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THE ROLE OF EPIKARST IN THE MORPHOGENESIS OF THE KARSTIC FORMS IN GREECE AND SPECIALLY OF THE KARSTIC HOLLOW FORMS

POMEN EPIKRASA ZA RAZVOJ KRAŠKIH OBLIK, PREDVSEM DEPRESIJ, V GRČIJI

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Kyriaki Papadopoulou-Vrynioti: The role of epikarst in the morphogenesis of the karstic forms, especially hollow forms in Greece

The role of epikarst in the morphogenesis of the subcutaneous karren and the karstic hollow forms is different. Cavernous karren and subcutaneous kluftkarren, are covered with terra rossa and show the activity of water. They are developed in the epikarstic zone due to the diffused corrosion on the joints through a capillary aquifer, situated in the high vadose zone. The rounded tops and the cavities of those subcutaneous karren are formed due to the continuous and uniform corrosion, acting by soil moisture in the high part of the epikarstic zone. Karstic hollowforms are developed in carbonate layers only, and also on the contact of karstified and non-karstified but easily erodable rocks. In this case, a lot of material is produced for the formation of soils that fill these landforms. Uvalas and poljes usually develop in sites of old valleys or tectonic depressions through the process of widening of the joints in the subcutaneous zone and the lowering of the latter zone. Simultaneously there occurs the gradual impermeability of the zone and the reinforcement of the lateral corrosion. These forms are mostly formed above the piezometric level. The poljes - periodical lakes are created due to the development when they temporary reach epikarstic water table.
Key words: karst morphology, karren, hollowform, soil, erosion, diffused-lateral corrosion, epikarstic aquifer, piezometric table.

Izvleček UDK: 551.4.(495)

Kyriaki Papadopoulou-Vrynioti: Pomen epikrasa za razvoj kraških oblik, predvsem depresij, v Grčiji

Vloga epikrasa pri nastanku podtalnih škrapelj in kraških depresij, je različna. Prevotljene škraplje in podtalne škraplje tipa »kluftkarren« so prekrite s kraško prstjo in kažejo na delovanje vode. Nastale so v epikraški coni ob razpokah s pomočjo difuzne korozije v kapilarnem vodonosniku v zgornjem delu vadozne cone. Zaobljeni vrhnji deli in luknje v škrapljah so nastale zaradi enakomerne in stalne korozije s pomočjo talne vlage v zgornjem delu epikraške cone. Kraške depresije pa so razvite v karbonantih plasteh in tudi na stiku zakraselih in nezakraselih, a eroziji podvrženih kamnin. V tem primeru nastane veliko drobirja, iz katerega nastane prst, ki zapolni te reliefne oblike. Uvale in polja so navadno razvita na mestu nekdanjih suhih dolin ali tektonskih udorin s pomočjo razširjanja razpok v subkutani coni in zaradi njenega spuščanja. Sočasno ta cona postaja postopoma neprepustna in s tem se krepi robna korozija. Te oblike navadno nastajajo nad piezometrično gladino. Kraška polja – presihajoča jezera pa so nastala, kjer so depresije občasno dosegle gladino talne vode v epikrasu.
Ključne besede: kraška morfologija, škraplje, depresija, prst, erozija, difuzna robna korozija, epikraški vodonosnik, piezometrična gladina.

INTRODUCTION

The area of Greece is characterized by the great development of karstified rocks, which constitute nearly one third of its lithology (Fig.1). Limestones are the most common carbonate rocks. The age of these rocks is Triassic, Jurassic and Cretaceous. Usually they are microcrystalline and either thin- or thick- bedded. They appear mainly in the following geotectonic zones: Paxoi, Adriatic-Ionian, Gabrovo - Tripolis, Parnassos-Ghiona and Eastern Greece. They are often in normal contact or tectonic contact with non-karstified and easily eroded formations such as flysch, schists and chlorites; these formations produce large quantities of weathered rock material that firstly make karstified rocks impervious to water, and secondly act at a local level of karstification.

The aforementioned factors combined with the predominant geotectonic and climatic conditions, lead to the development of remarkable karsticdynamics. The karsticdynamics in Greece show area variety and quantity of surface and underground karstic forms. In this paper the role of epikarst in the morphogenesis of karstic landforms is studied. Subcutaneous karren and karstic hollow forms are shown under different circumstances in many regions of Greece.

SUBCUTANEOUS KARREN

The covered karren of the type subcutaneous rundkarren, cavernous karren (cavernous karstic holes) and subcutaneous kluftkarren are the most common microforms. The latter two of these forms are the dominant karstic formations of Greek limestones. They are floored with terrarossa and were formed generally from Pleistocene to Holocene. (Zwittkovits 1966, Papadopoulou 1990). Their basic characterics are cavities and rounded peaks. The genesis of these karstic types is based on the ability of the soil layer to hold moisture even when the weather remains warm and dry for a long period of time. Moreover, the diffused corrosion that occurs in the subcutaneous zone is continuous and rather uniform. Extended occurrence of these karstic types is present everywhere in Greece either at high altitudes e.g. the mountains Helicon, Dirfi, Menikio and/or at lower altitudes e.g. Lakonia (Sparti, Mani); the latter is the product of the strong relationship between soilcover and chemical dissolution.

1. Cavernous karren

The cavernous karren of the regions Helicon, Lichada and Mani appear as holes with a diameter of 5-15 cm and a depth up to 2 m (Fig.2). They are mainly developed in limestones, whilst their depth is small in dolomite limestones. They are formed under a thin layer of clay-rich soil, where the capillary fissures of the rock have a high density especially along intersections. At the centre of these intersections in the middle, where the dynamic of the diffused corrosion was higher, the chemical dissolution of the rock moved radially towards the periphery. The result of this process of fissure enlargement is initially the genesis of small holes that subsequently become wider and deeper. Where the rate of dissolution expands deep into the bedrock, the karstic holes change to tubular karstic drains. Simultaneously, the inrush of soil into these karstic forms leads to the imperviousness of the karstic network resulting in the high imperviousness of the subcutaneous zone. Empty cavernous karren are formed due to the secondary removal of the terrarossa.

2. Subcutaneous kluftkarren

The subcutaneous kluftkarren of the region (e.g. Kopais, Dirfy) appear on rocks that have a high density of mechanical fractures, such as fissures, joints and minor faults (Fig.3). Due to the dynamics of diffused corrosion that apply under the soil-cover on the fragmented rock, the discontinuities are

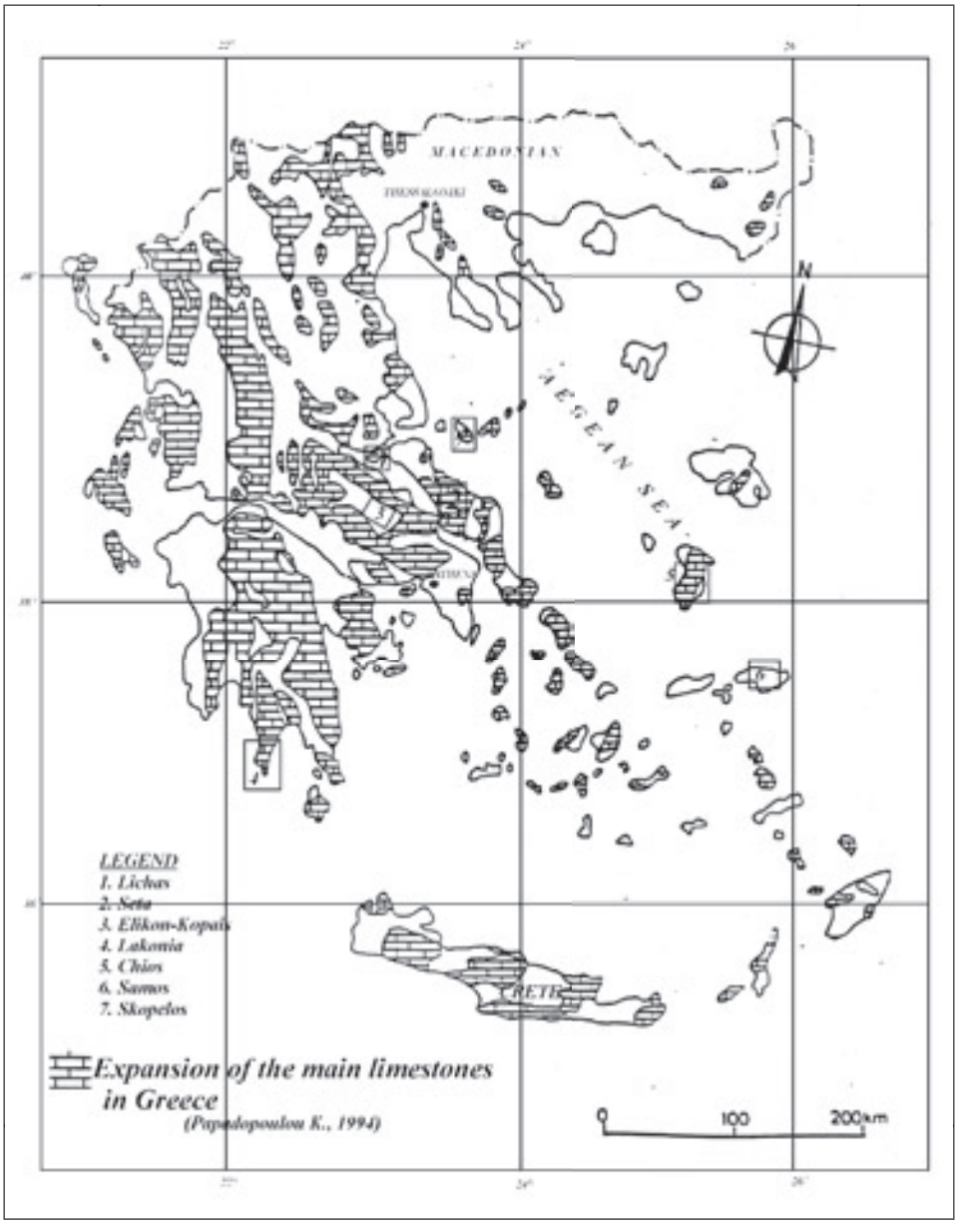

Fig. 1: The studied areas.

Fig. 2: Cavernous karren in Mani (Lakonia).

Fig. 3: Subcutaneous kluftkarren in Kopais region (at low altitude).

enlarged. The enlarged discontinuities are then filled with material of the soil cover. The chemical dissolution penetrates ever deeper where capillary movement of water through the soil still exists. We can therefore say that the subcutaneous zone extends very deep into the ground.

Along the subcutaneous zone, that lying the pedosphere, the diffused corrosion is applied in the same way in many directions. Thus, characteristic rounded limestone blocks, like humps are created (Fig.4). After the partial washout of the soil-layer at low altitude (200-300 m.), where the amount of precipitation does not exceed 600 mm/year, the limestone blocks appear from 10 cm to 1,5 m above the soilcover. This could also help us to estimate the volume of the eroded soil (Papadopoulou 1990). The widened discontinuities full of clayey (argilaceous) material are covered with vegetation. Therefore, the rocky landscape recalls sheep grazing in a meadow (Fig. 5). The small kamenitza and the rillenkarren originated from the effect of precipitation on uncovered rocks.

However, the landscape seems to be different at higher altitudes (over 800 m), where the amount of precipitation exceeds 900 mm/year and the frost conditions are more frequent. Here, the rounded pinnacles of the uncovered subcutaneous kluftkarren are destroyed due to the high rate of chemical dissolution in combination with the mechanical strain. This leads to the development of tower and conelike forms; such forms are seen at the altitude of 800 m, on the Mt Helicon.

III. KARSTIC HOLLOW FORMS

In this chapter, the processes that are responsible for the development of karstic hollowforms are analysed, with regard to the epikarst, in representative regions of Greece. We distinguish two main categories: A) Epikarst and morhogenesis in regions with exclusively karstified rocks and B) Epikarst and morphogenesis in regions with karstified and non-karstified rocks.

A. KARSTIC REGION OF THE LICHAS PENINSULA.

The Lichas peninsula lies in the NW edge of Euboea island in central Greece. Its surface area is only 80 km^2 and extends from sea level to an altitude of 740 m. The main lithology consists of dolomite limestones that belong to the periods of Middle Triassic and Jurassic. Pliocene sediments also exist. The paleosoil in the karstic forms belongs to the Pleistocene and is rich in terra rossa. There are also fluvial Holocene deposits. In the area, that belongs to the geotectonic zone of Eastern Greece, there are many fracture zones and faults with direction E-W and NE- SW. The same directions are followed by the karstic forms, represented by small poljes and uvalas with special morphogenetic interest, as they have developed in dolomite limestones, less soluble than the limestones (Papadopoulou 1998).

Site: St. Sotiras

Here the karstification appears at an altitude of 100-120 m (Fig.7). At an altitude of 90 m we see a small (16.000 m^2) triangular polje, that has not been formed through the junction of dolines. It has a bent slope and a flat floor, on which they are many Erdfälle (soil settled doline) exist (Fig. 8). The paleosoil filling the polje consists of residues of the limestone corrosion and also deposits moved by fluvial erosion. Red clay of the type B_V – C_{ca} - C appears on the slopes of the mountain. The relict soil is divided by Pleistocene debris from the slopes of the mountain together with al-

Fig. 4: Subcutaneous kluftkarrren in Mt. Helicon (at high altitude) and transformation into cone-like microforms.

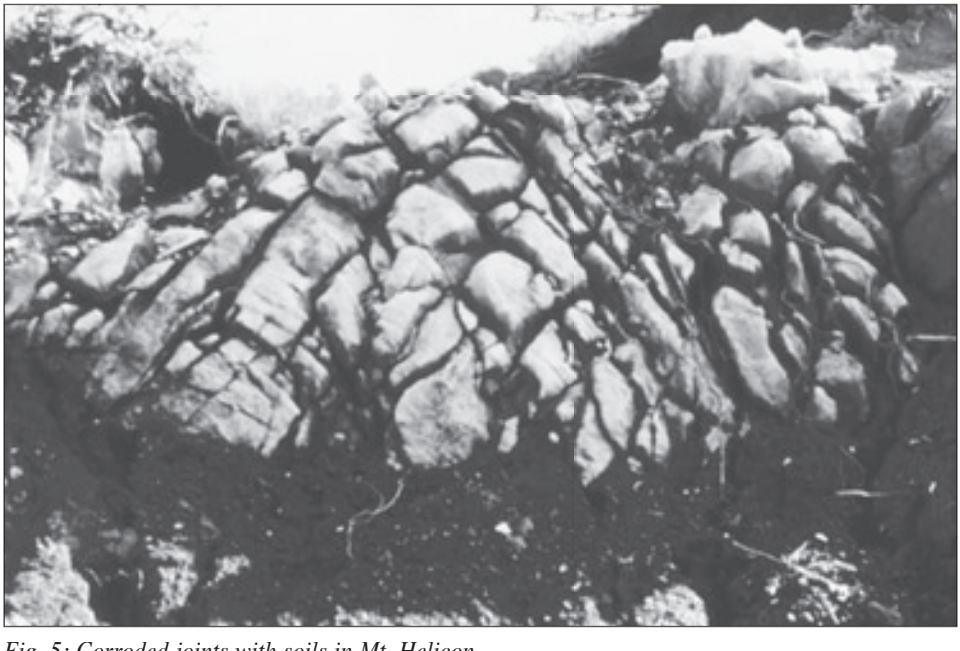

Fig. 5: Corroded joints with soils in Mt. Helicon.

lochthonous material of the type B_v.

Intensive diffused karstification acts on the underlying layer through the paleosoils, within which circulation of capillary water can exist. The corroded joints are impermeable in the places where paleosoil is deposited. Thus, karstic passage cannot continue to deepen at the same rate and start to widen. This impermeability takes place above the level of the piezometric surface of the underground karstic water-table.

The Erdfälle (soil settled dolines) on the floor of the polje resemble collapsed dolines of the bare limestones, but they have been developed solely in the soil cover of the small polje. They are also filled with water in the rainy seasons (Fig. 9). This water can supply the epikarstic water-table and the karstification can move deeper in the epikarstic zone.

Site: Friaki

On a higher karstic plane at 350 m altitude, an uvala has been developed at an altitude of 200 m in the deepest part of the valley. It is also filled with soil rich in terra rossa. The existence of five water wells at a steady distance of 15 m-20 m from each, in surface 500 m^2 is impressive. These were dug in the soilcover, for the needs of sheep farmers (Fig.7). They have water all the year with an unstable waterlevel, which does not exceed the depth of 16m. Their presence is the most important evidence for the existence of a water table in the soil cover. Therefore diffused corrosion takes place in the epikarstic zone of the strata, which at this site are very fractured. The imperviousness of the karstic joints and widening of the valley floor assisted by lateral corrosion have led to the genesis of the uvala.

Site: St. Nikolaos

On a higher karstic plane at an altitude of 500 m (Fig.7) another uvala has developed also in a valley, 320 m higher than the existed Neogene formation. Its soil material has the same origin and composition as the afore mentioned karstic hollowforms. A small periodic headspring, at the lowest part of this uvala, shows the existence of a capillary watertable in the soil. Like the previous karstic hollowforms, this uvala was also created above the old erosion basis. The erosion basis in this region is related to the Neogene sediments. The piezometric surface surface was very probably found at this level (320 m) during the Plio-pleistocene period. Consequently, the morphogenesis of this uvala, in Agios Nikolaos, was created by the processes that took place in the epikarstic zone just as with the karstic hollowforms at the afore mentioned sites.

Site: Island of Chios

The polje Pitious, lying in the northern part of the island of Chios, is formed in limestone. It is sunk to a Neogene valley and filled with Neogene sediments. Of the neogene valley transformation a polje may have occurred in early Serravall, following the processes of the corrosion of the enlarged joint of the subcutaneous zone, impermiability of the karstic drains and simultaneous widening the valley with lateral corrosion (Riedl 2000). These processes were favoured by the palaeoclimate, which was savannah - like, tropical with alternating moisture (Velitzelos & Zouros 1998). The polje Pitious, in contrast with the polje of Lichas karstic hollow form, must have been created at the level of the karstic water-table of the phreatic zone.

Fig. 6: Subcutaneous kluftkarren and firstkarren in Kopais region.

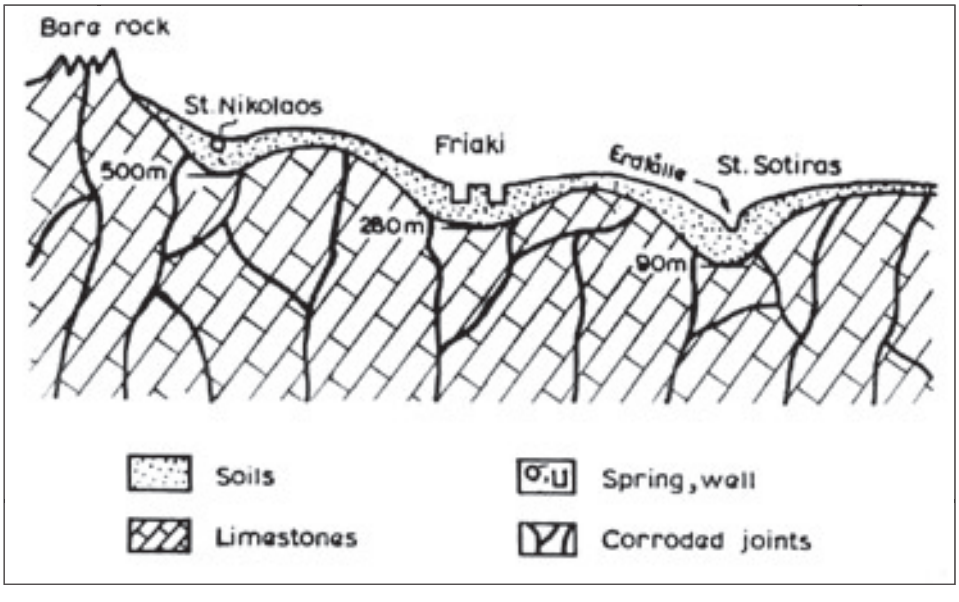

Fig. 7: Simplified section on the karstic hollowforms of the Lichas Peninsula.

B. KARSTIC REGIONS IN CENTRAL CONTINENTAL GREECE

Polje of Kopais

The polje of Kopais represents the biggest karstic hollow form of this type in Greece. It lies in Beoetia (central continental Greece) and is part of the Fokik-Beotic tectonic depression. This part was divided from the primary depression due to continuous sinkings and it was karstified (Papadopoulou 1990). The hydrographic basin of the polje lies at an altitude of 92-1525 m and it covers a surface of 600 km^2. This region belongs to the following geotectonic zones: Eastern Greece, Parnassos-Ghiona and Beotia. The directions of the primary faults are WNW-ESE, ENE-WSW and E-W. The lithology of the basin is: Late Jurassic and Late Cretaceous limestones (Fig. 10). It also consists of flysch and schist keratoliths. The thickness of the Plio-Quarternary sediments in the polje is approximately 900 m. The main source of the previously mentioned sediments are all the above easily-eroded rock-formations.

The paleo soil (polje-type), being also the product of erosion and corrosion, can be found in the eastern part at a depth of 100 m. This is an Early-Pleistocene, argillaceous, red-yellow marly, which covers a fossilized karst. Under this marginal plain soil-cover with the action of diffused corrosion the processes of enlargement and impermeability of the karstic joints took place in the epikarstic zone at the eastern part of the tectonic basin. As a result the lateral corrosion at the eastern margins of the polje was reinforced against the limestones. Thus, this part was karstified and formed an underground drainage system associated with sinkholes. Hence, it started to become a polje, expanding slowly to the west until it finally occupied the northern part and the SE part of the Kopais basin. The beginning of the karstification of the tectonic depression is not connected with the underground karstic watertable, but with the epikarstic water table. The starting point of these morphogenetic processes is considered to be the Early Pleistocene.

The natural drainage of the polje through the numerous sinkholes (Papadopoulou 1990) was unattainable. Thus, the periodic lake Kopais was formed at an altitude of 92-100 m with a surface of 250 km^2. The first successful artificial drainage of the lake was achieved in 1500 B.C. by the Minyes, the prehistoric habitants of this region (Papadopoulou 2000). The modern artificial drainage was completed in 1931.

The lake was initially created when the impermeability of the karstic drains, in the zone of the sinkholes, has reached a point at which the supplying of the underground karstic watertable was severe. Therefore the catoptric surface of the lake does not have any relation to the piezometric surface of the underground karstic aquifer.

Region of Mt. Helicon

The lithology of this region consists of limestones from the Tithonian, Cenomanian, Late Jurassic and Late Cretaceous periods. We also find Paleogene flysch, which consists of conglomerates, sandstones and calcitic argillaceous shales. Soil, formed by erosion of flysch and insoluble residues of limestones corrosion and bauxite rich in terra rossa, fill the karstic hollowforms. This region belongs to the geotectonic zone of Parnassos- Ghiona. It is characterized by the parallel synclines and anticlines with axis direction NW-SE, similar to the major faults.

The periodic polje - lake of Helicon (Fig.12) lies at an altitude of 800 m and inside a syncline, located between karstified (limestone) and non-karstified (flysch) rocks. Its soil-cover does not exceed 15 m. Erdfälle and Ponors are found at the lowest parts of the polje. The polje was created in

Fig. 8: Soil settled doline (Erdfälle) in Polje of Lichas (without water).

Fig. 9: Soil settled doline in Polje of Lichas (with water).

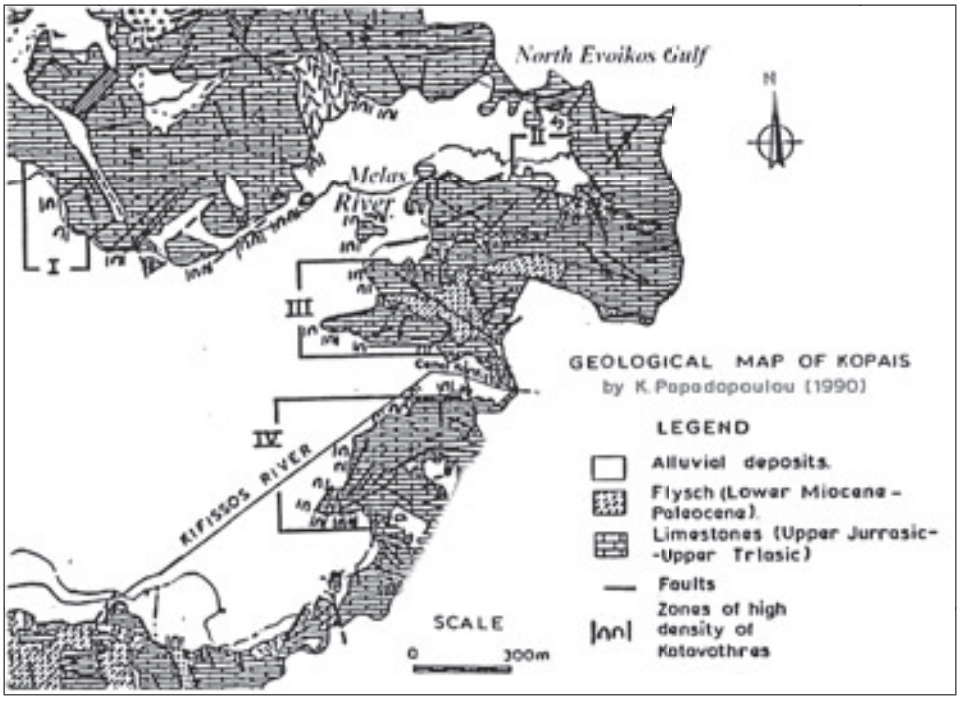

Fig. 10: Geological map of the eastern part of the Kopais area.

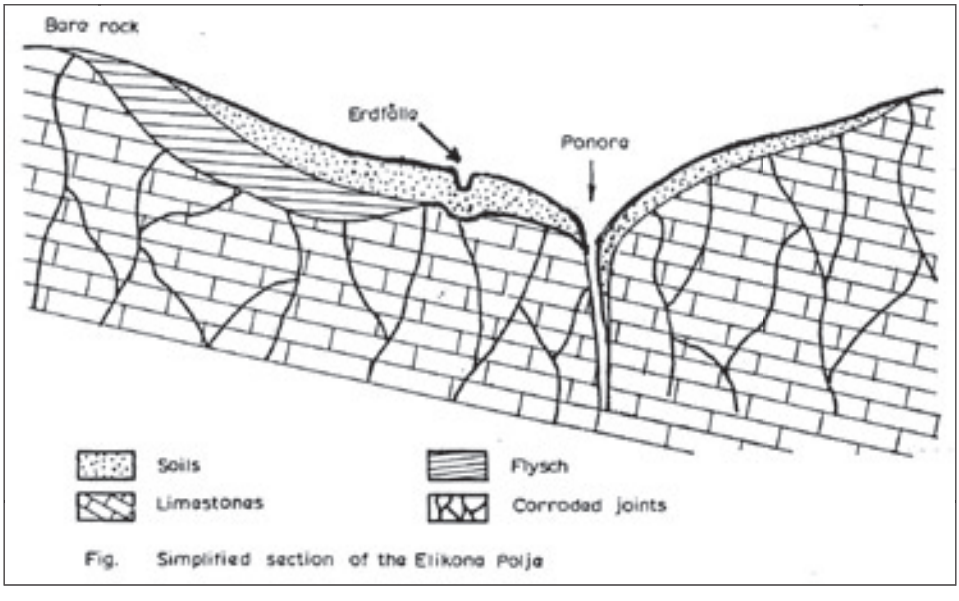

Fig. 11: Simplified section of the polje lake of Helicon.

Fig. 12: Polje lake of Helicon.

Fig. 13: The rich soilcover of the semipolje Seta.

a valley in a NW-SE direction, so it is a valley polje and marginal polje. The initial valley became a polje by the following processes: The rich supply of fluvial sediments from the flysch and materials from the limestone's chemical dissolution resulted the genesis of polje soil. The fast accumulation of these materials at the lowest parts of the valley initiated the impermeability of the enlarged joints (Fig.11). Simultaneously, the applied diffused corrosion through the soil in the epikarstic zone had the following result. The initial form became deeper and wider through marginal corrosion at the limestone sides of the valley and formed a ponor zone. The polje's incapability of draining during winter and spring led to the creation of a periodic lake-polje. Accordingly, this lake polje is not the result of an annual rise of the piezometric surface, but exclusively the consequence of a watertable in the poljesoil and/or a temporary rich epikarstic watertable.

The polje Striginia lies at an altitude of 680 m. It is also a valley polje, marginal polje, that was created according to the previously described morphogenetic processes. The only difference between Striginia and the polje of Helicon is that Striginia can be totally drained. The drainage of the polje does not occur exclusively underground through three ponors, but also surficially to the east; thus it is also an open polje that was originated through the following processes: diffused corrosion at joints in the epikarstic zone, deepening and simultaneously its impermeability and the enlargement of the initial form through lateral corrosion.

Region of Islands (Aegean Sea)

The creation of the polje Vlamaris on the island of Samos is related to the previous morphogenetic processes and refers directly to the epikarstic watertable and the rock's epikarstic zone. This polje lies in the mountainous region of Paleokastro at an altitude of 100 m. Moreover, on the island of Skopelos (Sporades), the development of small poljes, uvalas and solution dolines in the region of Glyfada (180 m) has very much in common with the previous processes. At this site the existence of an epikarstic watertable is proved by the watering places for the animals, were dug exclusively in the soil cover. The paleosoil in this place consists of aluminate brown-red and yellow clays, which had been created by the effect of tropic climatic conditions (Riedl & Papadopoulou 2001).

The direct association of epikarst with morphogenesis is also found in the case of Semipolje. Thus, the semipolje of Seta in the central of Euboea island (Papadopoulou & Kirdis, 1995) had been developed in Neopaleozoic impermeable formations, which consist of clorite, sericite and argilic schist, that are also the local base of karstification. A small appearance of permeable limestones (Upper Triassic, Jurassic) can be found in the SE, lying over the impermeable limestones. The latter host four sinkholes, within which sinking rivers terminate. Besides, these ponors are also used for the drainage of the semipolje (Fig.14). The semipolje's soil cover was created by the erosion of the impermeable formations, above which the semipolje lies (Fig.13). Today, underlying karstic rocks do not exist. The existing water table in the soil exits towards the SE, enhancing the potential lateral corrosion in the limestones; this favors the process of expansion of the semipolje and of the zone of the sinkhole.

CONCLUSIONS

Cavernous karren and subkutaneous kluftkarren are the primary forms of karstification in Greece. They are covered with terrarossa, and show the activity of the karsthydrology in these regions.

The subkutaneous karren are created in the epicarstic zone, in sites with high density of capillary discontinuities or diaclases, cataclases and small faults. At the same places diffused corrosion is applied through a capillary aquifer situated in the high vertical vadose zone.

The rounded peaks and the cavities of subkutaneous karren are created due to the continuous and uniform corrosion, that acts on soils in the high part of the epikarstic zone.

The karstic hollow forms in Greece are developed in places with karstified rocks, as also in places with karstified and non-karstified but easily eroded rocks. In this case, a lot of material is produced for the formation of the soils that fill these landforms.

Erdfälle, small seasonal springs, waterwells and watering places for animals, that are found in the filled material of the karstichollowforms, prove the existence of watertables in the soils.

Uvalas and poljes are usually developed in sites within old valleys or tectonic depressions. These forms are also created due to the diffused corrosion, exercised in the subkutaneous zone resulting in the widening of the joints and the lowering of the subkutaneous zone. Simultaneously the inrush of paleosoil leads gradually to the impermeability of the epikarstic zone, the reinforcement of the lateral corrosion and finally the expansion of the initial form.

These landforms were mostly created above the piezometric level of the underground karstic water-table and only in some cases on the catoptric surface of the phreatic zone.

The periodic lake-poljes are created when a temporary rich epikarstic water-table is developed due to incomplete natural drainage.

Fig. 14: Ponors zone of the semipolje Seta.

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