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FUNCTION OF AGRICULTURAL TERRACES IN MEDITERRANEAN CONDITIONS – SELECTED EXAMPLES FROM THE ISLAND OF IKARIA (THE SOUTHERN SPORADES, GREECE)*

Abstract: The aim of the research was to define the influence of agricultural terraces on slope erosion. There have been selected three plots located on the Greek island Ikaria. On the plots detailed geomorphological mapping was done, spatial relief models were created based on the measurements taken using GPS RTK, georadar profiles were made using RAMAC/GPR and the extent of destruction of terrace resistance walls was evaluated.
In comparison with similar forms on other Aegean islands, Ikarian terraces are narrow and high. Their stability depends on: lihtology, slope gradient, height and spatial arrangement of particular terrace steps and the current way of their usage. It was acknowledged that the most stable are the forms created on crystalline schists and gneisses, whereas the slopes, which erode the easiest, are the terraced ones consisting of carbonate rocks.
The obtained results indicate that on Ikaria similarly to numerous other regions the most significant factor facilitating erosion on the terraced slopes is the cessation of their agricultural usage.

Key words: Agricultural terraces, erosion, Ikaria, dry stone wall, georadar profiles

INTRODUCTION

Agricultural terraces supported with dry stone walls are one of the most basic anthropogenic elements of the Mediterranean landscape. They are

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especially common on the mountainous islands of the Aegean Sea – on some of them they take over 50% of the overall area, and many slopes have been almost entirely covered with terraces (Tsermegas, 2009).

The current recognition of these forms and the processes modelling them is definitely insufficient. Although they were numerously the subject of scientific research, they were usually investigated as the forms of archeological significance, e.g. attempting to reconstruct the ancient systems of soil cultivation (Brunet, 1990, Betancourt & Hope, 1992, Chaniotis, 1999) or analyzing the role of ancient agriculture in the transition of landscape (Acheson, 1997, French & Whitelaw, 1999, Butzer, 2005). It was as late as in the last decades of 20th century that focus turned to geomorphological and hydrological aspects of the contemporary functioning of the terrace systems. However, most authors dealt with the effects of the terrace abandontment (Harden, 1996, Garcia-Ruiz, 1997, Kosmas et al., 2000, Dunjó et al., 2003, Koulouri & Giourga, 2007). There are no studies concerned with the course of erosion on currently used traditional agricultural terraces. The aim of this study is to fill the aforementioned research gap.

AIM AND METHODS OF RESEARCH

The aim of the study was to determine the influence of agricultural terraces on slope erosion. It was fulfilled by the analysis of metrical features, internal structure and the stability of dry walls supporting the terraces. The research was run on the Greek Island of Ikaria, where threre plots were selected with the areas ranging from 1400 up to 2500 m^2 and height difference of 20-35 m. The geological basement of the forms researched consisted of: crystalline schists and gneisses in the eastern part of the island, crystalline dolomites in its central part, and in the west – granite gneisses (Fig. 1 and 2). On each of the plots there was a detailed geomorphological mapping done and measurements were taken using GPS RTK Altogether detailed plotting covered the area of 5591 m^2. Data from 4655 measure points was used to prepare three-dimensional models of each plot.

The examination of the structure of agricultural terraces required the usage of the least invasive methods possible. It was decided to use a Ground Penetrating Radar (RAMAC/GPR) with 250 MHz shielded antenna, which was towed on the ground surface (Daniels 2004). From 3 sites with different geological background a total 166 GPR transects was executed (with a total length 2019 m) (Fig. 3) Monitoring of terraces soil structure was done up to depth 6 m. The Topographical Models of sites show position of each GPR transect on the basis of GPS RTK data. In order to verify the thickness of particular layers on the selected terraces there were made outcrops. Four outcrops were dug on each of the bigger plots and three on the smallest one. Their depth reached from 30 cm up to 1.5 m depending on the depth where the solid rock was found.

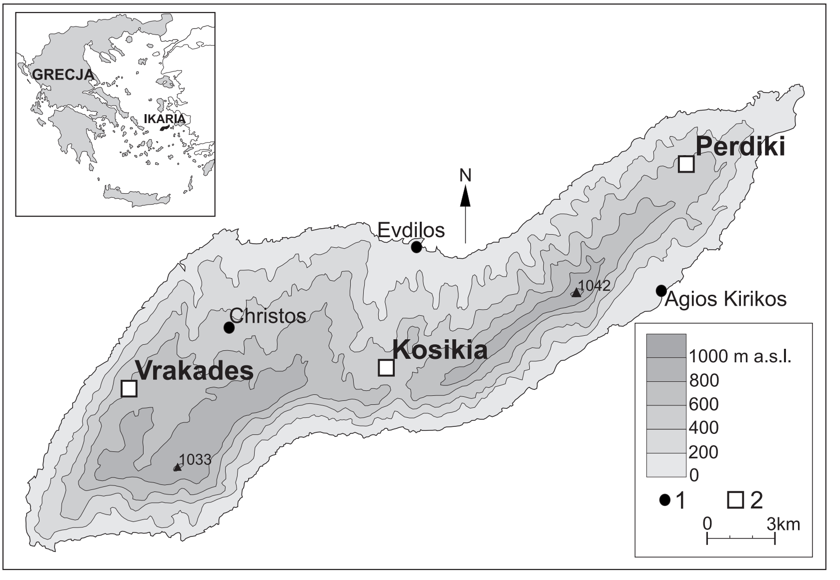

Fig. 1. Location of Ikaria and location of plots
1 – main places (administrative centres), 2 – research plots.

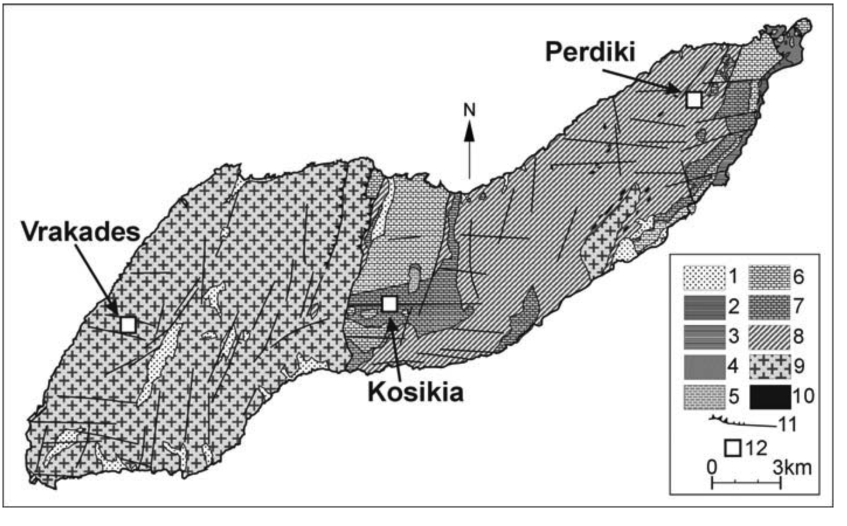

Fig. 2. Location of the plots and the geological structure of the island
1 – river, marine and slope deposits (Holocene), 2 – conglomerates and breccias (Pleistocene), 3 – conglomerates, sandstones and marls (Pliocene), 4 – ophiolitic molasse (Oligocene-Lower Miocene), 5 – crystalline limestones and dolomites (Upper Triassic), 6 – marbles and crystalline schists (Mesozoic undivided), 7 – marbles (Triassic), 8 – gneisses (Paleozoic), 9 – granites and granodiorites (Miocene), 10 – quartz and aplite pegmatites (Miocene), 11 – thrusts and faults, 12 – research plots.

The evaluation of the extent to which the terraces were damaged was done in order to determine the stability of walls supporting the terraces. We took into consideration: the way of construction of particular walls and their fragments, the extent to which the walls were damaged, the type of damage and the presence of visible repair traces. In order to determine the factors influencing terrace erosion also the conditions of their usage were considered. What turned out really valuable was the information obtained from the owners of the fields.

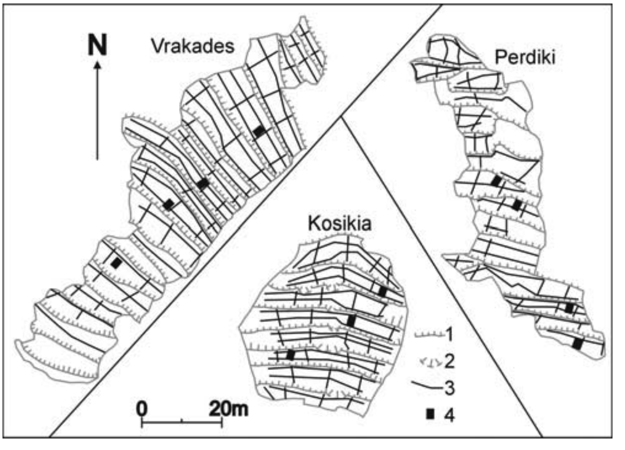

Fig. 3. The course of georadar profiles and the location of the outcrops

1 – the walls of agricultural terraces, 2 – damaged wall fragments, 3 – the lines of georadar profiles, 4 – outcrops made in order to verify the thickness of layers determined on the basis of georadar profiles.

THE AREA UNDER INVESTIGATION

Ikaria is one of the most mountainous Greek islands. It is located in the eastern part of the Aegean Sea. Its area is 255 km^2, and the highest peaks reach over 1000 m a.s.l. Apart from two oversea plains which cover jointly below 1 km^2, practically there are no flat areas appropriate for agriculture. Therefore, the slopes of the island have been terraced for ages in order to use them for agricultural purposes. Currently agricultural terraces take nearly 1/5 of Ikaria's area. Only their small part is used, while the others have been overgrown with vegetation or have been turned into pastures for the last few decades.

Crystalline rocks dominate in the geological structure of Ikaria (Fig. 2). The western part of the island consists of granite-gneisses (locally mylonites) and in the east there gneisses, crystalline schists, phyllites, marbles and crystalline dolomites appear. Unmetamorphised rocks occur only in the narrow zone along SE coast of Ikaria (*Geological Map*... 2005).

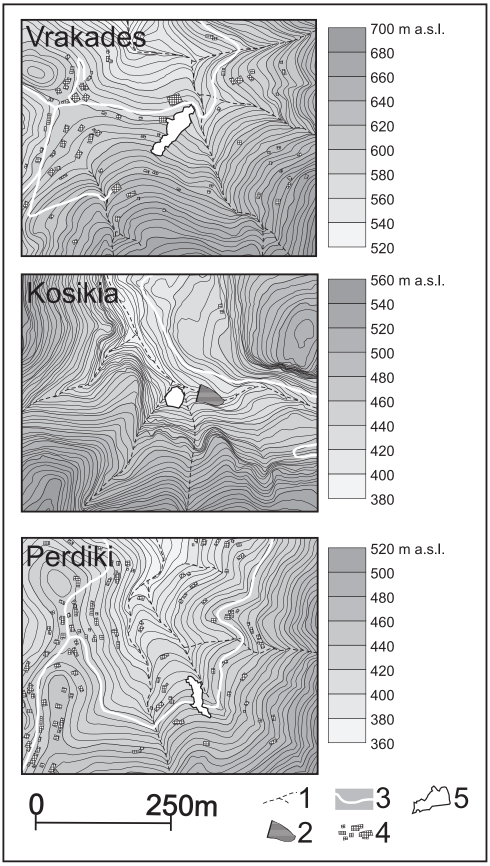

Fig. 4. Topography of the surrounding of the research plots

1 – the beds of temporary streams, 2 – artificial water reservoirs, 3 – hardened roads, 4 – buildings, 5 – the contours of the research plots.

Three regions lying within the limits of Vrakades, Kosikia and Perdiki were selected for the research (Fig. 4). The plot of Vrakades (Photo 1) with the area of 2548 m^2, located in the western part of the island was selected as representative of the terrains built of granite-gneisses. It encompasses 21 terraces with an average height of 1.7 m and the width of 4-6 m. They are situated on the SW valley slope in Vrakades. The height difference of the researched slope is 35 m and its inclination is from 15 to 20^o, on average 17^o. The fields located there currently are fallow land. However, in 2007 they were used for growing vegetables. On the terraces there grow a few trees, mostly chestnuts.

The plot Kosikia (Photo 1) represents the relatively rare in Ikaria terraces created on the base of carbonate rocks – strongly karstified crystalline dolomites. The area of the plot is 1401 m^2. It encompasses 8 terraces of the average height of 2.9 m and the width of 4-5 m, located about 500 m to the south from the houses of Kosikia village, on the S slope of the Voutsides stream valley in the vicinity of a small artificial reservoir. The average gradient of the terraced part of the slope reaches 23^o, the most in the scale

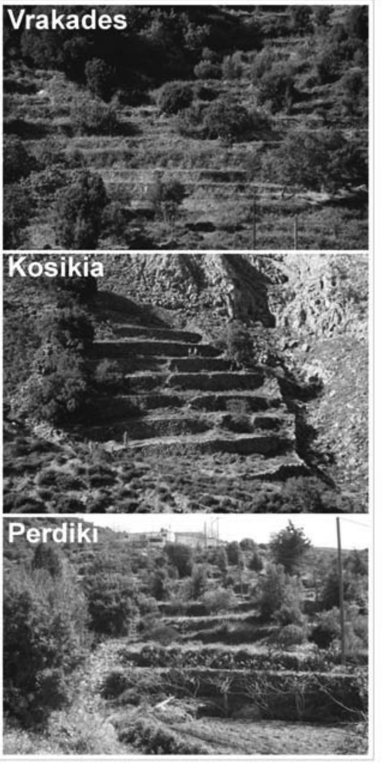

Photo 1. General views of particular research plots.

of the three examined plots and the difference in height between the highest and the lowest terrace is 20 m. The Kosikia plot has been used since 1980 as an orchard and probably for that purpose the terraces, which had existed there in the past, were reconstructed. All other forms of usage were out of question due to the lack of irrigation possibilities (no water souces on the slope beyond the plot). Figs were the most grown there. Only a few trees have survived until today, the terraces have been damaged siginificantly and the area is used as a pasture for a not very big flock of goats.

The plot of Perdiki (Photo 1) is situated in the eastern part of the village of the same name in the upper part of the Rouksouniou stream valley. Its lithology is crystalline schists and gneisses. The researched fragment encompasses the area of 1645 m^2 and is sloping towards north. Its average gradient is the lowest of all analyzed plots and it reaches 14^o. Also particular terraces are relatively low – the height of the walls supporting them is on average 1.5 m. The plot consists of 16 levels of fields with the width of 3-8 m. The difference in height between the highest one and the lowest one is 23 m. Grapevine is the dominant crop in this part of the village. Only small fragments of the terraces are currently used as vegetable gardens or for several years have been fallow land. There grow also several fruit trees. Terrace 11 is entirely taken by an asphalt road.

The exact age of Ikarian terraces is hard to determine, as these forms have repeatedly been destroyed and repaired, and also quite often built anew. The beginnings of their creation are to be connected with the Ikarians' settlement on the terrains distant from the island's coast. The traces of human in the Ikarian mountains date back to Neolite (Melas, 1955-1957). However, the number of the inhabitants at that time was probably too small to require the terracing of the slopes in order to satisfy their need for food. The location of the villages, where the research plots are situated, in the upper parts of valleys well protected and practically invisible from the seaside suggests that they were especially intensively used agriculturally in the XVI century, when the population of the island was hiding in the mountains from the attacks of the Turks and pirates (Melas, 1955-1957). The discussed terrace systems are therefore at least 450-500 years old, although particular steps and the walls separating them are definitely much younger.

RESULTS OF RESEARCH

To make the analysis of the stability of reasearched terrace systems we had to precisely determine their internal structure, especially investigating the thickness of weathered mantle, which presses the walls supporting the slopes of each terrace, when it contains water from precipitation and irrigation. Therefore, on the basis of georadar profiles the sections with the course corresponding with the slope gradient encompassed by the analysed slopes were compared (Fig. 5 and 6).

The results obtained on the basis of the georadar profile interpretation did not confirm the hypothesis set based on the information from the farmers and the introductory observation of the terrain, that the structures securing the terrace from erosion are situated directly on the solid rock. The results indicate, however, that some terraces correspond with the uneven surface of the solid bedrock (Fig. 6).

The thickness of weathered mantle on the researched plots reaches max. 5-6 m. The biggest one is on the plot built of carbonate rocks, where the soil contains the most large rock fragments.

On none of the plots there was registered an inrease in waste thickness towards the lower part of the slope.Profiles rather indicate that an opposite situation takes place there, which suggests that before the construction of terraces the surfaces were relatively stable. It was probably one of the reasons why the places were used for agriculture.

During the mapping special attention was paid to the way of constructing the walls which support the terraces. In all cases they are built from local material and they show the declination from the perpendicular of a few degrees in the direction of the supported terrace. The size and shape of the

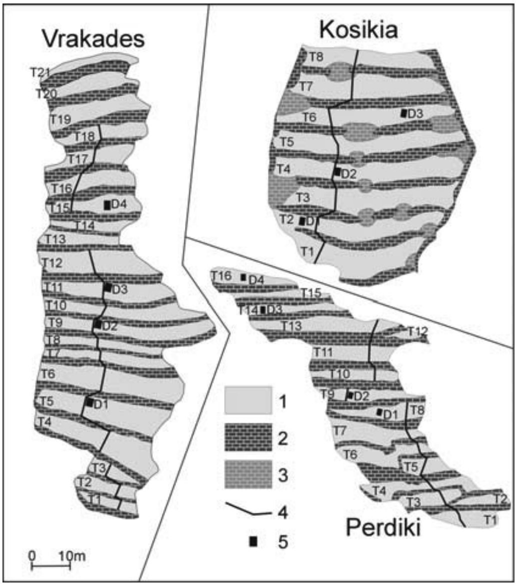

Fig. 5. Spatial models of the researched plots

1 – areas of the agricultural terraces, 2 – resistance walls of the terraces, 3 – eroded parts of terraces, 4 – the course of georadar profiles shown on Fig. 6, 5 – outcrops, T1-T21 – terrace numbers, D1-D4 – outcrop numbers.

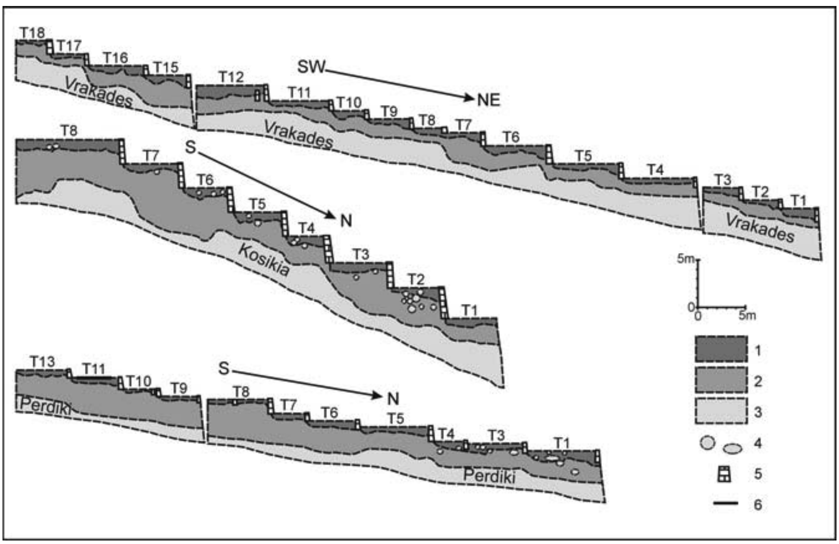

Fig. 6. The interpretation of selected georadar profiles. Their course was marked on Fig. 5

1 – current soil, 2 – weathered mantle, 3 – solid rock, 4 – larger rock fragments in the weathered mantle, 5 – walls supporting the terraces, 6 – asphalt surface of the road (on the 11th terrace of Perdiki plot).

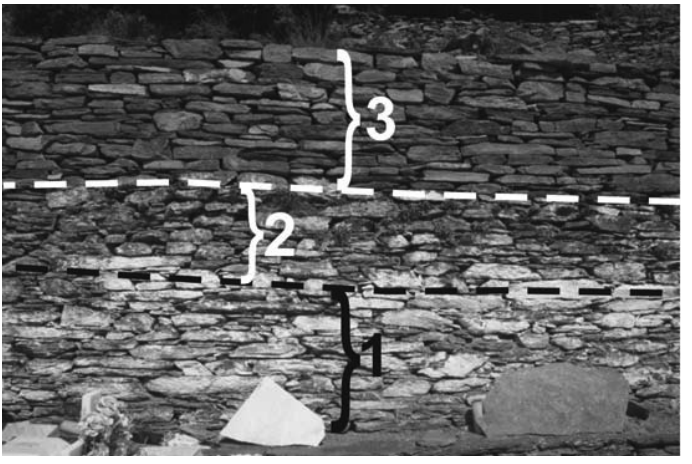

Fig. 7. Stages in the construction of a wall supporting a terrace

fragments used are diverse (from a few up to 50 cm) and they depend solely on local possibilities to obtain building material.The thickness of the walls (20-40 cm) was determined by the size of the stones used, which were put with their longer axis along the wall, the shorter one – crosswise and the shortest one vertically. The thickness of the wall was proportional to the width of the biggest stones. The wall structure proves that terraces were built in stages (Fig. 7), up to gaining a terrace of complex width, which would be a function of the slope gradient and the wall height ensuring its stability, determined probably on the basis of the local builders' experience.The beginning of each terrace system was the lowest terrace. It confirms the conclusions of other authors researching similar forms in the other parts of the world (e.g. Spencer, Hale, 1961, Treacy, 1987, Treacy, Denevan, 1994). On Ikaria this technique is also currently used.

The type, shape and the way of laying the rock fragments for the walls supporting the terraces are a very important factor of the terrace stability (Tuffnel et al., 1996). The research has shown that walls built from crystalline schists and gneisses are the closest to the ideal ones (Fig. 8).

Most of terraces was destined for crops requiring irrigation. However, only some walls, mostly those on the areas built from crystalline sschists and gneisses have soil drainage systems.

The researched terrace systems were used by at least a few generations of farmers. It was possible thanks to stable maintanance consisting mainly in the repair of the walls and completing the material. The research done has shown that:

- All walls in at least 50% of their length have signs of numerous damage and repair (Fig. 9);
- The main destructive factor is the concentration of precipitation water, which we can induce from the linear set-up of the damages. Cuts are

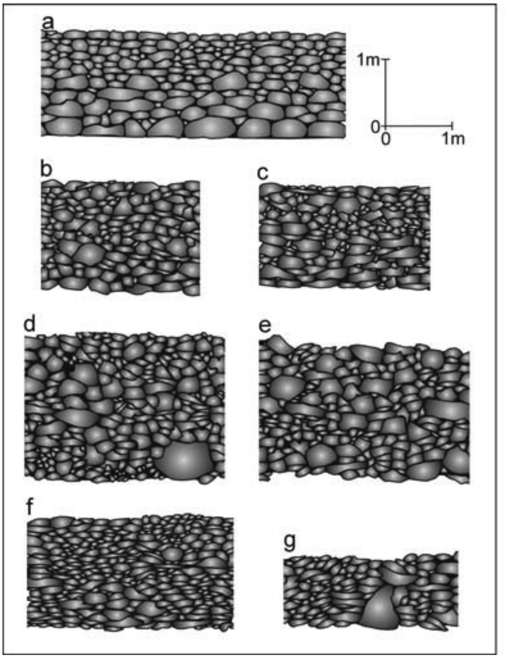

Fig. 8. Examples of setting the rock fragments making the walls of agricultural terraces

a – well-built stone wall (after Tuffnel et al. 1996), b and c – wall fragments from the Vrakades plot, d and e – wall fragments from the Kosikia plot, f and g – wall fragments from the Perdiki plot.

created in previously weakened places (construction defects, irrigation, grazing, fallen trees);

- The latest traces of erosion were observed in the central parts of plots within their most convex slope fragments distant from the natural drainage lines;
- In at least a few places in each of the plots it was found that once damaged and repaired part of a wall becomes damaged again more easily than the neighbouring parts of the same construction. In such cases there is an extra caution used quite often – namely the socond wall is built in front of the damaged fragment.

The most damaged are terraces on the slope, the bedrock of which consists of dolomites. 25 % of the walls were damaged completely or in part. The cause of this situation is probably not only lithology, although it seems to be constituting an important factor both directly and indirectly deciding about the stability of the terraces slope. The Kosikia plot is distinguished by a few features which might have influenced the bad condition of its terraces. A slope with gradient exceeding 20^{o} was used there for growing crops and there were created terraces with very high walls. For 30 years there were no repairs done there and at the same time goats have been grazing

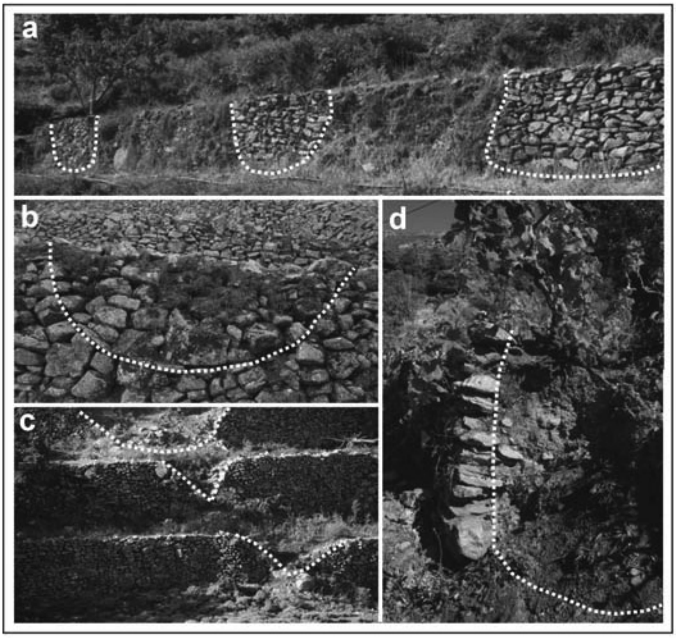

Fig. 9. Exemplary traces of damage done by water and the gravity processes and the results of the repairs done by farmers, observed on plots: a – Vrakades, b and c – Kosikia, d – Prediki

there. Some wilt trees, mostly fig trees with a horizontal root system collapsed creating large pits which facilitated the concentration of the surface flow. The bad shape of terraces on Kosikia plot can also result from the fact that local dolomites are not especially useful as a material to build dry walls, since there are only few flat and oblong rock fragments in their waste.

The least damaged terraces are found on the crystalline schists and gneisses (plot of Perdiki). Only 5% of the wall length is damaged there. It is connected with the fact that the slope gradient does not exceed 15°, and the terraces have relatively low walls, quite often with the vegetation growing on them, which is maintained there thanks to regular irrigation. An additional factor which makes the concentration of flow more difficult is the presence of soil and walls drainage and a good condition of the irrigation system. It might also be of significance that the researched terrace system does not have a classical step structure and the borders of some terraces run slantwise to the slope decline (e.g. T2/T3, T5/T6, T12/T13).

On the granite-gneisses, which is within the plot of Vrakades, the traces of damage have been observed on nearly 15% of the wall length. In that part of the island there is especially abundant precipitation – e.g. 18 and 19 October 2010 there fell 303 mm of rain in 29 hours, and the maximum concentration of precipitation reached 22.4 mm/10 minutes (data from the station in Raches located 2.5 km from Vrakades, offered by the National

Observatory of Athens). This extreme phenomenon did not cause any visible damage within the researched plot, probably due to the big permeability of the soil.

It seems that the cessation of the agricultural usage has an enormous significance for the erosion of the terraced slopes. As the earlier studies on Ikaria have proven (Tsermegas, 2008), the cessation of cultivation touches in the first place the terraces built on carbonate rocks. They usually can be found on the steep slopes and the soil has worse air-water conditions than on other lithology, whereas the lack of stable springs makes it impossible to irrigate, making the all-year agricultural usage more difficult.

CONCLUSIONS

The research done has proven that agricultural terraces on Ikaria which still are or were used not long ago have diverse metrical features, which depend on the gradient of the terraced slope and the thickness of the cover of soil and weathered mantle. The most often these forms are found on the slopes with the inclination of between several up to about 20°. It is worth underlining that the areas with smaller inclination can be found on the island only in the narrow bottoms of a few big valleys and on the high, rocky planation surfaces which cannot be used for cultivation. The dry stone walls of terraces reach the height between 0.5-0.8 m up to 2.5-3 m, and the width of the terraces usually does not exceed 4-6 m. In comparison with similar forms on other Aegean islands Ikarian terraces are relatively narrow and high (Grove & Rackham, 2003, Tsermegas, 2009).

The susceptibility of the researched slopes to erosion is influenced by numerous factors. Among them we can name: lithology, slope gradient, height of particular terrace steps, their spatial set-up and current way of usage. The most stable among the analyzed terraces are forms created on crystalline schists and gneisses, whereas the terraced slopes which are the easiest to be damaged by erosion are the ones consisting of carbonate rocks.

The research done has confirmed the regularity observed also on other islands of the Aegean Sea that the best lithology for the construction of agricultural terraces in Mediterranean conditions are rocks with oriented texture, especially crystaline schists and gneisses (Tsermegas, 2009). Such a material allows to create durable terraces, as it provides an easy selection of the wall material. At the same time soils on these rocks is a very fertile base, as it might be proven by a very profitable growth of grapevine in the village of Perdiki on a slope with northern exposure.

On Ikaria like in many other Mediterrenean regions the abandonment of terraced slopes is the most significant factor facilitating erosion. Over the last 50-70 years cultivation was stopped on many mountainous areas of the Mediterrenean zone (Baldock et al., 1996) and this tendency is not changing. On some islands of the Aegean Sea, including Ikaria, this process has been progressing more slowly due to the major force of the soil cultivation tradition. However, in the current socioeconomic situation chances of stable improvement of the condition of terraces seem little.

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