THE FAULT: CONTRIBUTION IN ARCHITECTURAL DESIGN

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ABSTRACT

The present day landscape is intended to be not only the point of view we watch nature, but also the result of climate and morphotectonic processes through time. Actually it is considered one of the important environmental and cultural issues of society and the central criteria in the urban design. Sustainable architecture, which uses landscape characteristics as well as nature protection, requires both a creative and a scientific approach as composed contribution. Strategies to develop the localities that constitute the coastal areas in the settlements Sisi and Milatou Beach in Eastern Crete, have been the focus of local society for the last years. A major focus of present paper is the localisation of elements that forms the character and structures the dynamic of individual spaces in this area, following detailed data evaluation, aiming at the attribution of protection, prominence and integration rules of natural landscape in the life and prospects of structured space.

The two coastal settlements were developed according to the existing geological map on marls and marly limestones of Pliocene age and partly on limestones of Tripolis Zone of Cretaceous-Upper Eocene age, that shaped tectonic horst in the area and determined the morphotectonic relief. The detailed geological mapping following the detailed topographic mapping with simultaneous collection of tectonic data and description of depositional lithofacies, allowed the possibility to include the morphotectonical data in the new planning and in the architectural design for the reformation of coastal foreheads in the two settlements. The obvious rotational fault fragments predominate in the asymmetrical troughs. The action of those faults has additionally controlled the spatial distribution of the local sedimentary deposits, namely mass flows, stratified breccias and breccio-conglomerates, and built the majority of coastal foreheads, which are similar to the stratigraphic succession of "Prina Complex". This new insight into rotational fault fragments suggests a novel approach to the development of an architectural solution, which elevates the geological background and engages the dynamics of space in new states of balance. The long term geological processes become part of the architectural thought and demonstrate capacity to interact with contemporary design theories.

Keywords: faults, geological mapping, coastal environments, architectural design, Eastern Crete.

1. INTRODUCTION

One of the outstanding scientific questions in the natural sciences is the linkage between landscape form and the wide range of processes that shape it. Landscape evolution is the result of a variety of geomorphological processes and their controls in time. Except of an internal system driven essentially by tectonic fluxes, the relative roles of eustacy and climate on weathering and erosion are recognized as the primary long-term controls governing landscape evolution and landform forming. Landforms were formed primarily by differential erosion of rocks, acting on structures produced by endogenic processes, under several climatic processes. In geologic time landforms are mainly formed due to rock and/or sediment accumulation, and by erosion of the existent soils or rocks. Most of the terrestrial surface, however, is composed of rocks and soils with different resistance to erosion and with different volume and spatial distribution. Each part of the land surface is the end product of an evolution governed by: (a) parent geological material, that is the lithology in the existing stratigraphic column, which represent the material to accumulate or to erode; (b) tectonic structure, which controls the 3-D distribution of the different rocks having different resistance to erosion (c) climatic evolution, which controls the type of erosive processes (arid or fluvial) (García-Quintana et al, 2004) and d) the position of the landform (mountainous or coastal), which also controls the type of erosive processes (gravitational, fluvial or marine).

In arid coastal areas landscape has been dramatically transformed within short periods of time due to the increase of mass tourism and the intensification of agriculture, resulting in a large-scale destruction of the coastal scrubs, the natural, endemic-rich vegetation. Additionally, the existing policies still promote high economic growth, associated with both a massive degradation of the landscape and a substantial strain on other natural resources. Consequently, there is a great need for studies combining economic development and the protection of the natural environment (Otto et al., 2007). A broad socialization of landscape took place in the last decade favored by the economic and cultural development of society. In developed societies, the change from primary/secondary-based economies to tertiary-based ones led from the territory as a resource to considerating it as a patrimony. This enhanced the development of the landscape as an asset. Detailed landscape design, creation of new spaces and use of characteristic, alive landscape material as well as nature protection, landscape ecology, landscape geomorphology and regional landscape planning require both a creative and a scientific approach (Gazvoda, 2002). Although landscapes are both materially and perceptually constructed (Terkenli, 2001), the result is a great expansion of the landscape concept, and a widening of the use of the landscape term in technical and academic fields, far from the original artistic and literary fields (García-Quintana et al., 2004). While applied urban planning of 20th century presents a relative failure to organize the chaos of the new era, the term ‘landscape’ is now shifting more and more its definition to mean a comprehensive “*humanistic”* tool for both understanding and designing wider urban areas, contaminated by the urban sprawl and the dispersed city fabric. Contemporary debate on Regional Planning includes issues like “nature conservation”, “steady state development”, “charts”, “land use”, etc. That one of Landscape Planning includes issues like “landscape economy”, “attractiveness”, “environmental impact assessment”. In Landcape Design, in all scales of intervention, issues like “landscape ecology”, “process”, “diagrams”, “art”, “form” and “planting plants” are the instrumentality and define the methodology of the design.

In Europe interest in landscape analysis is calling for government action to evaluate, protect and enhance the quality of landscape at the local and regional levels (Klijn et el, 1999). In this framework strategies to develop the localities that constitute the coastal foreheads in the settlements Sisi and Milatou Beach in Eastern Crete have been the focus of local society for the last years. One of the aims of this paper was to assess the sedimentary features related to tectonic structure. A major focus of present research in this area is the localisation of elements that forms the character and structures the dynamic of individual spaces, following detailed geological mapping, aiming at the attribution of the results for use in conceptual architectural design. The landscape of the entire area can be characterized as extremely dynamic due to the combination of strong tectonic features (horst, grabens structures, faults) which control the 3-D distribution of a distinctive sedimentary succession and determine the type of erosive processes, endemic-rich vegetation as well as a long and specific history of intensive modern economic activities (mass tourism).

In this context, geology becomes an important collaborator of Urban and Architectural Design (Lolarevic, 2003). If geology is the science comprising the study solidified matter and time, then architecture is composed by geological materials. It is the combination of the historical process and its own created models, composing a combined human installation on the earth. Connecting architecture with geology means to force architecture in facing much longer processes than usually concerned, processes that formed and continue to form sediments, interactions, fragmentations and several radical recompositions on earth's outer layers. As an independent sector of human activity, architecture tries to recompose a new world in a very short time. Its outcome is the result of compressed time and the given landscape. In the examined case, the ideal context is offered in order to extract instrumentality for the interaction between architecture and a much longer-period examining science, that of geology. Nowadays, while architecture uses movement and functionality in order to produce diagrams, the fluid and folding forms of the space could represent the geological morphogenesis. 'Violent' acts like pressure, tension and accumulation form the landscape that in a first gaze seems totally casual. In this process architecture tends to agree with its bearer, the Earth, from where architecture extracts construction materials in order to compose an architectural artifact.

2. GEOLOGICAL SETTING

Interplay between the African and European plates gave rise to the present-day structural and geomorphological configuration of Mediterranean and especially of Crete. The island of Crete is located north of the Hellenic trench. The geological framework consists largely of nappes of contrasting lithologies and metamorphism that were stacked southwards during an Oligocene to early Miocene N-S compression. Most of the whole nappe stack of continental Greece is recognised in Crete. It has however a reduced thickness and more important shortening. The nappes are stacked from top to bottom, i.e. from the most internal to external units in the following order: Asterousia nappe, Miamou nappe, Arvi nappe, Pindos-Ethia nappe, Tripolis nappe, Phyllite nappe and Trypali nappe. The Plattenkalk Group represents the lowermost known tectonic unit beneath the nappe pile of Crete and its formation has been involved in the tectonometamorphic process during the Oligocene-Miocene (Manutsoglu et al., 2003). During the Neogene above the Alpine substratum new sedimentary basins developed. The sedimentary history and palaeogeography of the Cretan Neogene is one of frequently changing land-sea distribution because of the complex interaction between fault blocks delimiting the different sedimentary basins (Drooger and Meulenkamp, 1973; Meulenkamp, 1979). In response to the dynamic crustal behaviour, most of the Neogene sediments are of detrital origin: breccias and conglomerates dominate in the continental to shallow marine basal units, whereas marls, including turbidites in the deeper basins, characterize the marine deposits. In eastern Crete limestones were mainly formed during the Late Tortonian-Messinian timespan (Fortuin and Peters, 1984).

An abrupt change of sedimentation conditions by the end of the Pliocene in Crete indicates the reversal of the vertical movements and the uplift of the island. By the late Upper Miocene to early Pliocene the conditions of deposition change from open sea (Meulenkamp et al, 1977) to coastal or terrestrial. The island rises gradually throughout the duration of the Quaternary, as evidenced by marine terraces and deposits of coastal Pleistocene terraces formed at the corresponding stages of uplift. After the end of the last englacial period, the island is sinking again. The submerged

Pleistocene marine terrace, marine notches, beachrocks at its SW and E coasts as well as the immersed parts of tyrrhenian terraces and deposits indicate that this sinking affected the whole island and caused a subsidence of the shores to a total depth of 10m (Mourtzas, 1990). During an intense paroxysmal tectonic incident 1,530±40yr BP (Pirazzoli et al., 1981/1982) the island was dismembered into two independent tectonic blocks along the active grabens of Spili and Amari. The western tectonic block, was then uplifted by about 10m and inclined northeastwards (Pirazzoli et al, 1981/1982; Pirazzoli et al., 1996). The AD365 earthquake due to the activation of a reverse fault or a thrust close to the area of maximum uplift, is related with this major tectonic dislocation in western Crete (Stiros and Drakos, 2006; Stiros, 2010). On the contrary, the eastern block, continued to sink as a single tectonic block throughout the duration of Upper Holocene (Mourtzas, 1990).

The Neotectonic structure of the entire area of Malia Gulf comprises a number of successive horsts and grabens, which delimit with normal extensional faults the Alpine formations from the sediments of Neogene and Quaternary basins. The study area comprises a variety of Neogene sediments, which were deposited mainly during the Early Miocene. Several outcrops of sedimentary rocks can be found along the coast, composed of small to large conglomerates, sands, silts and calcarenites. Sedimentary structures such as channels and bedding, marine slumps and mudflows are common. Remains of former soils occur. Normal extensional faults trending general N/S are dominant in the area. Depositional environments are interpreted from knowledge of the modern distribution of biota and sediment types. Modern river deposits consist of gravel and sand generally lacking biota. Modern barrier beach has abundant clastic carbonate in the sand fraction, derived from sediment brought down by rivers which drains a limestone hinterland. In contrast, a highly biogenic sand fraction characterizes the marine environment. Cemented micro–breccia and calcarenite are the result of beach-rock-type of cementation under conditions of strong evaporation or mixing of fresh and salt water.

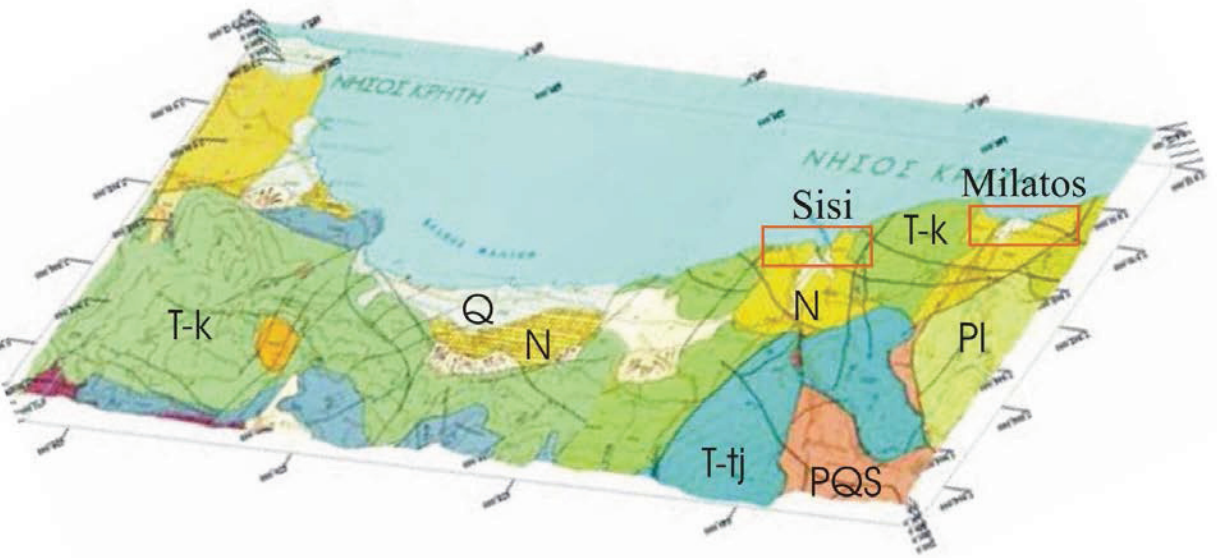


Figure 1 Geological 3D map of the entire area is presented (after Knithakis et al, 1987 and Vidakis et al, 1989). The two investigated areas are situated in eastern Malia Gulf, both sides of the horst structures of the Tripolis Zone of Cretaceous-Upper Eocene (T-k) age. Neogene(N) and Quaternary deposits(Q) can be observed along the present-day coastal zone. Pl=Plattelkalk Group, PQS=Plyllite Nappe, T-tj= Tripolis Zone of Triasic-Jurasic age.

2.1 Geological mapping

2.1.1. Sisi village region

Several studies have been implemented in the onshore coastal zone of Malia Gulf, analyzing the stratigraphy and tectonic of the Alpine and post-Alpine sedimentary sequences (Angelier, 1979, Meulenkamp et al, 1977; 1979; Mourtzas, 1990). Fieldwork comprised detailed geological mapping with emphasis on Neogene and Quaternary deposits and tectonic structures. All characteristic structures were photographed and reproduced in the maps. In detail, at the western part of the coastal zone near Sisi Village, thin bedded carbonate rocks appear, with intense dark blue and intercalations of breccia and conglomerate beds of the same lithology. They are intensely cracked rocks with apparently visible beds and lithological alteration. The combination of two conjugate normal faults with visible displacements of tens of centimeters bounds the Tyrrhenian deposits. The latter display a shallowing-upward succession from marine breccia to Aeolian calcarenites, showing distinct sedimentological features. According to Mourtzas (1990), the Tyrrhenian aged deposits begin at 0.30 m, which possibly means that this formation can be placed at a similar time range. This aspect can also be supported by the fact that the dip angle of these beds is much larger (39^o) at approximately the same dip direction NNW (294^o) of the substratum. A characteristic marine erosion structure is created: notch in thin depositional abrasions platform (Fig.3a).

Eastward for the next 50 m, there are successions of carbonates beds with micro-breccia and at positions well rounded conglomerates and boulder breccia mainly of Triassic parts of the Tripolis zone, dolomitic limestones with stromatolites. Their cracking has created small natural channels that connect to the sea. While at the lower horizons a characteristic material graduation dominates (massive carbonate that gradually pass from fine-grained to coarse grained conglomerates), at the eastern part (upper horizons) chaotic breccia into the main carbonate matrix, dominate. Eastward, bounded by a fault trending NE/ SW, a heterogeneous sediment association, built up of several lithologies which accumulated on top of, or were intermixed with, the underlying breccias occurs. The eastern part is also defined by a same direction (N-NE) fault. The succession of paleo-soil with well rounded pebbles of laminated sandy clay that evolves into yellow pelite, and a chaotic intermixture, leads to the conclusion that this formation consists of successions of terrigenous debris. Moving eastwards up to the area of the terrigenous debris, the succession of stratified breccia-conglomerate in alternations of carbonates beds dominate. The two faults trending N-NA that exist nearby the western buttress of the jetty, have created blocks, moving as independent “tectonic dipoles”. A dip angle of 20^o and a dip direction of 010^o (N-NE) characterizes the first of the faults, while the second one has a dip angle of 20^o and a dip direction of 020^o (N-NE), which slightly change at the other side of the jetty ($12\text{-}15^o$ dip angle, 020^o dip direction). The left block of the natural harbour consists of successions between carbonate beds and large conglomerate horizons. The existing faults of this natural slope form two discrete families. The first family created NNE-SSW trending faults. Those faults resulted thought extension, forming listric-fault planes in the rigid parts of the interbedded conglomerates. The second and youngest family is related to NNW-SSE striking normal faults and fractures the rocks of this area. This generation’s faults were possibly created at the same time with this areas submergence and the creation of the natural gulf.

The left slope of the gulf consists of an alternation of conglomerates and carbonates, the only difference being the thickness of the successions. At the right slope, rocks of similar lithology but of different depositional environment dominate. At the base of the slope, grey carbonate rocks with intense laminates that evolve into a chaotic, unsorted breccia-conglomerate which evolves into a much larger and thicker formation, appear. Overlying this chaotic formation, clay and sand bearing rest of paleo-soil, and this particular position is the intersection of a paleo-channel at a marine environment. The direction of this channel should be N-S. A second channel trending NNE-SSW, with terrigenous characteristics dominates. Conformably, overlying the terrigenous formations, at the upper corner of the village, characteristically colored clay sandstone appears which also slopes at a dip angle of 20^o towards NNE (034^o). This formation although it is not very thick, has a horizontal spread of over 100 meters, and evolves into a clearly marine formation. This marine formation consists of alternation of carbonate beds and fine- to coarse-grained, well-sorted, moderately cemented stratified breccia-conglomerate. This formation trending N-NE, spreads at several hundreds of meters until the eastern part of the coastal settlement and is covered by alternations of marls and platy limestones. At positions, it is crossed by NNE and NNW trending faults. Coarse grained sandstones are overlying. Its right side is clearly defined also by a fault. For the next 200 meters the alternation of conglomerates and thin-bedded carbonates continues. At positions, residues of the sandstones appear, that cover with angular unconformity this formation.

The carbonate alternation formations show characteristic laminoid structures that possibly show mechanical and chemical sedimentation of oversaturated marine solutions, after the forced emplacement of the breccia-conglomerate. The aggregation of shells indicates the aspect of a paleo-coastline. The cohesive cementation of the conglomerate indicates the existence of a mixed (phreatic and marine) zone. Far eastern, over a carbonate bed, the terrigenous characteristics flow reappears, looking like the one previously described at the left part of the village (carbonates – yellow siltstone- conglomerate). At this area, faults trending NNW dominate, whereas the dip direction of beds constantly remains towards N-NE (020^o). Generally, moving eastwards, the size of the conglomerate is increases.

<u>2.1.2. Milatos beach region</u>

At this area Pre-Neogene rocks appear, as well as rocks represented by cracked limestones, dolomitic limestones and dolomites of the tectonic cover of the Tripoli zone all along the coast, whereas there are characteristic parts with stromatolithic dolomites. The Alpine basement rocks are partly covered from Holocene incoherent fluvial conglomerates, and also, deeper, from Pliocene marls, upper Pleistocene sandstones and Holocene deposits. At the left part of the harbor a partially intense fault of N-S direction appears, whereas at the east side NNW-SSE direction fault, coming along with a tectonic breccia, appears. The dip directions of the beds remain NNW ($300\text{-}310^o$ degrees), even though at some positions they are folded. The Holocene fluvial pebbles are rather homogeneous, and have occurred as the result of clastic blocks of the Tripoli zone rocks, traveling through the bed of the river which runs the smooth flattening surface of the larger region.

3. Architectural Design

The modern movement in architecture of 20^{th} century has excluded history from the working process, denying the idea of a precedent to be continued. In this context architects try to propose methods, designing with no consideration to the traditional forms. Geology could become one of the new methodology criteria, as one of the main worktools in architectural thinking.

From another point of view, architecture could replace the nature's forces in a new geological metamorphosis attempt. The last one hundred years it has been demonstrated all over the world, in large scale interventions, like metropolitan areas, highways, harbours, ect. In the human scale, in limited areas and buildings, architecture contains the forces that could ensure the natural continuation of the given land's form. In addition to the worldviews and theoretical trends, good architecture is created using triggers from the site history and conformation, the functions and movements around its study area, the materials with which has to do the new configuration. The design attempt puts in perspective the characters of recognition and stability as part of the internal structure of its final products. Quite often, architectural design process derives inspiration, design tools and structural elements from architectural history itself and/or historic evolution of well-known examples. During this process, innovating forms, ideas and configurations are integrated in a continuity of a data series, stating evolution in an attempt of certification and certification of the idea itself.

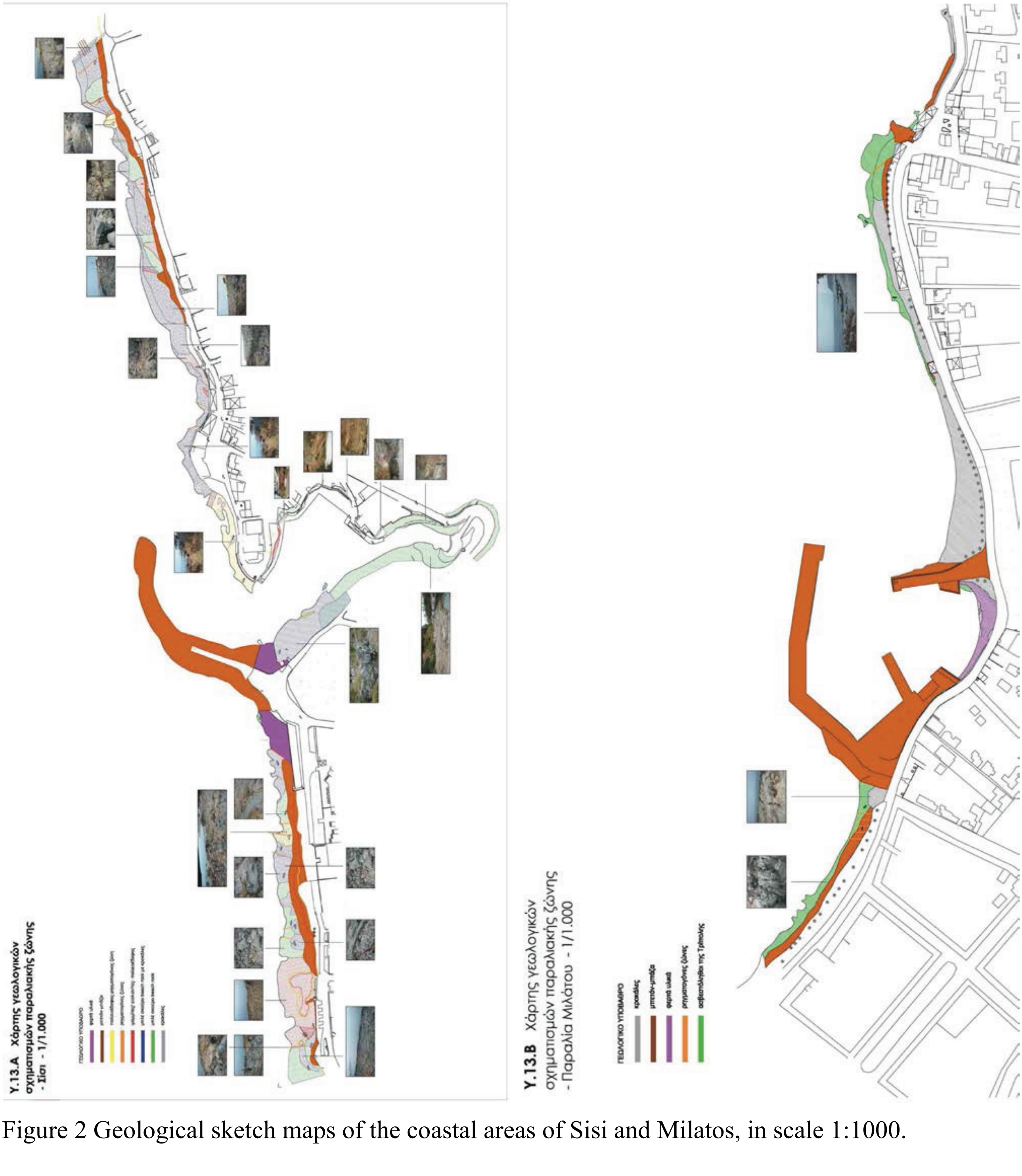
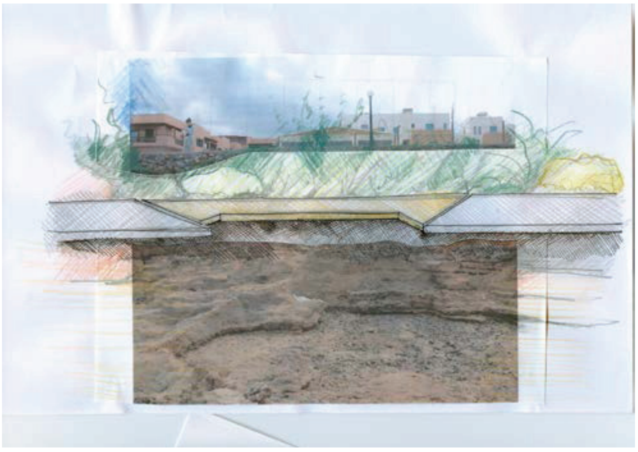


Figure 2 Geological sketch maps of the coastal areas of Sisi and Milatos, in scale 1:1000.

Sissi is a minimal fishermen's shelter, located on the natural port that is formed by geological fault. Its location is due to obvious security reasons. The new town, expanded around, is an extension of the old settlement and is in dialogue with the open sea through the intermediate layer of the sediments of sandstone, limestone and dark beachrocks, denoting the power of time passed. In the case of the design of Sissi waterfront, "legitimation" was searched through another kind of historic evolution, that of natural formations and geological sedimentation. The new city, without any historic background, is more related to the sea, the horizon, the natural forces, and the geological processes that formed the landscape as a momentary present crystallized form, where the city stands upon. In the inner side of the port, a newly constructed bridge that secures the continuity is formed by two mirrored cantilevers with a joint that follows the direction of the natural crack. The same disturbance forms also the sides of the path, so that the crack is denoted as form-generator through all the interference.

The topological and topographical analysis took under consideration the conclusions of the geological mapping, leading to the idea and the work-out of the architectural proposal. The last one, as a landscape interference, tries to strengthen and enchant the sense of openness to the horizon at the west and east waterfront, while at the port area accentuates the sense of introversion, depth and folding, proposing small bridges and pathways. The pedestrian paths on the seafront are formed by small slabs with an inclination to the sea side and to the wave direction at a dip angle of 20^o towards NNE ($034\ ^o$). They are both imitating and helping the dynamic of the sea forces, while they consist of a combination of extrapolated materials from the 'topos' itself and reinforced concrete, condemned to age together.


a)


b)

Figure 3 Draft conceptual architectural design of the study area: a) custom plates in raised notch in thin depositional abrasions platform, carved into pre-existing breccia - conglomerate beds, b) big blocks of local grey stone, in an irregular grid.

In Milatos beach, two kilometers eastern from Sissi, pebbles are substituted partially by big blocks of local grey stone, in an irregular grid, in order to block the waves as a natural barrier and to avoid the deformation of the pebble beach. This barrier serves as a bathers' sitting area, achieving the combination of "human-centre" design, "landscape-sensitive" design and "natural-phenomena-prevention" design.

4. CONCLUSIONS

Neotectonic blocks and their marginal faults are developed over the Alpine formations and formed in the grabens sub-basins for the marine Neogene sediments. The geological formations in the area are distinguished in Alpine basement (mostly the rocks of the Tripolis Zone) and in Neogene to Holocene sediments. Thus, the area shows the deformation pattern approximately over the last 12 million years. The topographic difference of the top of the Alpine formations at the horsts with their unconformity below the Neogene marine sediments at the grabens gives a minimum estimate of the total throw of the marginal faults of the basins. The fault activity in combination to subsidence of the basins, the sea transgression and the types of sedimentation during the Neogene, the followed uplift (during the (Pleistocene) determined the current picture of the coastline and the ports at both sites under study. The paleogeographic change described between subsidence of the basins during the Neogene and the following uplift (during the Pleistocene) marks an interruption of the general N–S extension that produced the post-Alpine basins not only in this area but even in western Peloponnesus (Papanikolaou et al., 2007).

The obvious rotational fault fragments that predominate in the asymmetrical troughs, the action of which has additionally controlled the spatial distribution of the local sedimentary deposits, which are mass flows, stratified breccias and breccio-conglomerates, similar to Prina Complex (Fortuin & Peters, 1984). This new insight into rotational fault fragments suggests a novel approach to the development of architectural solution, which elevates the geological background and links with the dynamics of space in new balances. The long terms geological processes become part of the architectural thought and demonstrate capacity to interact with contemporary design theories.

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