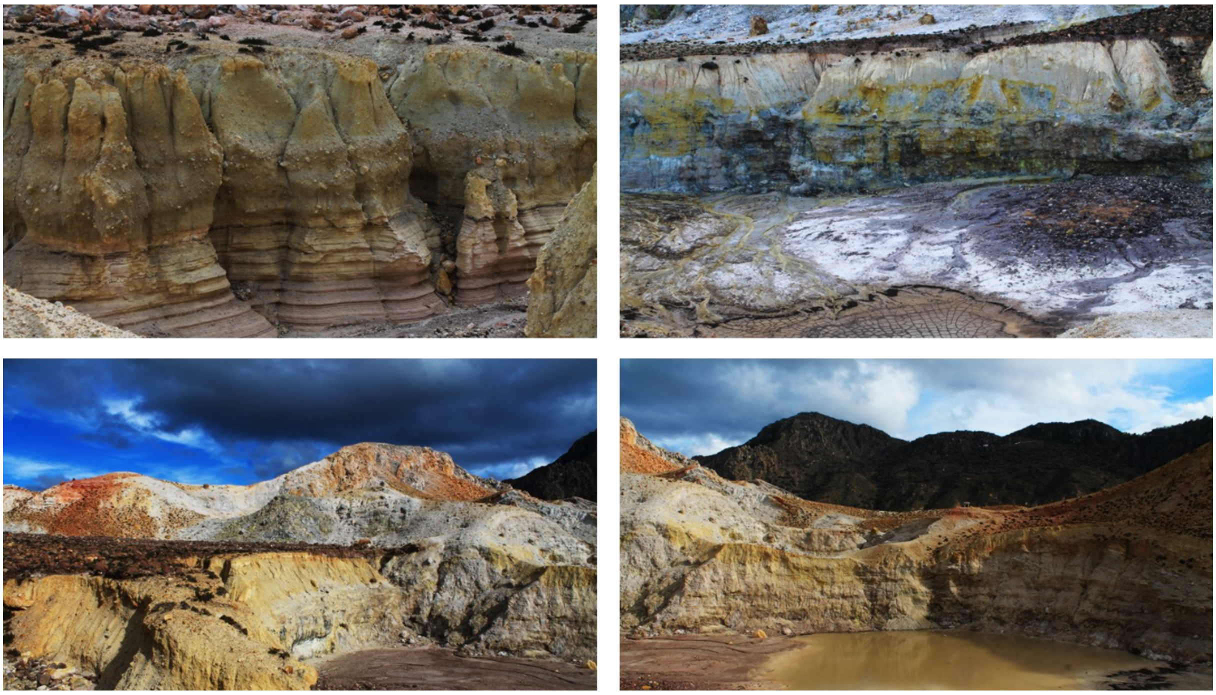


Fig. 3.2.12: View of the impressive floor and wall of Megalos Polyvotis crater.

Similar to Stefanos, the walls of Megalos Polyvotis exhibit a stratigraphy that includes lacustrine sediments and loose clay material at the bottom, transitioning to chaotic ejecta from earlier magmatic events in the upper portion. The western part of the crater floor often transforms into a lake following heavy rainstorms, characterized by yellow and purple-colored varved clay layers that are 1.5 meters thick, providing evidence of a past lake's existence.

Fig. 3.2.13: Panoramic scene showcasing the interior of Megalos Polyvotis crater.

Geosite 09 | Mikros Polyvotis Crater

As you make your way towards the Lofos volcanic dome, a short trek from the Lakki plain below and Stefanos crater exposes Mikros Polyvotis, also known as the Giant of Greek Mythology. Situated to the east of Megalos Polyvotis crater (Geosite 08), Mikros Polyvotis stands out as the youngest hydrothermal crater in the Active Hydrothermal Field, resulting from the hydrothermal eruption in 1887.

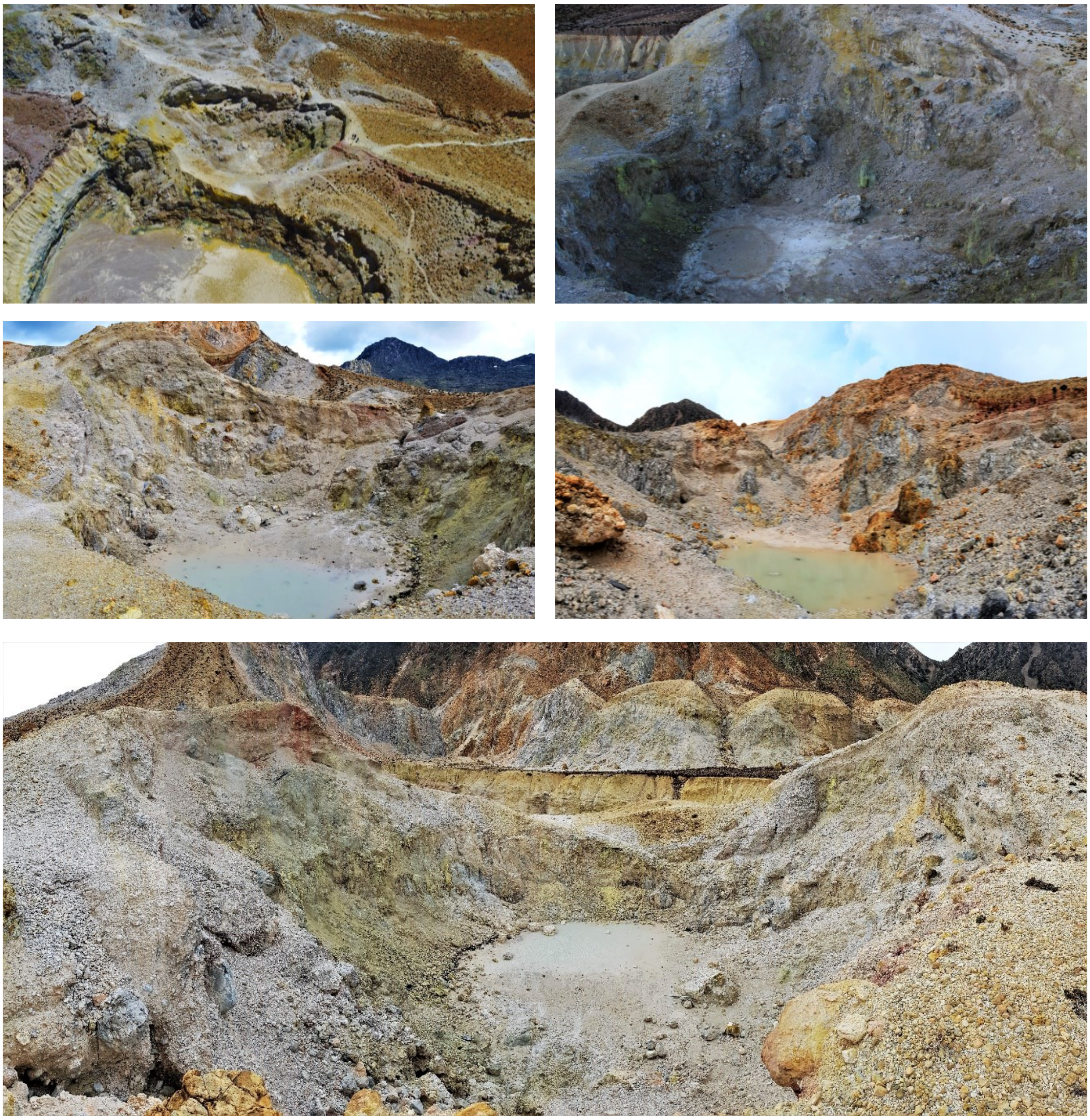


Fig. 3.2.14: View of the interior of Mikros Polyvotis crater.

Geosite 10 | Flegethron

The southeastern part of the area is occupied by a large, elliptical-shaped crater known as Flegethron or Alexandros. This crater intersects with Megalos Polyvotis. Moving towards the southwest, the crater collapsed and became filled with its own debris. The history of this hydrothermal crater dates back to 1971 when the first recorded hydrothermal eruption occurred in the western part of Lakki, giving rise to Polyvotis and Flegethron. The activity continued in 1973, accompanied by steam release, loud explosions, and the ejection of lithic material from the Lofos Rhyodacitic dome. There were no signs of magmatic activity during this time. Lacustrine sediments cover the floor of the southern part of the crater.

Fig. 3.2.15: View of the majestic Flegethron crater on Lofos volcanic field.

Geosite 11 | View of Lava Terraces

During the Caldera Forming eruptive cycle at Nisyros, there were two significant and violent plinian-type eruptive events that occurred. In between these events, the first caldera formed after the initial eruption. Following that, there were at least three major rhyolitic lava flows, with a thickness exceeding 150 m and a total volume greater than 1 cubic km. This particular type of lava is known for its high silica content and high viscosity, causing it to flow slowly like a thick, viscous fluid on the surface. The magmas responsible for this lava also contain large amounts of gas, resulting in explosive eruptions accompanied by pyroclastic flows and the deposition of tuff, similar to the caldera forming eruptive events.

The glass-rich and partly perlitic flows descend from the eastern caldera walls in the present-day area between the Monastery Panaghia Kyra and the village of Nikia. These flows then enter the sea between the beaches of Pachia Ammos and Avlaki. Along the trail connecting Nikia to Fylakio, one can appreciate the distinct lava flow structures characterized by terraces within this form.

Fig. 3.2.16: Cultivation terraces built on lava deposits.

Nisyros' topography is characterized by steep inclines, which pose obvious obstacles for farming. Nevertheless, the scenery boasts these terraced fields, known as "pezoules" in the local dialect, ingeniously built using rocks on top of lava deposits. These terraces convert the sloping land into a sequence of stepped levels, serving as a lasting legacy of centuries of extensive agricultural practices that endured until the 20th century. They serve as a testament to the most noteworthy and extensive human impact on the Aegean Islands. Nearby is Nikia, a charming traditional village in Nisyros, accompanied by the Volcanological Museum and the Volcanic Observatory.

Fig. 3.2.17: A scenic village highlighting the excellent Nisyrian architecture.

Geosite 12 | Volcanic Observatory

This viewpoint provides a stunning panorama of the flat expanse of the Lakki Plain within the caldera. Here, you can see the distinct Stefanos crater, as well as the hill that encompasses the post-caldera craters of Alexander (Flegethron), Mikros and Megalos Polyvotis, and Logothetis. These remarkable features can be admired from the volcanic observatory located in the courtyard of Prophitis Ilias chapel in Nikia. The caldera itself is nearly circular in shape, characterized by steep walls that drop 300-400 m between the northern and eastern rims. It has a diameter of approximately 3.6 km. Inside the caldera, you will find the Lakki Plain, situated at an elevation of 110 m above sea level to the east. To the west, there are towering rhyodacitic domes that reach heights of up to 698m.

These domes were formed during the island's most recent period of magmatic activity. They are the result of two massive plinian-type eruptions that took place over 24.000 years ago during the Caldera Eruptive cycles of Nisyros. These eruptions occurred due to a lack of magma within the magmatic chambers that produced them. Within the Lakki Plain, there is ongoing geodynamic activity, which manifests as high seismic unrest, fumarolic activity, and hydrothermal explosions. Currently, there are steam vents and fumarolic activity taking place within the hydrothermal crater. Additionally, there is also activity coming from various smaller fractures within the Profitis Ilias dome.

Fig. 3.2.18: Panoramic view of the Lakki plain, hosting the hydrothermal craters of Nisyros volcano.

The entrance to Nikia settlement is where you'll find the one-of-a-kind Volcanological Museum of Nisyros, the only establishment of its kind in Greece. Located in the renovated building of the abandoned Nikia school, this museum offers a unique opportunity for visitors to explore volcanic rocks, learn about the geological history of Nisyros through informative displays and panels, and participate in hands-on experiments and computer simulations. For those interested in a closer examination, the museum provides microscopes that allow visitors to study thin sections of rocks and gain insight into the scientific methods used to uncover the volcano's secrets.

Fig. 3.2.19: I)The Volcanological Museum at Nikia & ii) Nikia Settlement.

Geosite 13 | Parletia Rhyolitic Lava Neck

During the cycle of volcanic activity known as the Caldera Forming, two significant and intense eruptive events occurred on the island of Nisyros. In between these events, there was an initial formation of a caldera following the first eruption. Subsequently, there were at least three major rhyolitic lava flows, each with a thickness exceeding 150 meters and a total volume surpassing 1 cubic kilometer. This particular type of lava is distinguished by its high silica content and high viscosity, causing it to flow slowly like a thick, sticky fluid. The magmas responsible for this lava also contain large amounts of gas, resulting in explosive eruptions accompanied by pyroclastic flows and the deposition of tuff, as seen during the formation of the caldera.

During the eruption of these molten rocks, a formation known as Parletia was created, along with domes that shaped the eastern boundary of the initial volcanic crater. The Parletia mound, which was once utilized as a Medieval castle in Nisyros, is formed by this geological feature and is home to remnants and water reservoirs. This geotope not only showcases a significant volcanic formation but also highlights the interconnectedness of geological and cultural heritage, making Nisyros an exemplary case study for understanding UGGp sites.

Fig. 3.2.20: A mound of rhyolitic rock formed by the solidification of lava ejected during the Caldera Collapse cycle.

The Parletia lava neck served as one of the Medieval castles of Nisyros. Today, remnants and water tanks from this era can still be discovered on this site. Functioning as a strategic stronghold, the castle commanded control over the entire valley and maintained visual communication with all other castles on the island, with the exception of Mandraki. Thus, this geosite is a tangible link between geological processes and human activities and contributes to the unique geo-cultural heritage of Nisyros.

Geosite 14 | Panoramic View of the Craters

The mesmerizing beauty of Nisyros is truly inspiring and can be admired from the current geosite designated as"Panoramic View of the Craters". On the left side, we are greeted by the presence of Mikros Stefanos, also known as Andreas, and Stefanos. Meanwhile, on the right side, a majestic rhyodacitic hill, Lofos, houses the remarkable craters of Alexander (Flegethron) (1871-1873), Mikros (1887), Megalos Polyvotis (1871-73), and Logothetis. Above them all, the western part of the caldera is adorned with striking rhyodacitic lava domes that add to the enchanting landscape.

Fig. 3.2.21: Panoramic view of the caldera.

The design and structure of the Nisyrian towns and cities clearly show the influence of the architectural characteristics found in the Dodecanese region. Alongside this remarkable feature, the rural houses (caves) surrounding Nikia also hold historical importance. These houses have been designated as a protected zone with a radius of 100 meters due to their significant role in the history of Dodecanese architecture.

Fig. 3.2.22: Aerial view of the picturesque village of Nikia, built on the rim of the caldera.

Geosite 15 | View of Lakki Hydrothermal Craters

The current geosite named "View of Lakki Hydrothermal Craters" provides a magnificent panoramic overlook of the caldera's phreatic craters. Nisyros Island, situated in the Aegean Sea, is a hidden gem renowned for its exceptional volcanic terrain. One must not miss the opportunity to visit Lakki, the flat area within the caldera, particularly if they are nature enthusiasts. At this location, visitors can witness an awe-inspiring view of the rhyodacitic hill that houses the hydrothermal craters, including the renowned Alexander or Flegethron, Mikros and Megalos Polyvotis, and Logothetis. Dominating the center of it all is the circular phreatic funnel of Stefanos crater, whose raw beauty never fails to mesmerize. The village of Emborios in the background further enhances the magical allure of this already breathtaking scene.

Fig. 3.2.23: Panoramic view of the Lakki hydrothermal craters.

The wide variety of flora that has been recorded renders the island as the only green active volcano in the Aegean Sea, with its unique combination of volcanic activity and lush vegetation.While the recent volcanic eruptions from 1873 to 1877 had a devastating impact on the flora within the crater area, it is incredible to see how nature has bounced back. The volcanic materials that filled the caldera have provided fertile ground for new plant life to thrive, resulting in a vibrant ecosystem. Notably, Nisyros also plays an important role in conservation efforts, being home to endangered species such as the endemic Campanula nisyria and the internationally recognized Pinna nobilis.

Fig. 3.2.24: The monastery of Stavros located near this geosite.

Fig. 3.2.25: Wildflowers of Nisyros.

Geosite 16 | View of Rhyodacites

The Caldera's Rhyodacitic Domes, seen from the west, are the most recent lava intrusions from the 'Post-Caldera Eruptive Cycle'. These rhyodacitic lava domes consist of six groups of endogenous domes, accompanied by light gray perlitic lava flows that originate from them. They were formed during the final eruptive phase of the Nisyros volcano, characterized by effusive activity and the absence of any explosive precursors. The names of these domes are Mt. Profitis Ilias (698 m), Boriatiko Vouno (437 m), Nymfios, Visternia, Dhiavatis, Trapezina, and Karaviotis (539 m). Additionally, there is a smaller dome (Lofos, 214 m) located in the southeastern edge, which has been heavily affected by recent hydrothermal explosions and fumarolic activity.

All the domes can be divided into four older central groups, namely Dhiavatis—Profitis Ilias, Nymfios, Visternia, Trapezina, and Lofos, and two relatively younger domes, Boriatiko Vouno in the Northeast and Karaviotis in the Southwest, along with the silicic flow lobes of Kateros, Kilia, and Drakospilia. These domes have steep spines and scoria on their surfaces and are devoid of soil deposits and minor proximal scree deposits.

Fig. 3.2.26: View of the rhyodacites from the sea, as seen during the circumnavigation of the island.

Fig. 3.2.27: i)View of Pachia and Pergousa volcanic islets & ii) Mediterranean monk seal Monachus monachus

This site holds great significance for wildlife conservation due to its large population of Mediterranean monk seals (Monachus monachus). These seals, the only members of the Monachus genus, seek refuge along the island's coasts. The total seal population is estimated to be less than 600 individuals, dispersed across four isolated enclaves. The most important enclave is located in the Eastern Mediterranean (Aegean Sea) and is home to approximately 300 seals. On Nisyros island, the presence of these endangered marine mammals has been documented specifically on the western shores, in a coastal area known as Fokiokremara.

Geosite 17 | Kateros Rhyodacitic Lavas

During the eruption cycle that took place around 15.000 years ago, Nisyros underwent significant magmatic activity in the aftermath of the Caldera collapse. This activity led to the release of large amounts of rhyodacitic lavas, which contributed to the formation of the present-day caldera. These lavas, known for their high viscosity, created a series of internal domes. Over time, these domes gradually expanded and partially occupied the western part of the caldera and the southwestern coast of the island. Interestingly, there were no indications of explosive events during this process. One particularly notable dome, named Karaviotis, reaches a maximum elevation of 539 meters. It is generally younger than the domes within the caldera and its lava flows extend towards the southwest, eventually reaching the sea. Karaviotis offers exceptional views of Nisyros' most recent magmatic formations.

Fig. 3.2.8: View of Kateros rhyodacites from the sea, as seen during the circumnavigation of the island.

Fig. 3.2.29: Kateros Rhyodacitic Lavas which resulted from significant magmatic activity.

Geosite 18 | Basaltic Andesitic Lavas Covered by Scoria

During the eruptive phase known as the Composite Stratovolcano eruptive cycle, the island experienced the eruption of lavas and pyroclastic deposits from the growing cone. These eruptions primarily originated from lateral and scoria cones. Today, there are still remnants of these satellite cones that can be observed, which played a significant role in the development of the stratovolcano and contributed to the formation of locally deposited geological features. The southern coast of Nisyros showcases basaltic-andesitic lava flows covered by remnants of a basaltic andesite cinder/scoria cone. The outcrop is particularly remarkable, consisting of a 20m thick pyroclastic unit composed of black lapilli, as well as red and black scoria fallout deposits.

In the early 1900s, there was a location known as Avlaki where the Thermal Baths were situated. These baths were strategically built near the volcanic lava flow that flowed into the ocean, which facilitated the development of a harbor. The baths took advantage of the natural outflow of highly saline thermal waters that occurred exclusively at sea level during low tide. These waters had the highest surface temperature compared to other thermal springs on the island, with temperatures reaching up to 60 °C. Unfortunately, today only remnants of the original bath complex can be found.

Fig. 3.2.30: Impressive basaltic andesitic lava flows covered by remnants of a basaltic andesite scoria cone.

Geosite 19 | Nikia Rhyolites

During the eruption cycle known as the Caldera Forming, Nisyros experienced two significant and intense plinian-type eruptions. In between these eruptions, the first caldera was formed after the initial eruption. Subsequently followed at least three major rhyolitic lava flows with a thickness exceeding 150 meters and a total volume greater than 1 cubic kilometer. This type of lava is characterized by its high silica content and high viscosity, causing it to flow slowly like a thick, sticky fluid. The magmas responsible for this lava also contain large amounts of gas, resulting in explosive eruptions accompanied by pyroclastic flows and the deposition of tuff, similar to the eruptive events that formed the caldera. The glass-dominated and partially perlitic lava flows descend from the region located between the Monastery Panaghia Kyra and the village of Nikia on the eastern walls of the current caldera. They enter the sea between Pachia Ammos and Avlaki. Presently, these lavas can be observed off the southeastern coast of the island.

Fig. 3.2.31: Glass-laden, perlitic flows shape Nisyros' southeastern coast at Cape Avlaki.

Fig. 3.2.32: Remnants of explosive eruptions showcase Nisyros' fierce past on the southeastern beaches.

Geosite 20 | Pumice

Cape Katsouni, situated on the northern coast of the island, showcases impressive geological formations resulting from two of Nisyros' most renowned volcanic cycles. The lower formations comprise of a lava flow composed of basaltic andesite from the eruptive cycle of the Composite Stratovolcano, which is then covered by layers of ancient soil. However, these basal formations are overlaid by two significant deposits of pumice known as the "lower" and "upper" pumice.

During the Caldera Eruptive Cycle, two extensive sequences of rhyolitic pumice, formed through plinian eruptive cycles, were deposited and separated by materials resulting from explosive volcanic activity. This includes the effusion of voluminous rhyolitic lava flows and the collapse of a large caldera, which shaped the present-day dimensions.
The Lower Pumice was created as a result of the initial eruption that formed the first of the two major Calderas. This eruption occurred when a reservoir of rhyolitic magma, likely located in the upper crust, erupted. The Lower Pumice consists of deposits from the early stages of the eruption, as well as surges and pyroclastic flows. Following the emptying of the magma reservoir, the first caldera collapse occurred due to a significant decrease in volume within the chamber. It is believed that the two vents of this eruption occurred in areas between the current southern and northeastern rims of the caldera.

Fig. 3.2.33: Some of the thickest pumice deposits of (60 m), with outstanding geological value, are found at the NE part of the island.

Upper Pumice was the result of Nisyros' second Caldera-Forming eruption, once again of the Plinian type. This explosive event produced a thick layer of rhyolitic pumice, reaching up to 60m in thickness. The sequence of fall-surge-flow-surge can be observed not only at Cape Katsouni but throughout the entire island. The deposit contains formations that provide scientists with valuable insights into the evolution of the eruption. These formations include extensive bedding, non-turbulent pyroclastic flows, lithics (remnants of older volcanic or non-volcanic rocks from deeper layers, brought to the surface by the force of the eruption), and wavy surges. The eruption is believed to have originated from an eruptive center in the north-western part of the caldera and was followed by a subsequent collapse, forming the iconic caldera of Nisyros as it appears today.

In the northeastern part of the island, there are hot springs that have been used since Roman times. The most significant hot spring, called "Panagia Thermiani," is located near Cape Katsouni and has a chapel with the same name. It dates back to Roman times, and an ancient inscription discovered nearby indicates the presence of an earlier Greek "Hippocratic" bath in the area. Although only stagnant water remains today, there is still a considerable potential for thermal waters.

Fig. 3.2.34: The vault of the Roman thermal bath of the spring Panagia Thermiani east of Pali.

Geosite 21 – Basaltic Andesitic Lava Neck

At the Kato Lakki area, there is an exposed neck made of basaltic andesitic lava. These volcanic formations are cylindrical bodies of lava, as well as agglomerates and breccias, that fill the former pathways through which lava used to flow to the surface. Over time, due to varying rates of erosion between the surrounding igneous rocks and the solidified lava, the latter becomes resistant and eventually forms a standing tower-like structure.

Fig. 3.2.35: i) Basaltic andesitic lava neck & ii) Evangelistria Monastery.

The geosite can be reached from the starting point of the G2 hiking trail, which starts from the unique Evangelistria monastery and concludes at Emborios. This monastery holds great historical significance and serves as a significant meeting place for the people of Nisyros. It was established in the 18th century and is a subsidiary of Panagia Spiliani, dedicated to the Annunciation of the Virgin Mary. The remaining silver-plated icon depicting the Annunciation bears the engraved date of 'February 20th, 1753'.

Geosite 22 | Strongyli Crater

Strongyli islet, a volcanic cone situated to the north of Nisyros, rises from a depth of approximately 675m to an altitude of 128m. This cone stands out as the most distinct volcanic structure in the area, characterized by its steep slopes, reaching up to 60 degrees. At its summit, there is a small crater measuring 200m in diameter and 30m in depth, with remnants of ancient terraces that were once used for cultivation. Made up of gray andesites and some pyroclastics, this cone-shaped volcanic edifice showcases an ideal geometric form.

Explorations conducted using the THETIS submersible and the ROV Hercules have revealed fascinating features in the submarine region surrounding the islet. Along the northwest flank, there exists an underwater crater spanning several meters in diameter, accompanied by fractures extending in various directions from northeast to southwest and east to west. Additionally, new underwater craters trending from east-northeast to west-southwest have been discovered, although no signs of hydrothermal activity were observed.

Fig. 3.2.36: The volcanic islet of Strongyli, with a 200 m diameter crater on its top.

Geosite 23 | Pachia Islet & Geosite 24: Pergousa Islet

Pachia is a volcanic islet to the west of Nisyros, featuring basal-dacitic lavas, covered by pumice from the Kos Plateau Tuff unit. This unit originated from a massive eruption 161.000 years ago in the Eastern Mediterranean and is mostly visible on the nearby island of Kos. The highest part of Pachia islet has a thin layer of ash, possibly from an eruption of the Nisyros Composite Stratovolcano. The absence of pumice from Nisyros and Yali shows that the islet was completely underwater during the time of the eruptions of these islands, and that it very recently uplifted to expose the KPT pumice.

Fig. 3.2.37: The volcanic Pachia islet.

Fig. 3.2.38: The volcanic Pergousa (right) and Pachia (left) islets.

Pergousa is a volcanic islet that consists of weathered thick lava flows and domes of andesitic to dacitic composition. These formations are covered by pumice deposits of KPT from nearby Kos (they were deposited in a submarine environment, as indicated by bivalves and biogenic remains). Its volcanic edifice with altitudes between 65 and 83m resembles in parts the pre-existence of a stratovolcano. Several monolithic blocks and pyroclastic deposits are interpreted as witnesses of a nearby collapse structure. Furthermore, the absence of pumices from Nisyros and Yali shows that the islet was completely underwater during the time of the young Plinian-type eruptions of these islands, and that it very recently uplifted to expose the KPT deposits. At the northwest coast of Pergousa, a gray, 1 m thick tuffite, rich in sponge needles, occurs.

4. Science Communication Tools & Visibility

Nisyros Geopark has taken significant strides in enhancing its visibility and accessibility to the public, aiming to enrich visitors' experiences and deepen their understanding of the island's geological heritage. To achieve this goal, informative leaflets detailing key aspects of the Geopark have been strategically distributed across all museums and visitor centers on Nisyros Island (Fig. 4.1). Particularly noteworthy is the inclusion of these informative materials at the hydrothermal craters' field information point, ensuring that visitors to this iconic geological site are well-informed about its connection to the Geopark and its underlying geology. By providing readily accessible information, Nisyros Geopark aims to foster greater appreciation and awareness of the island's unique geological features among both local residents and tourists, encouraging sustainable tourism practices and preservation efforts.

Fig. 4.1: Interpretative material (leaflets, maps) and souvenirs provided in the geopark’s information center.

In addition to enhancing its presence through physical materials, Nisyros Geopark has embraced the digital realm as a means to further elevate its visibility and engage with a wider audience. Through active participation on various social media platforms, including the Facebook page "Nisyros Geopark - Γεωπάρκο Νισύρου" and the Instagram account @nisyrosgeopark, the Geopark shares regular updates, captivating imagery and insightful content. Furthermore, the Geopark ensures an informative online presence through its regularly updated webpage, nisyrosgeopark.gr. This webpage serves as a comprehensive hub for news, updates, and valuable resources about the Geopark, including detailed information on the various geosites and georoutes available for exploration throughout the island.

Furthermore, two user-friendly mobile applications have been developed specifically for Nisyros Geopark. The first of these apps (Fig. 4.2), named the "Nisyros Volcano app," serves as a valuable tool for enriching the services provided by the aspiring UNESCO Global Geopark of Nisyros. Available for download on both Google Play and the App Store since June 30th, 2022, this innovative application focuses primarily on the active hydrothermal field of Lakki, which forms the core of the Geopark's geological significance. The application offers users an immersive exploration of the unique volcanic landscape of Lakki through a modern design and user-friendly interface. The app highlights the Caldera-Lakki route, featuring three Points of Interest along the volcanic routes of the hydrothermal field through its rich content, including high-quality photos, 360° panoramas, videos, and maps.

The second mobile app (Fig. 4.3), “Nisyros Geopark App” serves as a digital guide, providing users the opportunity to explore all 24 distinctive geosites through engaging material. The application highlights sites of geological, cultural, and ecological significance across the island of Nisyros and the surrounding islets encompassed within the Geopark’s territory. Users can explore the stunning volcanic landscape using the app's comprehensive content, which features high-quality photos, panoramas, videos, and the digital map of the Geopark. Consequently, it functions as a valuable digital pocket guide accompanied by the Nisyros Volcano app.

Fig. 4.2: Nisyros Volcano App.

Fig. 4.3: Nisyros Geopark App.

Moreover, Nisyros Geopark has implemented interpretative geosite signs, designed and installed at each geosite across the island. These signs serve as educational tools, offering visitors insightful explanations about the geological formations, historical significance, and ecological importance of each location. By integrating interpretative signage within the natural landscape, the Geopark ensures that visitors can immerse themselves in a self-guided educational experience, deepening their understanding of Nisyros's geological heritage. These signs not only enhance the overall visitor experience but also promote conservation efforts by fostering a sense of appreciation and stewardship for the island's unique geodiversity.

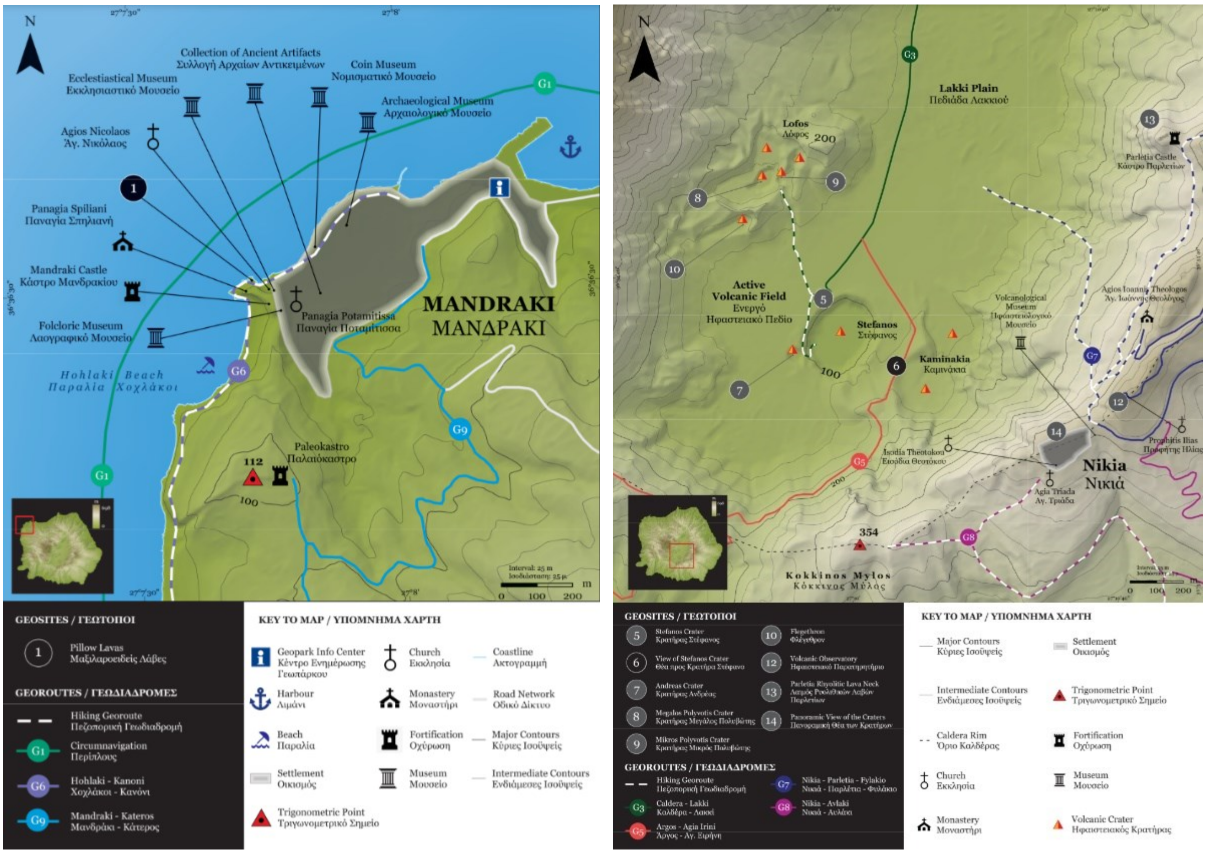


Fig. 4.4: Maps of Geosites 1 & 6.

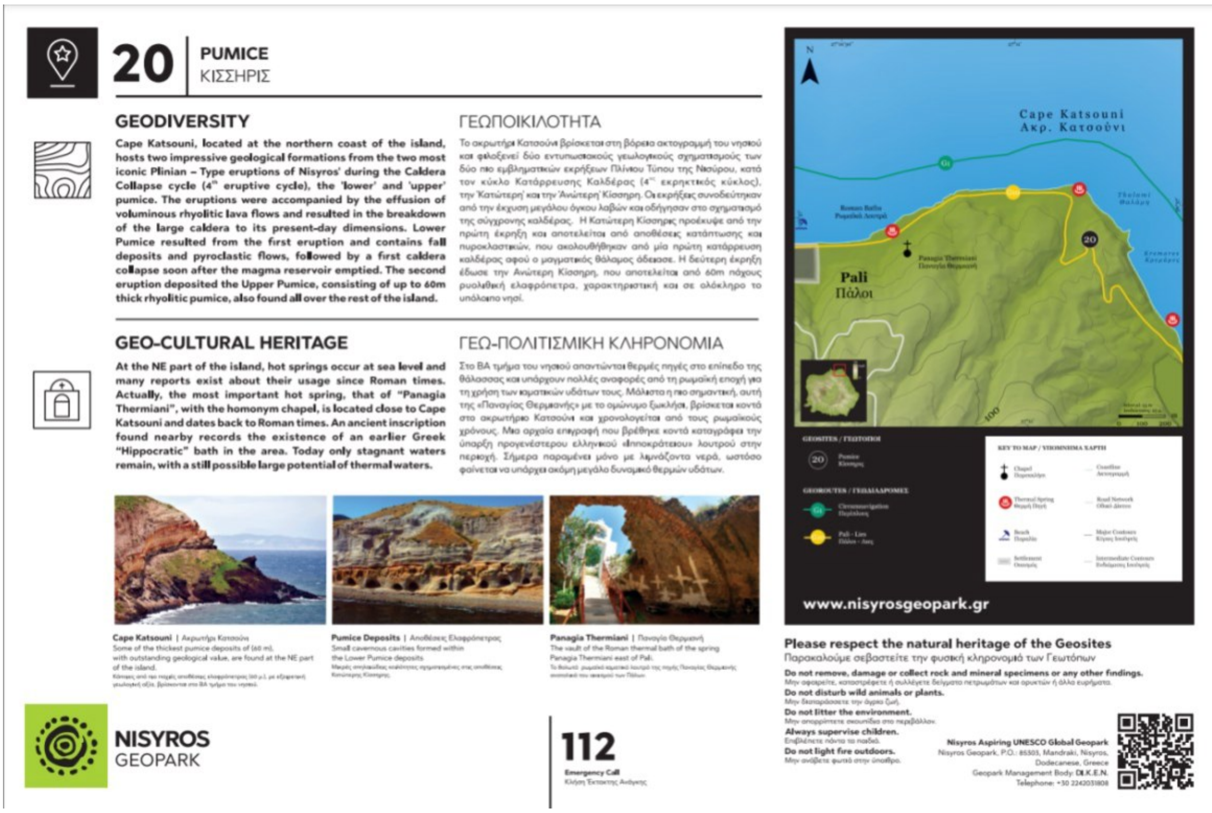


Fig. 4.5: Geosite 20 informative sign.

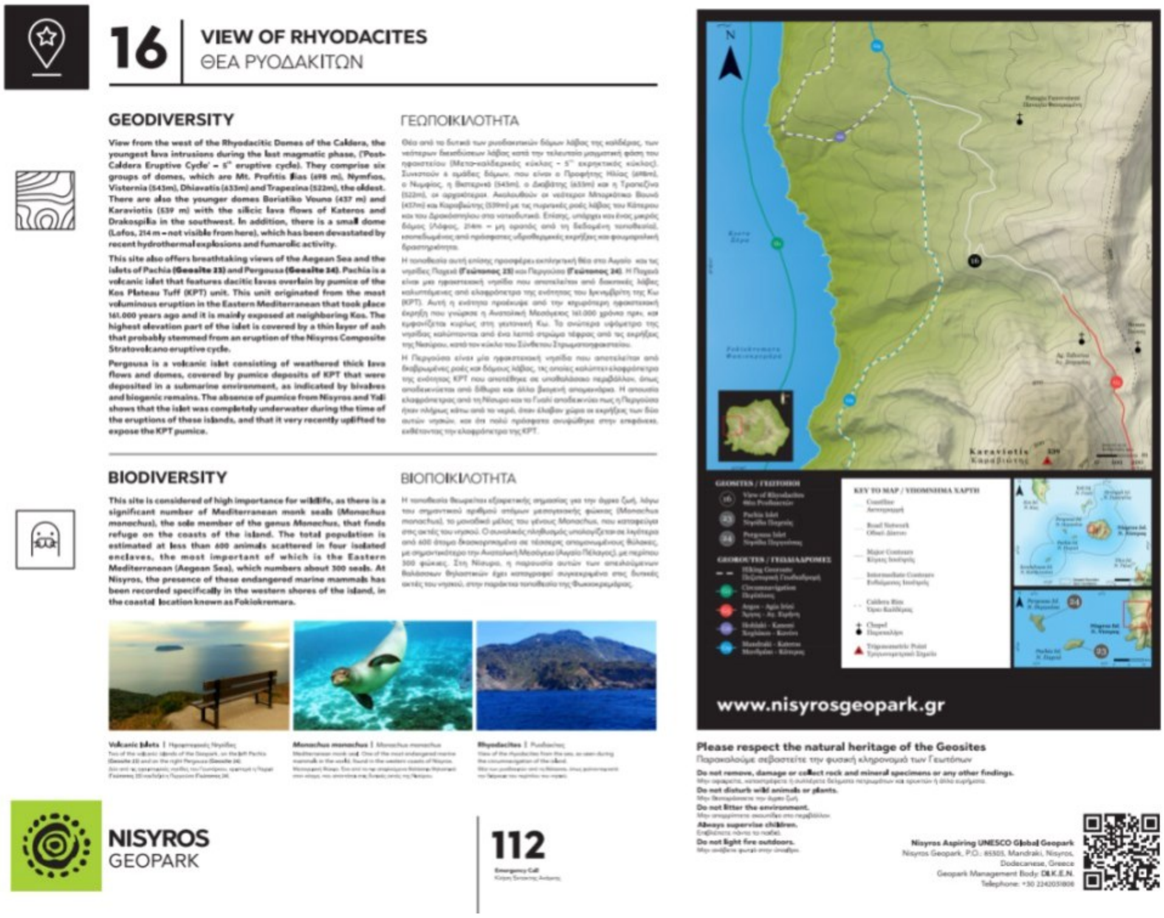


Fig. 4.6: Geosite 16 informative sign.

Fig. 4.7: Installed geosite signs in Lakki Hydrothermal field.

5. Conclusions

Nisyros aUGGp, located in the southeastern Aegean Sea, is a proposed UNESCO Global Geopark that showcases exceptional geological, natural, and cultural features. The geopark includes the main island of Nisyros and the smaller islets of Pachia, Pergousa, Strongyli, and Kondeliousa, as well as the surrounding marine area. It is situated on the South Aegean Volcanic Arc, one of the world's most active volcanic regions, and has been shaped by volcanic activity over the past 161,000 years. Visitors and scientists can explore an active volcano, diverse volcanic formations, and the island's five eruptive cycles, including one of the largest hydrothermal craters on the planet.

The coastline of Nisyros is dotted with thermal springs, which are part of the island's long tradition of thermal baths and spas. Efforts are underway to revive public baths. The geopark offers a network of trails and 24 geosites, facilitating exploration for both tourists and locals. The offshore area is of significant scientific interest, featuring underwater volcanic structures and the Avyssos caldera, site of the largest volcanic event in the Eastern Mediterranean 161,000 years ago. Nisyros Geopark is also a biodiversity hotspot, with two Natura 2000 protected areas covering its entire surface. These areas safeguard 450 plant species, 85 bird species, seven reptile species, and notable species like the endemic Campanula nisiria, Pinna nobilis, and the Monachus monachus seal. The designation as a UNESCO Global Geopark would support conservation efforts and promote environmental education.

The island's cultural heritage is rich, with continuous habitation for millennia. Nisyros is linked to Greek mythology and features impressive historical sites, such as the well-preserved Palaiokastro fortress, Mandraki castle, and numerous Byzantine churches. This heritage will gain global visibility through the geopark designation. Tourism infrastructure and educational initiatives are well-developed, including publications, signs, maps, a website, mobile apps and social media. The island is accessible by boat from Kos, which is reachable by ferry from Piraeus or by plane. The road and trail networks facilitate easy exploration of the island, and marine activities offer additional ways to experience the region.

Concerning the potential threats, the island's volcanic nature exposes it to the ongoing risk of volcanic activity, impacting geological features and landscapes. Uncontrolled tourism poses a threat through over-visitation, leading to soil erosion, habitat degradation, and physical damage to geological formations. Climate change, with rising temperatures and sea levels, may affect the stability and preservation of geological features. The introduction of invasive species can disturb local ecosystems, impacting both biological and geological diversity. Natural disasters such as earthquakes, landslides, or tsunamis pose significant threats to the island's geological stability. Poor land management practices, including improper agriculture and deforestation, contribute to soil erosion and habitat loss. Pollution from various sources, such as waste disposal, can negatively impact geological formations and ecosystems. Insufficient conservation measures, monitoring, and public awareness may lead to the deterioration of the island's valuable geoheritage over time.

Nisyros Island can protect its unique geoheritage through sustainable conservation practices by establishing and enforcing comprehensive regulations. Key measures include the implementation of strict guidelines for geological site protection, zoning, visitor management, and building codes to control infrastructure development and minimize environmental impact. Promoting responsible tourism is essential for mitigating threats to the island's natural landscapes. This involves the development and promotion of sustainable tourism practices, such as eco-friendly accommodations and guided tours. Additionally, limiting the number of visitors to sensitive geological sites is imperative to prevent over-visitation and potential damage.

In addressing the island's volcanic nature, a robust monitoring system for volcanic activity should be implemented. This system would provide early warnings and establish evacuation plans to ensure safety. Regular geological assessments are necessary to understand and manage the impact of volcanic activity on the island's landscapes. Adapting to the impacts of climate change is paramount for the long-term sustainability of Nisyros Island. Strategies should be developed and implemented to address rising temperatures, changing precipitation patterns, and sea-level rise. Integrating climate change considerations into land-use planning and conservation strategies is essential.

To manage the threat of invasive species, preventive measures and strict biosecurity protocols must be established. Additionally, invasive species control programs should be developed and implemented to minimize their impact on local ecosystems. Preparedness for natural disasters, including earthquakes, landslides, and tsunamis, is crucial. Emergency response plans should focus on protecting geological sites and ensuring the safety of both locals and visitors. Regular drills and training for local communities and authorities can enhance preparedness.

Developing educational initiatives for both locals and visitors, and engaging local communities in conservation efforts, cultivates a sense of responsibility for preserving the island's geological treasures.
Ongoing research and monitoring are fundamental to better understand the island's geological features and ecosystems. A robust monitoring system should be established to track changes in geological formations, biodiversity, and the effectiveness of conservation measures. Through collaborative efforts involving local communities, government authorities, environmental organizations, and researchers, Nisyros Island can ensure the long-term sustainability and conservation of its valuable geoheritage.

By implementing these measures, Nisyros Island can effectively safeguard its geoheritage while promoting sustainable development and resilience against natural threats. Nisyros aUGGp's inclusion in the Global Geoparks Network would enhance its recognition and support its mission to link geological heritage with natural and cultural heritage, demonstrating the integral role of geodiversity in ecosystems and human interaction with the landscape.

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