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Comparative investigations on Karst generations mainly in the Aegean Archipelago

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Mit 5 Abbildungen

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Zusammenfassung: Vergleichende Untersuchungen über Karstgenerationen vorwiegend im Ägäischen Archipel. – Der Beitrag behandelt Parameter bestimmter Paläokarstgenerationen, wobei die Karstbecken im Vordergrund stehen. Es erweist sich, daß die großen Poljen und Halbpoljen bereits im Miozän ihre Initialgenese erfuhren, während die kleineren Karstbecken im Plio/Pleistozän und Altpleistozän geformt wurden. Die Fallstudien über die ostägäischen Inseln zeigen am Beispiel von Lesbos den Spezialfall einer miozänen Poljengenese in Peridotiten. Auf den Kykladen und am Festland-Griechenland spielt die plio/pleistozäne-altpleistozäne Poljengeneration die größte Rolle. Bei der Darstellung der beiden Paläokarstgenerationen werden die paläo-ökologischen Parameter der Karstprozesse im Sinne der Klimamorphologie diskutiert.

Summary: The contribution presents arguments of distinct palaeokarst generations, mainly of karst basins. It gets clear, that the large karst basins already were formed in Miocene, whereas the smaller karst basin generation was shaped in Plio/Pleistocene and Lower Pleistocene. The case studies from the East Aegean region show besides the main Miocene age of the karst basins the special case of karst phenomena in peridotites of Lesvos. On the Cyclades and in continental Greece dominates the Plio/Pleistocene-Older Pleistocene generation of karst basins. At last the palaeoecological conditions of karst-processes are discussed.

1. Introduction

There exist only a few investigations about palaeokarst in continental Greece. In the Cyclades and East Aegean islands there do not exist any papers dealing with these topics. Until now neotectonic aspects dominate the investigation of the continental karst basins (VAVLIAKIS & al. 1993). The author worked above all the last 40 years on the Cyclades, Eastaegean islands and Northern Sporades besides in continental Greece and Peloponese and observed mainly climato-morphological aspects (RIEDL 1984).

Austrian geographers worked about the karst of Akarnania (FINK & VERGINIS 1974, 1976), and about the palaeokarst of Thasos (WEINGARTNER 1994). STOCKER 1976 proved a pre-Pliocene karst generation on Mani Peninsula. Among Greek geographers Papadopoulou recently worked about the polje-karst of the Lichas-Peninsula in Northern Euboea. She shows similar to RIEDL 1973 and his investigations in the Skiritis on Peloponnese, that ancient poljes may be associated with recent lateral karst processes. PAPADOPOULOU 1990 showed also the complex structure and genesis of Kopaida-karst basin.

With regard to the genesis of poljes we know two theories: the genesis of poljes in the level of the piezometric surface of the karstwater-body and on the other hand the genesis of poljes on the level of insoluble alluvial sediments. At the first model the polje-bottom is explained as success of solution of all the carbonate rocks up to the karst water table and

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general base level of erosion (Cvijic 1893, Grund 1903, 1912, Zötl 1961, 1974). This is the case in tropical karst, where marginal karst plains are cutting through all the strata, and the polje-bottoms are connected with the base levels of erosion (Lehmann 1954, Wissmann 1954).

The second model represents the genesis of poljes sometimes high above the base levels of erosion and independent of the piezometric surface of the karstwater-body. Louis 1956) described the example of Taurus poljes, in which the swallow holes are filled with insoluble material from alluvial fans. Under such circumstances corrosion at the margins of the poljes can be very successful and at the margins of the alluvial fans originate systematically new karst plains cutting all the structures.

2. The Neogene palaeokarst

2.1 Chios

The ancient karst of Chios island situated in the Pelagonian Zone (Jacobshagen 1978) appears with its large morphological units more outstanding, than the Neogene palaeokarst of Cyclades or of Northern Sporades. The specific character of the palaeokarst in Chios consists in poljes, large marginal karst plains and ancient flat floored valleys, which are all covered by fluvial sediments and lake deposits of Miocene age. As in the whole Aegean Archipelago the large-scale continental style of forms stands in contradiction to the small-scale recent islands. North Chios shows a complex 16 km long hollow form, striking NE-SW, which traverses nearly the whole island from Kardamila as far as the bay of Elintas. The ancient valley presents at a height of 540 m a valley-watershed 2 km SW from Pitious. The valley like hollow form is drained in SW-direction by Dipotamos River, which is 11 km long, and in NE-direction by Rachis River with a length of 5 km. The NE-part of the Kehltalung (Louis 1967) of Pitious presents a clear width of 3,5–4 km and a bottom's width of 0,3–0,5 km. The relict bottom is 20–50 m deep dissected by Rachis river. Important is, that Neogene covers the relict valley bottom in a thickness of only a few meters to a few decameters. From the morphographical point of view we have to take into consideration a polje (Fig. 1), because hums are forming the boundary of the hollow form in its SW- and NE-part. The relict karst basin is situated in massively bedded Anisian limestones. The bottom of the polje cuts these strata in a discordant way. The Neogene consists of yellow and brown coarse sands, green-grey loams and yellow marls. These sediments are similar to the Zyfia-layers in SW-Chios (Besenecker 1973) and were accumulated in Early Serravallian (Böger 1983) by a river system having drained the region of greywackes. The transformation of the Middle-Miocene kehltalung in a polje must have happened at the level of the karstwater table during Early Serravallian. For lateral corrosion and the polje's genesis in the level of an ancient piezometric surface the palaeoclimate was a determinant factor. Subtropical leaf-findings of laurel and cinnamon tree (Besenecker 1973) in the Zyfia-layers indicate an ancient vegetation zone, whose related species are found recently in the forests of south-eastern Asia (Zonobiom V after Walter 1984). That suggests also the petrified forest of Lesvos, which is buried by the Sigri pyroclastic formation (Velitzelos & Zouros 1998). At last the somewhat younger Keramaria-layers bear witness of a semihumid tropical savannah-like palaeoclimate on grounds of the mammal-fauna from Younger Serravallian up to Tortonian (Böger 1983). Therefore the large relict polje of Pitious was already subsided in Middle Miocene as low as 250 m relating to the marginal karst plain of Rachonas in the east and relating to the peneplain of Oros-Pelinaion in the west as low as 860 m. That also show phenorhyolitic ignimbrites (Herget 1968, Besenecker 1973) of Upper Middle Miocene at an altitude of 560 m on the western slopes of the polje. In

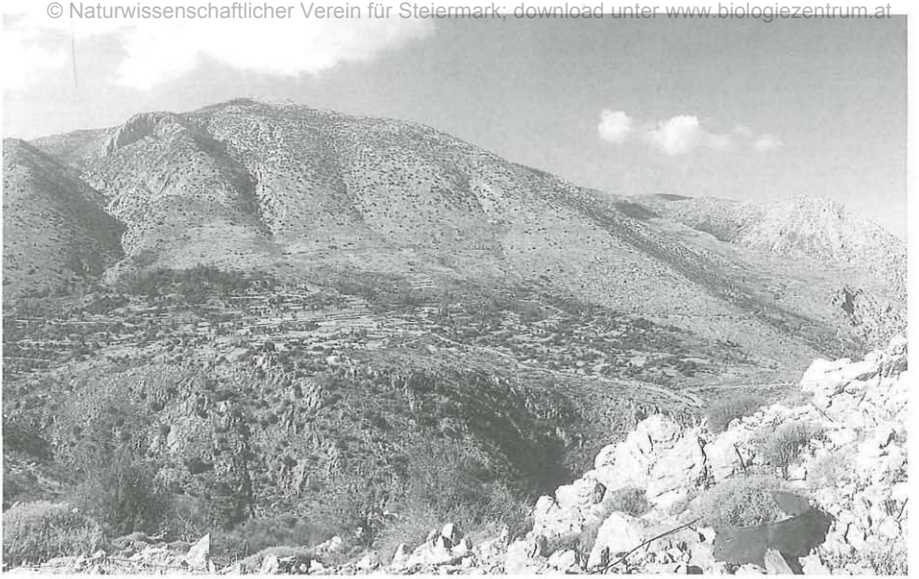

Fig. 1: The relict polje of Pitious (N-Chios). In the background: The mountainous region of Oros (1186 m) with Ladinian-Carnian limestones (massive, light-colored with Algae) in the uppermost parts of the slopes and Ladinian dolomites and limestones (thick-bedded, light gray, mostly detrital with thin lamination) at the upper and middle parts of the slopes. At the lower section of the slopes in the back-, middle and foreground Skithian and Anissian limestones and dolomites (massive and thick-bedded, light gray, sometimes pinkish, locally with ooliths and breccias). In the middleground: The geomorphical sequence of "smooth slopes" – pediments-glacis cutting the Lower Serravallian sediments (zone of arable land). The relict, hum like bottom of the polje, partly exhumed, is dissected by the Rachis River in the foreground.
Das relikte Polje von Pitious (Nord Chios). Im Hintergrund die Altlandschaft des Oros (1186 m) mit Kalken (Ladin-Karn) im Bereich der Altlandschaft und den höchsten Hangabschnitten. Ladinische Dolomite und Kalke im Bereiche der oberen und mittleren Hänge des Oros. Im Bereiche der Unterhänge des Oros, im Mittel- und Vordergrund Kalke und Dolomite aus dem Skyth-Anis. Im Mittelgrund die morphologische Abfolge von Glatthang-Pediment-Glacis. Letztere kappen im Bereich des Fruchtbaum-Trockenfeldanbaues die Sedimente des Unteren Serravalls. Im Vordergrund zerschneidet der Rachisfluss den humförmigen Poljenboden, wobei die Felspartien von Neogen bereits exhumiert wurden.

Post-Middle Miocene time the polje had been uplifted, in the course of which the karstwater table comparatively was lowered at simultaneously beginning of dissection. The Miocene polje had been transformed by pediments with an inclination of 7–10°, covered by Young Pleistocene alluvial accumulations. Together with backwards-erosion of Rachis river, the Miocene sediments got removed and the polje together with its hums was exhumed.

The palaeokarst of SW-Chios (Fig. 2) is characterized by a similar high degree of relief energy like in Northchios. The karst basin of Armolia with thick fillings by the Zyfia-layers, which go lower than the recent marine surface, represents one example. Another example offers the relict karst basin of Elata with a length of 6 km and a width of 1,5 km. The Miocene shows a minimum thickness of 120 m. The whole in Triassic and Jurassic limestones situated karst basin of Elata is independent from the recent morphology of valleys and coasts. South of the relict karst basin of Elata are situated from W to E: the large basins of Mesta, Olympi and the double basin of Pyrgi. Between this

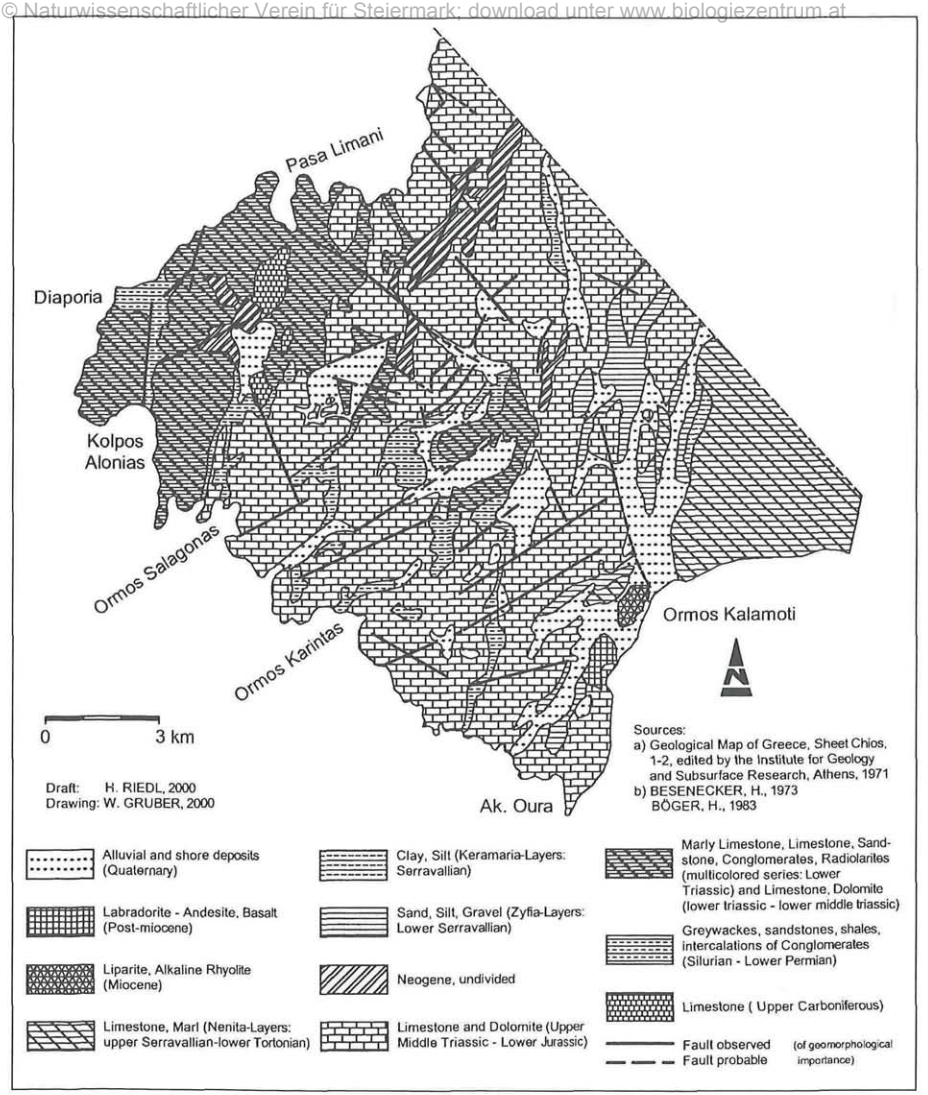

Fig. 2: (a) Geological map of SW-Chios (simplified).

row of large karst basins of Mastichochora and the incrusted karst basin of Elata 5 very small karst basins are located. The medium distance of all hollow forms amount to only 1 km. All the large karst basins show NE-SW linear extension controlled by NE-striking faults. All the margins of the basins are situated in Mesozoic and Palaeozoic carbonate rocks with a high degree of solubility. But in the large basins of Mastichochora we notice near the basis of the slopes outcrops of non soluble schists, quartzites and conglomerates of Palaeozoic age. Herewith the large poljes of Mastichochora must be termed as semipoljes. The developed basin-bottoms in 110 m altitude (Mesta), at a height of 140 m (Olympi) and 100 m (Pyrgi) consist of sand, clay, allochthone red soils, gravel and debris. In the basin of Mesta the Miocene gravel bearing marls plunge eastward below the Pleistocene/Holocene accumulations. Thereby one might assume also for the other large

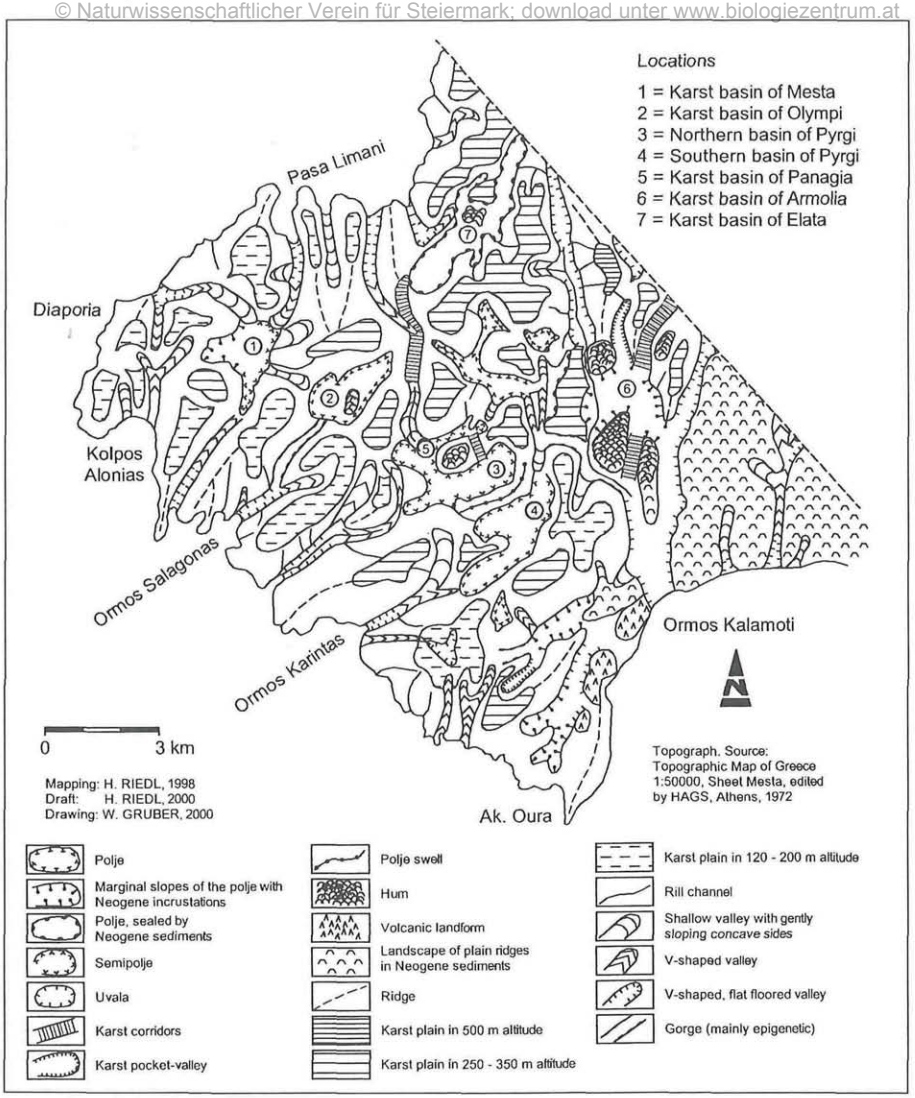

Fig. 2: (b) Geomorphological map of SW-Chios.

semipoljes of Mastichochora a Miocene primary age. The northern row of small basins reaches only to a length of 1–2 km. The axes are bound at NW-SE striking faults. The bottoms of the poljes are placed with altitudes of 160–280 m higher than the semipoljes of Mastichochora. The northern small basins constitute except the basin of Panagia typical poljes. All the semipoljes and poljes in SW-Chios represent primary allround closed morphological units with subterranean draining. Only in Postneogene time the basins were opened and integrated within the modern fluvial pattern.

The Chiotic palaeokarst therefore was shaped during the ancient stage of continental development long before the genesis of the island. By Young Lower Miocene-Old Upper Miocene accumulation of tropical-subtropical savannah rivers and lakes, the palaeokarst has been buried. The post Neogene mainly Young Pleistocene dominant fluvial linear

erosion, hand in hand with pedimentation of slopes produced the exhumation of the Middle Miocene palaeokarst.

2.2 Lesvos

Lesvos belongs like Chios to the Pelagonian Zone and shows an ophiolite nappe (Katsikatsos 1998), which contains basic and ultrabasic rocks, also fine grained deep sea-sedimentary rocks, metamorphites, amphibolites, metabasites and meta-sediments. This nappe had been overthrusted upon the autochthonous unit of Permo-Triassic age. The youngest unit consists of volcanites, Neogene marine and limnic sediments. The volcanic rocks present a radiometric age (Phytikas 1998, Pe-Piper & Piper 1992, 1993) of 15,5–21,5 M.a. The pyroclastic formation of Sigri is connected with the development of the famous petrified forest (Velitzelos & Zouros 1998). The centre of our interest represent the peridotites and serpentinites of East Lesvos. The typical feature of the peridotite-landscape is the development of peneplains. Two main levels of peneplains are developed: The first level is situated at an altitude of 200–450 m, in the southern part the second level at an altitude of 760–780 m dominates over the landscape of peridotites. Both levels overlap from the peridotites also on Late Palaeozoic green schists, Permo-Carbonian marbles and schists of the autochthonous unit. In the green schists the level of 760–780 m is modified by numerous marble-crests, which form monadnocks. The development of the peneplains cutting different rocks in eastern Lesvos must be younger than all the rocks of the autochthonous unit and the overthrust of the ophioloitic nappe. There exist some criteria, that the extensive peneplain with altitudes of 200–450 m received a primary predisposition at 17,0 M.a. ago (Pe-Piper, Piper 1992, 1993), because 750 m NW of altitude point 259 m (Pagani ridge) at an altitude of 180 m the peneplain lies in serpentinized peridotites covered by 1 m thick layers of Polychnytos ignimbrite (17,0 M.a). Here the peneplain is proved to be of pre-Upper Burdigalian age. This Miocene peneplain shows a similar high degree of relief energy like in Chios. In the region of eastern Lesvos between Akrasion and Kastri a volcanic cuesta landscape (Maull 1938) is developed: the ignimbrite recesses over the deeply weathered serpentinite peneplain. In the region of Namiata a 2 km^2 large peneplain at an altitude of 245 m buried by pre-Upper Old Miocene got exhumed. Because near Kato Stavros and Stavros the recent valley bottoms are situated in ignimbrite rocks, the pre Upper Old Miocene peneplain has been incised by ancient valleys with a depth of 200 m. Otherwise there is no doubt that the recent peneplain also cuts the ignimbrite; one can observe this at the whole eastern margin of Kalloni bay. In spite of the Old Miocene predisposition the large peneplain in the peridotites of Eastlesvos originates finally from post Old Miocene times. Therefore a high degree of similarity exists between the peneplains of Lesvos, Chios and Samos (Riedl 1989, 2000).

The most surprising phenomenon of this complex landscape of peneplains consists in numerous basins. As example only the basin of Megali Limni (Fig. 5) will be described. The basin of Megali Limni consists of a NNW running partial basin, which near Panagia bends into a SW going partial basin. The length of this complex basin amounts to 4 km. It is 0,5–1,5 km wide and lies at a height of 320–330 m. The basin primarly has been without draining off on the surface. After the uplifting of Eastlesvos the basin came to be the water shed between the bays of Kalloni and Geras, since it get drained nowadays towards SW by Vodamon river and towards E by the right branch valley of Evergetoulas river. The axis of Megalo Limni-basin is formed by an artificial open drain. The whole basin is situated in the large pinus brutia forests of the peneplain of 200–450 m height. Still the bottom of the basin got cleared. During winter time every year a shallow lake develops very similar to Zirknitz polje in the classic karst of Slovenia. A lot of birds of

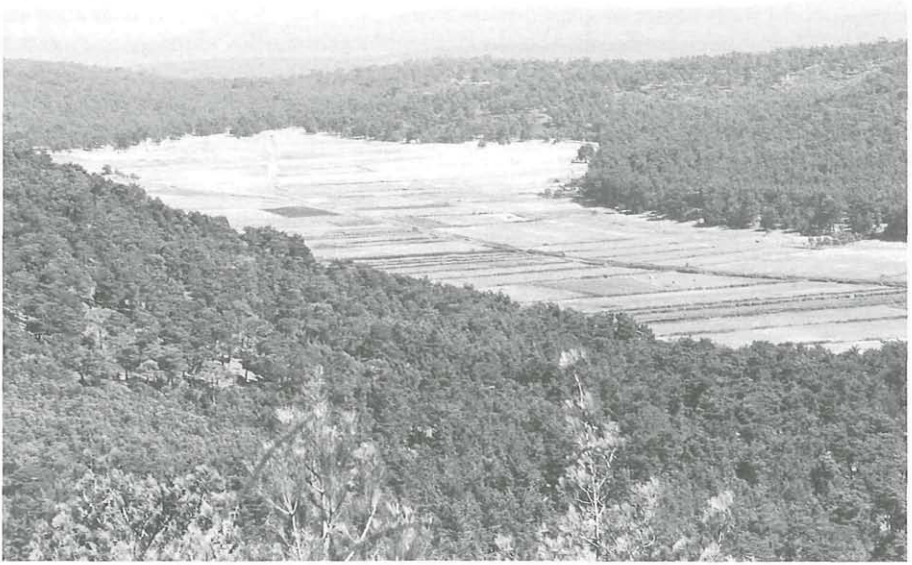

Fig. 5: Polje of Megali Limni (Lesvos) situated in the ophiolite nappe of deeply weathered serpentinized peridotites. The NW-part of the basin is deepened into the Miocene peneplain of 200–450 m height. The agricultural landscape of the polje's bottom, inundated by a shallow lake in winter lies at a height of 320–330 m and is surrounded by extensive forests of pinus brutia.
Megali Limni-Polje auf Lesbos. Das Becken liegt in der ophiolitischen Decke tiefgründig zersetzter, serpentinisierter Peridotite. Der NW-Teil des Beckens ist in die miozäne Rumpffläche von 200–450 m Höhe eingetieft. Der im Sommer landwirtschaftlich genutzte Poljeboden liegt in 320–330 m Höhe und wird von ausgedehnten Aleppokieferwäldern umgeben. Im Winter wird der Poljeboden von einem seichten See eingenommen.

passage populate the lake. During summer besides fruit trees mainly tomatoes, melanzanis and melons are cultivated, whereat pump lift irrigation is to be seen on marshy like soils. The entire basin is deepened into the peneplain on an average of 150 m. Similar to the poljes the basin is bordered by convex slopes with sharp basal edges. There exists an apparent contradiction, because in our case ultrabasic rocks prevail and we don't find here carbonate rocks like in view of poljes. Nevertheless it is important, that the peneplain in the peridotites is covered by a thick chemical weathering layer, like it is perfectly to be seen in the landscape of Stavrolangada at an altitude of 200 m in an exposure at the main road Mytilini-Molivos. The in situ-weathering material of peridotite shows small contents of MgO and high contents of ferric oxides. Into the 8–10 m thick chemical weathering zone unaltered rocks are embedded. The weathering front is not homogenous. The entire matadero-weathering (Riedl 1991) is overprinted by thick red soils in which the Mg-silicates are largely dissolved. In many exposures of the peneplains we can also observe, that there exists a well developed vertical joint system with narrow joint spaces. In the course of these facts karstification of peridotites is clear.

The peridotite basins of Lesvos are similar to karst basins described from Wirthmann 1970 in the peridotites of New Caledonia (18–23° s.L.). There the landscape of peneplains is individualised in numerous small and large basins like in Lesvos. In New

Caledonia like in Lesvos these basins did not develop tectonically and did not originate by accumulation. In new Caledonia too, the basins are genetically connected with deep chemical weathering and the karstification of peridotites. A striking similarity to Lesvos represents the high degree of conservation of the karst basin-bottoms, and though we have in Lesvos relict landforms, the simultaneous recent further development of the bottoms, we can also observe. The genesis of karst basins (poljes) in ultrabasic rocks needs therefore a tropical-subtropical, wet or semihumid climate. Certainly the medium precipitation per year should not remain below 2000 mm. The peridotite poljes of East Lesvos are the best argument for tropical-subtropical climate in Middle Miocene times during peneplanation. The valleys are prephases of the basin's development. This is to be seen at Vouvaris River at a height of 240 m, at Achladeris River in 200 m altitude, at Makris River at a height of 200 m and at Kryo Nero-River at a height of 260–280 m. In the basins of Makris River there prevails a 8–10 m thick accumulation of only weak rounded periglacial debris. The surface of the fan is situated 30 m higher than the recent erosion basis and overlies the yellow-orange, chemical weathering zone of the serpentinized peridotite.

2.3 Samos

The palaeokarst of Samos is very similar to Chios and Lesvos with regard not only to the Miocene dating but also relating to the tropical-subtropical heritage of geomorphology. Occupying a mean altitude of 1000–1153 m, the Karvouni level dominates the central mountainous region on middle Samos (Riedl 1989). It is encircled by younger levels, thus forming a Piedmont benchland that is finally bordered by systems of pediments and glacis. Developed entirely on marble, the flat surface of the topping Karvouni level is dissected by grikes that are incised several decameters deep. These karst corridors are several meters wide and end in cockpit dolines with wide bottoms that are irregularly surrounded by rock walls. The dolines with their star-shaped contours as well as the grikes signify old landscape features. Similar to the association of deep rundkarren pavement and stockkarren, they indicate a time of intense, deep corrosion. Simultaneously, haematitic paleosols developed. In terms of correlate deposits, this palaeokarst may be compared with the base gravels of the basin of Mytilini (Meissner 1976) that Böger 1983 determined as Upper Serravallian. In the area of the watershed between the Mavratza and Kavuraki Rivers, we may frequently discover well-exposed loams in 430 m altitude showing a thickness of several meters and a bright reddish-orange colour (2,5 YR 5/8). The loams (Riedl 1989) are succeeded by cemented sands whose crevices are filled with red soils (terra rossa). The sequence continues with 1–2 m thick, slightly cemented layers of 5–30 cm long marble debris, characterized by a loaf-shaped roundness which indicates short-distance transport. The covers of palaeosols, whose residuals still occur in situ on the palaeokarst in 1000–1153 m altitude (Riedl 1989), proved the first to be eroded. With the increasing uplift of the palaeokarst in the course of the Upper Middle Miocene, erosion also attacked the palaeokarst bedrock. With regard to palaeogeomorphology, this implies a seasonally humid savanna climate for the upper Serravallian which sponsored the formation of red soils (terra rossa) and deep corrosion. In the case of Portugal, Antunes & Pais 1984 assume warm, semiarid, savanna-like conditions or a steppe drained by seasonal rivers. In contrast, Muller 1984 points out that 11 to 14 millions years BP the climate probably was cool and arid.

The eastern part of the island of Samos offers an impressive example for the interlocking of the palaeokarst landforms of Middle-Late Miocene and Plio/Pleistocene age. In the Upper Serravallian, the mountainous region of Palaeokastron was structured by large poljes, whereas in the Thio Mountains, cone and dome-shaped karst forms

developed, and the area of Zoodochos Piji became occupied by marginal karst plains situated in 260–300 m altitude. Simultanously with epirogenetic downthrusts in the Tortonian, the large poljes were buried up to 300 m present-day altitude. Located below the cone karst of the Thio Mountains, the karst morphological cycle of Late Miocene and Lower Pliocene times is characterized by the formation of pediments and pocket valleys in 200–220 m altitude as well as by karst basins in 180 m altitude. The initial outline of the large polje of the Vlamaris may also be assigned to this period. In the course of the Upper Pliocene, we recognize the beginning of a partial burial of the Vlamaris polje. The development of the recent small poljes and semi-poljes started with the Plio/Pleistocene, leading to the destruction of the Late Miocene karst pediments.

The landforms in the east of Samos, marked by once buried, now mostly re-exposed poljes, by marginal karst plains, as well as by cone and dome karst forms, turn out to be striking equivalents to the Karvouni level of middle Samos. The rate of uplift of the Middle Miocene paleokarst on eastern Samos, however, is 700 m less than that of the mountains on central Samos. All the characteristics of the Late Miocene-Lower Pliocene karst pediments, which also embrace the present-day poljes (Riedl 1989), correspond to those of the mountain margins on western and central Samos. It must be noted, however, that the pediments of eastern Samos are situated nearly 400 m lower than those on the margins of the central Ampelos Mountains. These results may illustrate the fact that the analysis of palaeokarst generations may also reveal clues on the morphotectonic development, which started on eastern Samos with downthrusts in the upper Middle Miocene. After the burial of the karst forms during the Tortonian, the vertical rates of the various phases of uplift that may be distinguished on eastern Samos strongly lagged behind those that were achieved in the mountainous region of central Samos.

2.4 Cyclades

Though in the Cyclades the younger Plio/Pleistocene palaeokarst is well developed, there yet exist examples of Miocene palaeokarst in the marbles of the schist series. Because the geotectonical position of Cyclades was consolidated not before the intrusion of the plutonites and the overthrust of the Aegean nappe (Böger 1983), one can only expect youngest Miocene (Messinian) palaeokarst. Notable on Siros (Riedl 1981) the palaeokarst of Late Miocene age in the landscapes of Anomeri (Stonichas, Pirgos) includes residuals of marginal karst plains as well as slope concavities and pediments adjusted to the marginal plains; those constitute still prominent landmarks. Latest Miocene marginal karst plains with cupolas appear also on Siphons (Riedl 1983) and Paros (Riedl 1982b).

2.5 The Archipelago in Comparison with Continental Greece and Peleponese

As Fink & Verginis (1974, 1976) had already illustrated by example of the karst depressions of Acarnania in western Greece, the large poljes of Greece have to be regarded as polygenetic landforms. It must be emphasized that some of the essential elements of the large poljes may be traced back to the Late Miocene-Lower Pliocene relief generation (Riedl 1979), even though they underwent manifold modifications. According to the very thorough mapping by Katsikis (1981, 1992), the polje of Joannina (Epirus), which is 35 km long and 3 to 10 km wide, must be interpreted as a polygenetic polje. Its southern part may be classified as a marginal polje, the north as an overflow polje. Although the polje of Joannina expanded considerably in Pleistocene times – thus showing a similar development to the Acarnanian poljes (Fink & al. 1974) – and although we may also observe trends of recent further development in the karst basin, as

manifested by such keyforms as pocket valleys and blind valleys, the character of this most complex, extensive landform is still considerably shaped by the palaeorelief of Late Miocene and Lower Pliocene age. The recent large depression reveals incrustations by sediments of an Upper Pliocene lake. The corrosional processes, however, attacking the pre-Upper Pliocene basin, could set in only after the Middle Miocene because up to the Burdigalian, the Ionian zone was affected by marine sedimentation. Furthermore, we must bear in mind that the tropical, seasonally humid climate in the Late Miocene and Lower Pliocene greatly contributed to the degree of corrosion modelling the primary polje. The presence of flysch in the vicinity also played a significant role because the eroded, insoluble flysch material sealed the network of fissures and joints, thus accelerating lateral corrosion as well as inducing the genesis of the subsequent Upper Pliocene lake of Joannina.

On the Peloponnese, a marginal karst plain dominates the Mani peninsula, which is composed of very pure marbles (Stocker 1976). The karst plain is two to four kilometers wide and occupies nearly 60% of the surface of the Mani. Humshaped karst domes and mogotes (Riedl 1976) represent typical features. Developed on the same marble, we find pediments adjusted to the marginal karst plain. The foots of the pediments gently slope at angles between 3 and 5°. It seems important to register that the Upper Pliocene pediments bear no genetic relationship to the plain which would imply a simultaneous formation due to abrasion (Philippson IV 1959). On the contrary, the Upper Pliocene transgresses the plains in the south by more than 100 m. The pediments of this relief generation are marked by the fact that the basal slopes do not continue below the plain and that they are not succeeded by glacis. One may rather trace their course down to the foot zones and follow their transition to the plain. Thus the pediments represent a group of forms that developed synchronously to that of the karst plains. The Upper Pliocene transgression discordantly cuts the complex palaeorelief which implies that the pediments and the marginal karst plain as well as the upper smooth slopes must be older than the Upper Pliocene transgression. The conglomerate mantles and the layers of petrified soil sediments (Stocker 1976) may serve as evidence that these specific palaeokarst landforms developed under a seasonally humid, tropical climate and not under an arid one. From a genetic point of view, creeping and sheetflood erosion on thick soil covers may be considered as the essential processes affecting the pediments and slopes.

Similar to the Mani peninsula, pediments without glacis that open out into the marginal karst plain also dominate the Piedmont benchland of Arcadia (Riedl 1978). Both, the marginal karst plains, located at an average altitude of 1150 m, and the pediments of the Maenalon Mountains turn out to be older than the ancient surfaces of the glacis of the large intramontanous basins of the Peloponnese. In Arcadia, the group of forms, consisting of marginal karst plains and pediments, discordantly cuts the pre-Neogene palaeokarst. The development of the Arcadian marginal karst plains is closely related to the effects of corrosion that were generated at the interfaces of the flysch contact zones. It seems a significant fact that in the post-Upper Pliocene the whole group of forms was uplifted for about 1000 m, which is twice the amount of the pre-Upper Pliocene uplift subsequent to the tectogenesis.

The landforms comprising the Late Miocene-Lower Pliocene large poljes in continental Greece, Peloponnese and the Archipelago indicate a palaeoclimatic setting that is in accordance with the research results obtained by Bernor & al. 1979, Marasti & al. 1979, and Thunell 1979. In the Late Miocene, the hygric seasonality seems to have increased and the vegetation cover was dominated by sclerophyllous scrub with interspersed grasslands. With regard to the Pliocene, Marasti & al. 1979 assume an affinity to tropical conditions. The results of the deep-sea drillings, carried out by Thunell 1979 in the Tyrrhenian and Ionian Seas, imply that the maximum summer sea-water tem-

peratures amounted to 26° C in the Early Pliocene. The summer air temperatures presumably averaged 30–32° C. These figures suggest a certain similarity to the summer temperatures of A_w–climates with summer rainfalls. These climatic conditions assisted a deep-reaching corrosion of the carbonate rocks, sheetwash, and the development of plastosols. Morphological evidence of the salinity crisis could only be discovered on the East Aegean Islands where deep chemical weathering and corrosion was blocked in the Late Miocene. Sheetwash activities, however, continued and generated extensive glacis. The border line between humidity and aridity in the Late Miocene and Lower Pliocene may be drawn between Mykonos & Ikaria (Riedl 1989).

3. The Plio/Pleistocene-Older Pleistocene palaeokarst

In contrast to the Miocene polje-karst with already deeply incised v-shaped valleys and kehltäler the Plio/Pleistocene polje-karst is marked by the association of pediments, glacis and coastal marginal pediments. Moreover the axes of the karst basins do not reach some decakilometer but only a few km of length. Typical is also the absence of open ponors. Often dominates the diffuse drying up of the winterly precepitation on allochthonous sandy clay fillings of the poljes. Because in Cyclades often the relief of hogbacks prevails, poljes and uvalas are connected with subsequent zones of this structural relief in the marbles.

3.1 Pholegandros

In SE-Pholegandros the hogback relief (Fig. 3), determined by marbles of the Attic-Cycladic complex, is marked by large pediments. For instance a pediment leads from Oros Elevtherios to the flat pass of Chora at a height of 200 m. The Panagia–hogback also gets bordered by proximal 7° inclined marble-pediments on the front slopes of the cuesta. On Ag. Pnevma-hogback the pediment developed at a height of 190–230 m, running through the same hogback as pediment-gap; it interlocks with the broad subsequence zone of Petousis in 220–234 m altitude. In a similar manner the pediment breaks through the Petali-Proph. Ilias hogback at a height of 230 m. By those pediment-flat passes the hogbacks are transformed to karst-cupolas. Important is, that the pediments cut the limnic-terrestrial Pliocene and therefore must belong to the Plio/Pleistocene (Oldest Pleistocene) pediment-glacis generation of the intramontanous basins in continental Greece and Peloponnese and must be in accordance with the coastal marginal pediments of Cyclades (Riedl 1982, 1984).

The pediments function as control system of the karst basins, which are deepened into the pediments. The flat pass of Chora Pholegandros, consisting of Pliocene, represents the initial genetical plain for the genesis of the polje at a height of 170–200 m with a length of 1250 m by a width of 250–400 m. The largest part of the polje is laid out in marble. The karst basin primarily had subterranean discharge. On it, the canon shows it, which nowadays drains the subsequent structured polje, dissecting it in SE direction towards the coast with 160‰ angel of inclination. The canon follows partly cave-systems dependent on E-W and N-S striking faults. The joints are incrusted by red soils and calcsinter. After the subterranean discharge, the fluvial linear erosion started. The polje's genesis happened after the erosion of the Plio/Pleistocene pediments and before the accumulation of Middle Pleistocene and Würmian talus stretching into the canon. There, the polje of Pholegandros has probably Older Pleistocene age. The polje's opening and the destruction of subterranean drainage must be happened therefore in the course of faulting tectonics in the Late Old Pleistocene and during the genesis of the island on the turns of Lower Pleistocene to Middle Pleistocene.

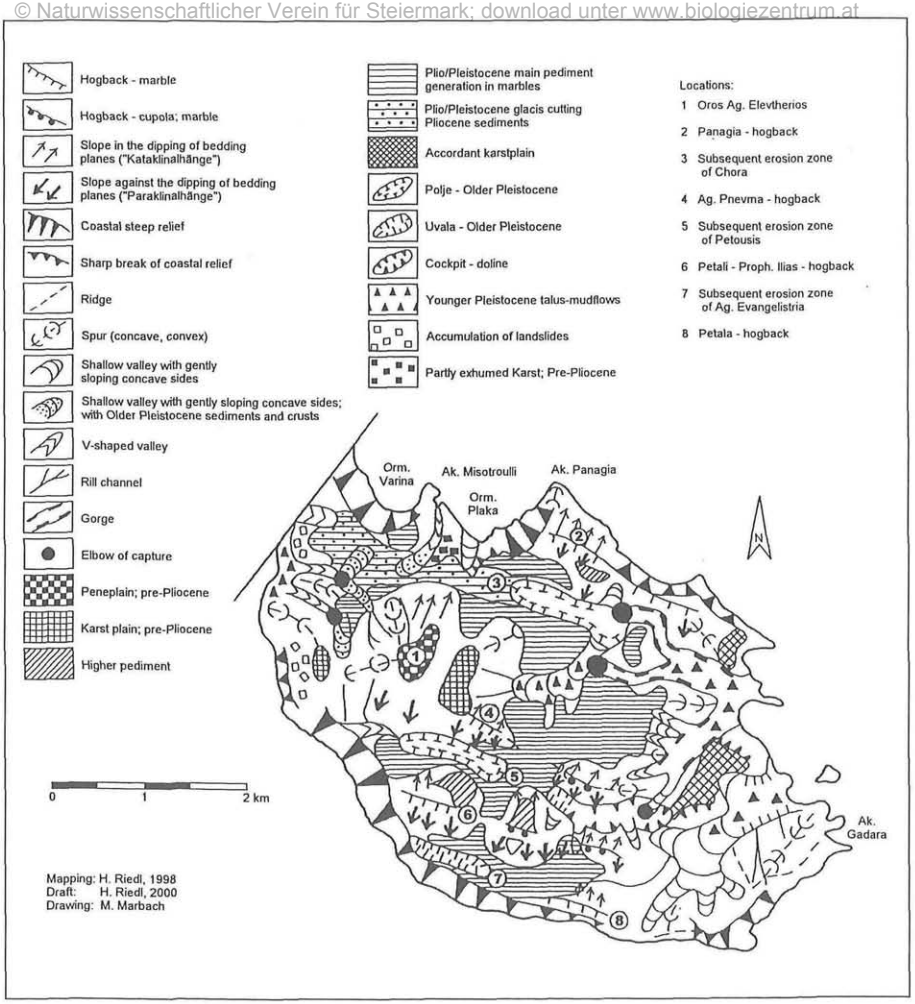

Fig. 3: Geomorphology of SE-Pholegandros.

The subsequent pedimented pattern of Petousis is deepened by a polje in the region of Ag. Nikolaos and easterly of it. The polje is incised by a small gorge. The subsequent zone, transformed in an uvala westerly from the hamlet Petousis ends in 160 m altitude in a cockpit doline, to which all shallow valleys converge with gently sloping concave sides. In this way hogback cupolas are finally transformed into karst cupolas. It is essential that the sequence: Polje – uvala – cockpit doline at 140–160 m height shows an elbow of capture by the Geras river. The fluvial capturing has been promoted by the marine retreat during Würmian stage.

So we are seeing that in the Cyclades pediments and poljes developed as typical sequence of geomorphological elements in Plio/Pleistocene and Older Pleistocene.

The investigations of Thunell 1979 about the Late Neogene deep-sea drilling sequences from the Mediterranean, the investigations of Marasti & al. 1979 about the palaeoclimatic meaning of Pliocene mollusces in the Mediterranean, and the analyses of Frydas (1998) about Upper Pliocene diatoms and silico-flagellates show in regard to the

Upper Pliocene a tropical-subtropical palaeoclimate. Upper Pliocene, allochthonous red soils, alternating with the Upper Pliocene marls on Pholegandros, correspond with the biooecological results. Since 3.2. M.a B.P. (THUNELL 1979) a cooler climate phasis existed with summerly seawater temperature means of only 14° C. In the Aegean continental stage we notice a stronger drainage phasis at the beginning of Oldest Pleistocene. In this phasis the patterns of pedimentation were established by resequent and obsequent fluvial elements. It is proved to be seen, that still in Plio/Pleistocene the warm features of climate returned until the Older Pleistocene (Blanc Vernet, 1979) being substantiated by the widening of resequent and obsequent rill channels to triangular embayments of the pediments and pediment flat passes. The Plio/Pleistocene – Older Pleistocene sequence of pediments and poljes shows clearly, that the pediments and poljes, connected with the hogbacks, originated not only under tropical-subtropical climate, but also under the morphological conditions of an extensive continental development in the area of the Attic-Cyclades complex. Pediments, uvalas and cockpit dolines were formed by entire independence of the recent coastal geomorphology and the recent valley system of the island.

3.2 Paros

The karst basin of Marathi – 3 km long and 0,5–1 km wide – strikes W-E and is situated not only in the area of marbles but also in that of schists. The basin lies in the Marathi nappe (PAPANIKOLAOU 1977). The bottom of the basin is situated in 120–160 m altitude. A special phenomenon represents the complexity of the basin's bottom. Near Ag. Minas SE from Marathi the karst pediments are optimally developed. They grow into the v-shapped valley with inclinations of 30–50‰ and are overprinted by hump like karren. The karst pediments, covered by thick red soils cut distally also the schists, whereas the karst pediments pass over to the type of semipolje. W of Marathi the karst pediments advance toward the counterslope, and the semipolje changes to the type of a marginal polje. Characterizing is the sharp convexe corrosive edging between bottom of the basin and counterslope. It is important, that there exist also identical pediments outside the basin, north of the basin's northern frame. There not only the metamorphic series are cut by the mountain marginal pediments but also the whole Marmara nappe (DERMITZAKIS, PAPANIKOLAOU 1980) consisting of non metamorphic rocks (ophiolites, Barrem-limestone, Burdigalian-molasse). The Mamara nappe has been overthrusted in pre-Messinian. Afterwards the autochthonous sediments of Pliocene travertines and silificated breccia were accumulated. All these layers are cut by the montainous marginal pediments in a length of 1,5 km and by an inclination of 40‰. So the Parian pediments represent Plio/Pleistocene pediments very similar to Pholegandros (RIEDL 2000), Seriphos (RIEDL 1986, 1991), Syros (RIEDL 1981) or Siphnos (RIEDL 1983).

3.3 Skopelos (northern Prorades)

The coastal marginal pediments (Fig. 4) are developed at an average altitude of 120 m. The coastal marginal pediment is not only found on the smoother northern slope of the Glossa Peninsula, but it also constituted the initial surface for the present-day outline of the bays (Elios, Panormos, Limnonari). Only after the formation of the coastal marginal pediments, the tectonic break-up of the Aegean continent set in and the calas and rias we observe today were formed. Just like on the Cyclades, this decisive stage of development with pedimentation extending across the present-day bays is linked to the Oldest and Older Pleistocene. The pediments are associated with a typical sequence of forms following a regular pattern. In the depression of Staphylos the pediments, which

are covered by debris mixed with loam, merge into glacis. At the counter discharge margin, formed by the slope of the karst block of Mt. Plakes, these glacis are connected with karst blind valleys. Only after the development of this synchronously modelled sequence of forms, the blind valleys were transformed into poljes and uvalas. Both types

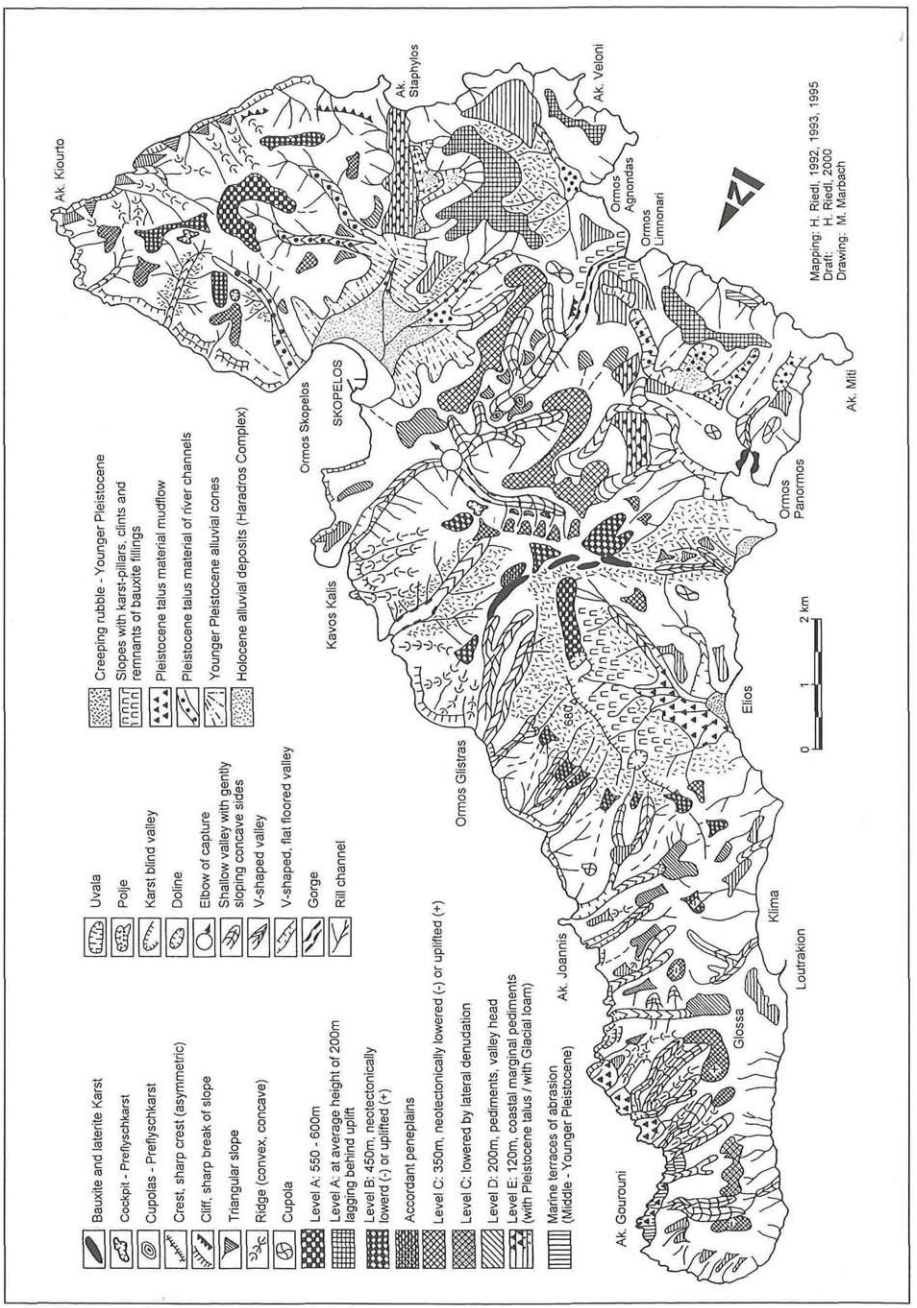

Fig. 4: Geomorphological map of Skopelos.

of karst depressions could only develop before the emergence of the island in post-Lower Pleistocene times (RIEDL & VRINIOTI-PAPADOPOULOU 1998b, RIEDL 1998a).

3.4 Comparative Aspects of Continental Greece and Peleponese

The Plio/Pleistocene relief generation in Greece, characterized by the association of pediments and glacis, represents a prominent group of forms that models the Late Miocene-Lower Pliocene primary outline of the large poljes. In the polje of Joannina (KATSIKIS 1981), for instance, the topping zone of pediments, which developed after the initial polje had been buried in the Pliocene, may be identified most distinctly in the hum hillside. The associated glacis cut the Pliocene lake sediments. The pediments actualy denote the starting area for the more recent, Pleistocene interplay of forces, above all for the development of asymmetric valleys and limnic abrasion terraces of Late Pleistocene age. These forms indicate a young assemblage whose genetic processes initiated the exhumation of the pre-Upper Pliocene ancient form.

On the meso-scale of forms, the Plio/Pleistocene-Early Pleistocene paleokarst generation reveals a close dependency on the ancient surfaces of the intramontanous Neogene basins. In this respect, the basin of Sparta (Riedl 1976) may be considered a most illustrative example. The whole margin of the Parnon Mountains in the east of the basin is occupied by a zone of pediments, 300 to 600 m wide and developed on Tripolitza limestones. In 520–400 m altitude, the pediments change to glacis that cut the Upper Pliocene sediments of the basin at an acute angle. On the glacis, we find red soils that are covered by Early Pleistocene breccia composed of sharp-edged slope debris. The whole area of the Parnon Mountains is structured by shallow, troughshaped valleys that end on the Plio/Pleistocene- Early Pleistocene glacis. The trough-shaped kehltäler were modified by uvalas, karst depressions, and small valley-shaped poljes. Subsequent to the uplift of the Parnon Mountains, the formation of this complex association of paleokarst forms set in during or immediately after the genesis of the glacis.

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