Quantitative-Geomorphological study of Lesvos Island and drainage network (Greece)*

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ΠΕΡΙΛΗΨΗ

Η εργασία αυτή αφορά στην ποσοτική γεωμορφολογική μελέτη των υδρογραφικών συστημάτων της Νήσου Λέσβου. Στη Λέσβο αναπτύσσεται πλήθος υδρογραφικών συστημάτων, που σύμφωνα με την κατάταξη κατά HORTON (1945) και STRAHLER (1957) διακρίνονται, 1 αυτοτελής λεκάνη απορροής 6ης τάξης, 16 αυτοτελείς λεκάνες 5ης τάξης, 34 λεκάνες 4ης, 69 λεκάνες 3ης τάξης, καθώς και μεγάλος αριθμός λεκανών 1ης και 2ης τάξης, που αποστραγγίζουν κυρίως την παράκτια ζώνη.

Η μορφή του υδρογραφικού δικτύου είναι κυρίως δενδριτικού τύπου, αλλά σε περιορισμένη έκταση παρατηρούνται μορφές ορθογώνιου κλιμακωτού.

Η πυκνότητα και συχνότητα του υδρογραφικού δικτύου μεταβάλλεται στις διάφορες θέσεις γιατί επηρεάζεται από ποικίλους παράγοντες, αλλά κυρίως από τη λιθολογία. Μελετήθηκαν και αξιολογήθηκαν επίσης στοιχεία που αφορούν τόσο στην ανάπτυξη των ρευμάτων όσο και στη λεκάνη απορροής και από τα στοιχεία που προέκυψαν εξήχθησαν συμπεράσματα σχετικά με τη δημιουργία και εξέλιξη του υδρογραφικού δικτύου.

Η σταθερά συντήρησης του υδρογραφικού δικτύου C έχει γενικά χαμηλές τιμές.

Ο συσχετισμός των D, F, 01, F1 και C δείχνει ότι οι λεκάνες βρίσκονται σε νεαρό στάδιο εξέλιξης.

ABSTRACT

The quantitative geomorphological analysis of Lesvos' island drainage network is presented. There, a well developed drainage network is created. According to STRAHLER (1954-67) classification 1 drainage basin of 6th class, 16 drainage basins of 5th class, 34 of 4th, 71 of 3rd class and many drainage basins of 1st and 2d class are distinguished.

The pattern of the drainage networks in general is dendritic. Though in some places the growth of stepping rectangular type drainage networks is observed due to tectonic activity.

The drainage density and channel frequency is highly variable as a result of many factors, most important of which is lithology. The coefficients of drainage systems and of drainage basins are studied and conclusions are drawn on the creation and the evolution of drainage network.

The constant of channel maintenance C has in general low values.

The correlation of D, F, D1, F1 and C indicates that the basins are in a young stage of evolution.

INTRODUCTION

Lesvos is an island of the eastern Aegean. The island's area is 1636.7 km2. As it appears in geological maps (HECHT,J., 1972-73, -74, -75, -75) the island in its bigger part (875.949 Km^2, the 53.5% of the total area) is created by volcanic rocks of the Neogene Age. In the northern and western parts of the island neogene and quaternary formations like marls and limestones are observed, while the southern part is constructed by preneogene metamorphic rocks like marles, phyllites, schists, and greenschists (Fig.1).

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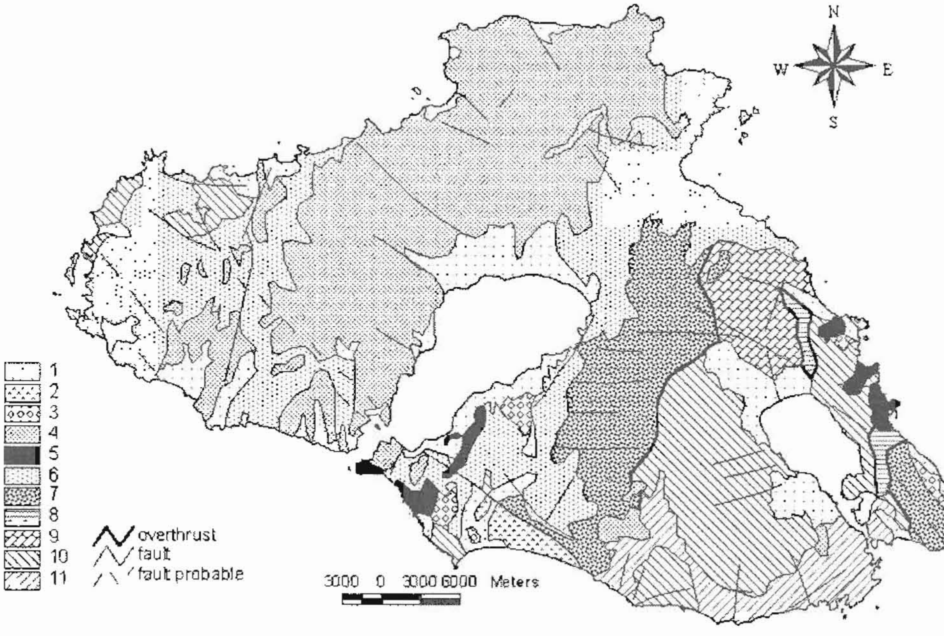

Fig.1. Geological map of Lesvos island baced on the maps of I.G.M.E.,(1983, 1989, 1993). 1.Alluvial deposits, 2.Pleiocene deposits, 3.Mio-Pliocene deposits, *Mio-Pleistocene:* 4.volcanic tuffs, 5.basalts, 6.volcanic rocks (rhyolites, dakites and others.), 7.basic and ultra-basic igneous rocks (diabeses, peridotites, dunites, ophiolites and others.). *Jurassic:* 8.schist-cherts and schist-sandstones with ophiolites. *Permo-carboniferous:* 9. kristalline limestones, marbles, greywackes, schists, prasinites, volcanites and others, 10.greenschists, schists, phyllites, greywackes and others, 11.schist, phyllites, greywackes, marbles and others.

Three main faulting systems are observed: one in the dominant northeastern orientation, one other of northwestern, where the longer faults are observed, and an other with N-S orientation (Katsikatsos, G. et.al., 1993). Except of the faults the rocks are insensitively cut to pieces and a regolith of great thickness is formed.

The shape of the island is almost triangular with two very deep gulfs at the southern part alongside the base, i.e. the gulfs of Geras and Kaloni. Three mountainous bulks are distinguished: mount Olympos (summit Profitis Ilias, 967m) in the south, mount Ordimnos (summit Vigla 589m) and mount Lepetimnos (summit Vigla 968m) in the north. The relief of the island in general is smooth. 30% of the area has slopes with 30% dip and only 5% of the island has inclination higher than 65%. The area consisting of volcanic rocks has the most intense relief.

From the above mentioned mountains the drainage networks of the island spring and grow radiantly around them. These directions indicate that the drainage networks are controlled mostly by lithology and secondary by neo-tectonic activity. According to HORTON (1967) and GREGORY K. et al. (1973) the pattern of the drainage networks in general is dendritic. Though in some places the growth of stepping rectangular type drainage networks is observed due to tectonic activity.

ORDERING OF THE DRAINAGE NETWORK

The study, the distinction and the ordering of the drainage networks of Lesvos island was constructed on the topographic sheets (scale 1:50.000) of the following areas: Mitilini, Ayia Paraskevi, Mithimna, Eresos, Polichnitos, and

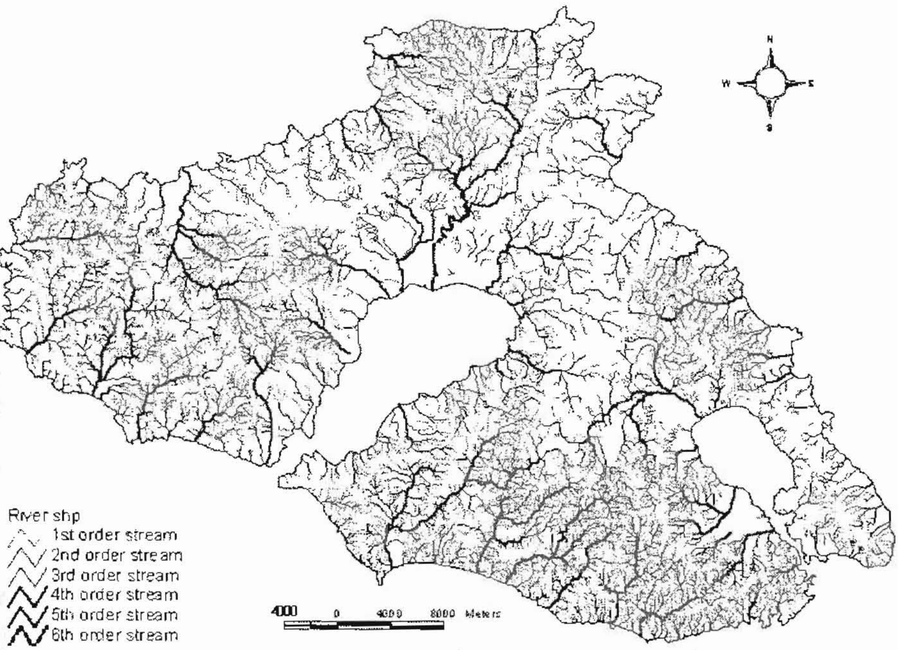

Fig.2. Map of the drainage networks of Lesvos Island.

Plomarion according to the system of HORTON (1945) and STRAHLER (1954-64). For the mapping of the drainage network aerial photographs were utilized. The entire ordered drainage network is presented in fig. 2. The streams of the different orders are indicated by special symbols.

After ordering of the drainage networks of the island, its quantitative analysis took place. Each stream of the drainage networks possesses its own basin of the same order that includes the lower order basins. All data evaluated for streams and basins (higher than 3rd order) of the island are given in maps and diagrams (Fig. 2-12).

The higher order independent drainage network, which is observed on the island, is of the 6th order, while the rest of them are: 16 of the 5th order, 34 of the 4th order and 71 of 3rd order. Except the above mentioned drainage systems, there are 2 of the 5th, 5 of the 4th and 19 of the 3rd order included in the 6th order basin. Also, 42 of the 4th and 155 of the 3rd order included in the basins of the 5th order and 105 of the 3rd order included in the 4th order basins.

The influence of the tectonic activity on the development of the drainage network was investigated. The directions of the streams per order of the drainage networks were measured and the corresponding rose diagrams were drawn (Fig. 3). 21% of all streams have NE-SW, 20% E-W and 18% NW-SE orientation (Table 1). The orientation

Table 1. Streams orientation of 3rd, 4th and 5th orders streams.

	3rd order streams	*4th order streams*	*5th order streams*
N-W	25%	20%	5%
NE-SW	23%	22%	30%
E-W	25%	25%	40%
NW-SE	27%	33%	25%

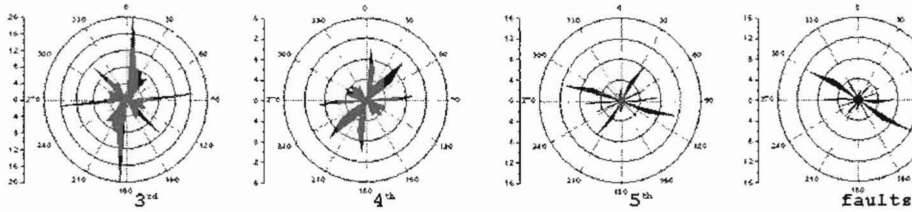

Fig.3 : Rose diagrams showing all streams of the drainage networks, as well as the faults of the island of Lesvos.

of the higher order streams (6^{th} and 5^{th}) coincides with the N-S faulting systems, the dominant orientation of the 4^{th} order streams is N-E and coincides with the dominant faulting system, while the lower order streams are dispersed randomly.

Geographical distribution

The geographical distribution of the basins (Fig.4) shows that most of the 5^{th} order basins are assymetrica1 1y distributed on the southern part of the island flowing into the south. They occupy the inner part of the island and are surrounded by basins of lower orders. The 4^{th} order basins are dispersed all around the area of the island as well as the 3^{rd} order basins. More precisely the larger basins are on the northern part of the island and the smaller ones are on the southern part. The 6^{th} order basin occupies the central part of the island and flows into Kaloni Bay.

Number of streams per order.

The number of streams per order in all basins shows a high degree of variation. Thus, in the 3rd order basins, N1 varies between 4 and 56, N2

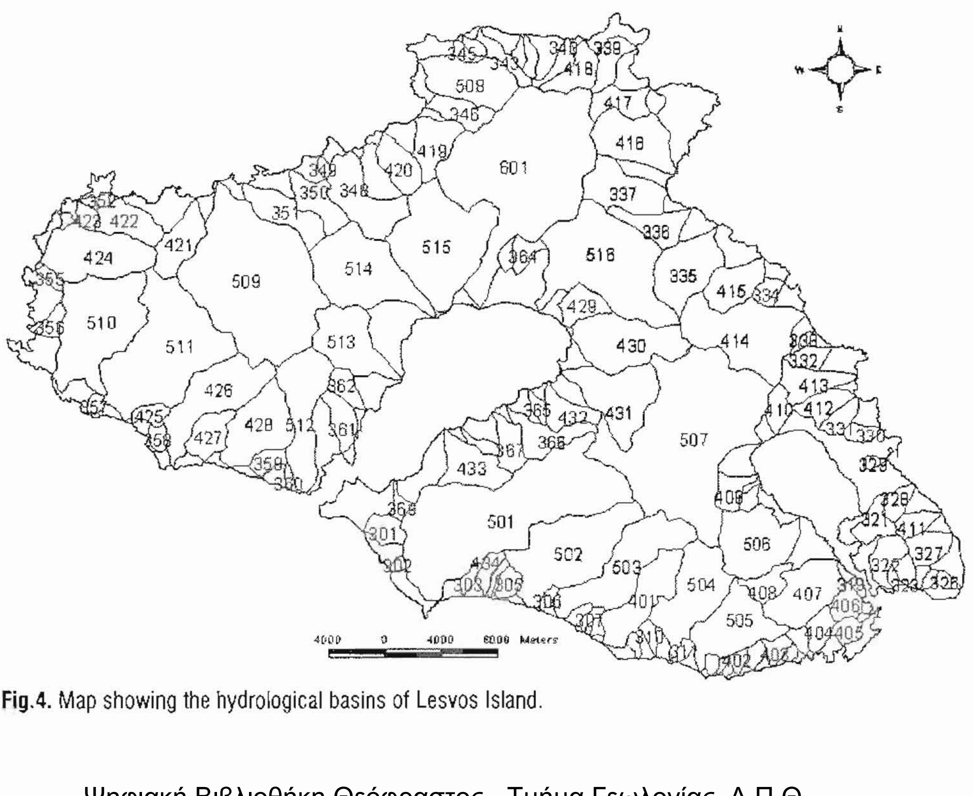

Fig.4. Map showing the hydrological basins of Lesvos Island.

between 2 and 11, in the 4th order basins N1 between 10 and 135, N2 between 4 and 38, and N3 between 3 and 4. In the 5th order basins N1 varies between 62 and 370, N2 between 17 and 95, N3 between 5 and 20 and N4 between 2 and 6. In the 6th order basin there are 269 N1, 68 N2, 18 N3, 6 N4 and 2 N5 streams.

After the ordering of the drainage networks, the theoretically expected number of streams has been calculated according to the 1st law of HORTON (1945) for each order. Positive deviation values show the presence of more streams than expected, while negative values show less than expected.

The number of streams of each order shows great divergences among the basins of the same order, as well as among the basins of different orders. Divergence values are negative for all 1st order streams of all order basins (Fig.5). Also, negative divergence values are observed almost for streams of all orders, with exception of the basins 501, 504, 509, 513 and 515 that show positive divergence for the 5th order streams. The 4th order streams on basin 509 show the highest positive divergence of 38%. In general, lesser streams than expected are observed in most of the basins. In the 6th order basin the deficiency of streams is 13% for 1st order, 31% for 2nd, 42% for 3rd, 39% for 4th and 36% for 5th order basins. The divergence for each order of streams is shown in diagrams 5,6,7b,7c and maps (Fig.9).

Smaller number of streams shows that the drainage network has not been completed yet and it is at a young stage of evolution. The lava from volcanic activities formed a primary relief on which formation of drainage networks occurred, preserving yet young stage features. Besides, field observations identify recent uplifting movements.

The highest negative deviation of all streams is observed in the 4th order basin 434 (-60%) and the highest positive deviation is observed in the 4th order basin 407 (+62%).

The 2nd law of HORTON (1945) has been applied for the mean length of streams ($\bar{L}$) and the divergences of the theoretically expected values have been calculated. Deviations of the length of the streams are observed in many basins. Posi-

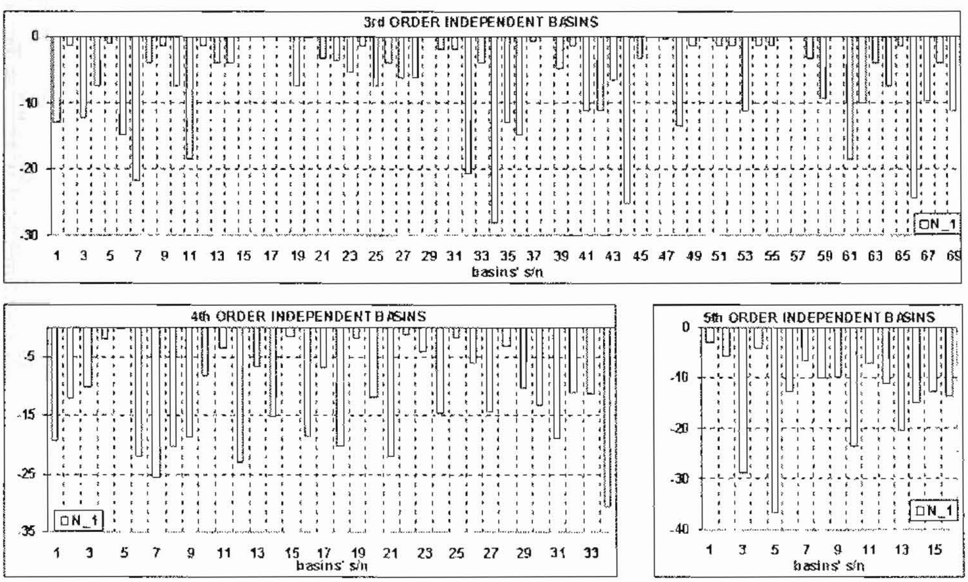

Fig.5. Diagrams showing the deviations of the number of 1st order streams on the independent basins of 3rd, 4th and 5th order respectively.

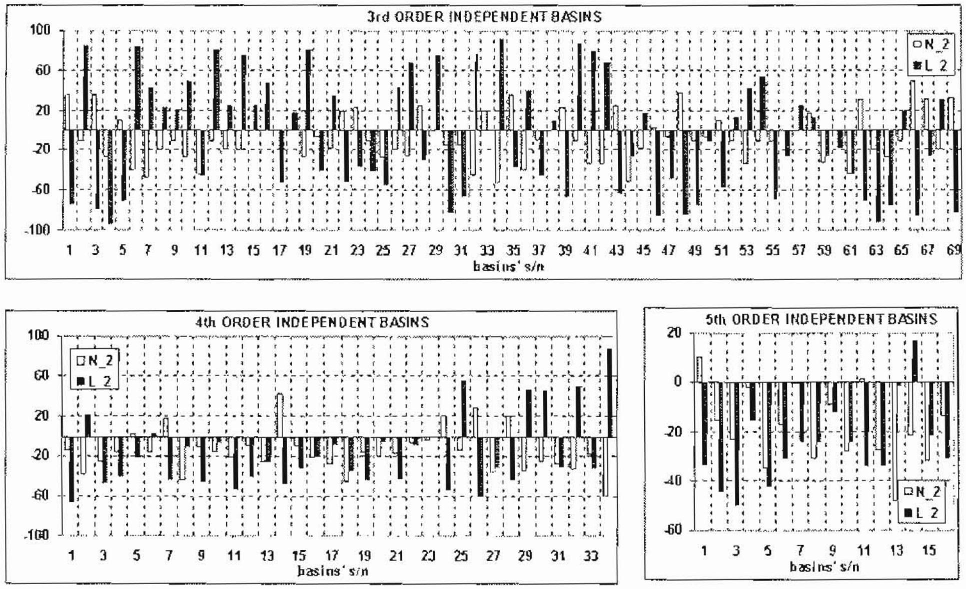

Fig.6. Diagrams showing the deviation of the number and length of 2nd order streams on the 3rd, 4th and 5th order basins.

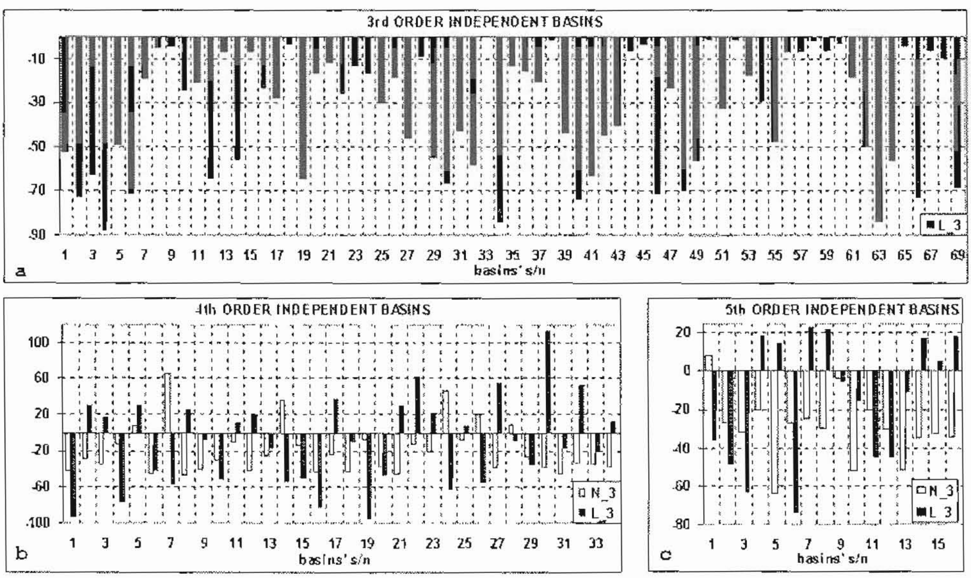

Fig.7. Diagram showing the deviation of the length of the 3rd order streams on the 3rd order basins (a) and of the number and length of 3rd order streams on the 4th (b) and 5th (c) order basins.

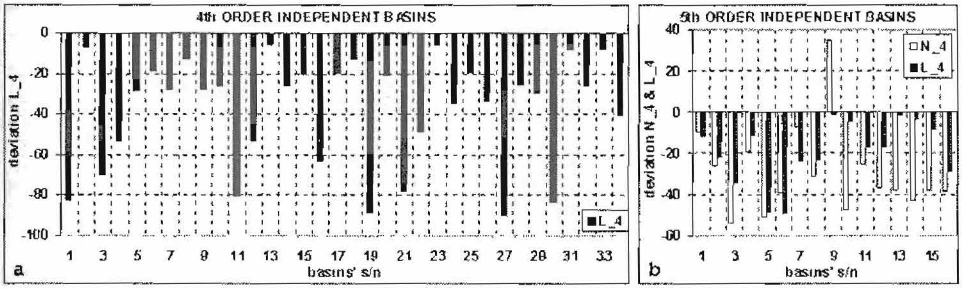

Fig.8. Diagrams showing the deviation of the length of 4th order streams on the 4th order basins (a) and of the number and length of the 4th order streams on the 5th order basins (b).

tive divergence values indicate a length longer than the ideal, whereas negative divergence values show a smaller length than the expected. Most of the divergence values are negative. The divergences for each of the stream's order are shown in diagrams (Fig. 6-8,10). The relation between the number of the streams and their lengths is also defined in the diagrams of the Fig 6,7b,7c,8b. The divergence values of the 6th order basin are for L2 –12%, for L3 +5%, for L4 –16%, for L5 –10% and for L6 –5%.

For the calculation of the mean stream length, the cumulative mean stream length has been considered. As for the mean stream length, the following observation have been made: The deviations of the 2nd order streams' length is negative on all 3rd order basins and on the most basins of the 4th and 5th order, while on the 3rd order basins 45% are positive. The deviations of the length on the 5th order basins of all 5th order streams are negative, while those of the 4th order streams are positive. The correlation of the deviation values between the length and the number of streams per order (Fig.6, 7b,7c,8b) show that 45% of the 3rd order basins have positive deviation in length of 2nd order streams. In most cases the deviation of length and the deviation of number of streams have opposite signs.

Streams that show positive divergence at smaller orders and negative at higher ones are in state of transition to a higher order. This results to a smoothing of the network with lower divergences. These branches are in a more advanced stage than those that have negative values in each order. Positive divergences occur due to lithology, because the streams are developed on impermeable formations. Negative divergences occur due to the large inclination of the relief.

Table 2. Mean values of bifurcation ratio and drainage area ratio of the drainage basin of Lesvos island.

basins' s/n	Rb	basins' s/n	Rb	basins' s/n	Rb	basins' s/n	Rb	basins' s/n	Rb	basins' s/n	Rb	basins' s/n	Rb	RA
301	5.14	319	2.75	336	3.25	353	3.00	401	5.19	418	3.60	501	4.42	3.39
302	2.25	320	3.17	337	4.38	354	2.25	402	2.83	419	3.26	502	4.05	2.12
303	3.70	321	3.67	338	2.00	355	2.25	403	3.07	420	3.17	503	4.38	2.51
304	2.75	322	4.20	339	4.10	356	3.00	404	3.44	421	3.65	504	3.71	2.04
305	3.63	323	3.25	340	2.25	357	2.00	405	2.81	422	3.43	505	4.07	0.71
306	3.25	324	2.25	341	3.00	358	3.38	406	3.62	423	2.50	506	3.31	1.91
307	3.75	325	2.75	342	3.00	359	4.33	407	5.43	424	5.41	507	4.32	3.53
308	2.50	326	2.50	343	5.57	360	2.00	408	3.75	425	2.17	508	2.91	0.62
309	2.25	327	4.00	344	4.00	361	3.50	409	3.37	426	5.00	509	4.44	3.70
310	2.75	328	4.00	345	3.67	362	3.80	410	2.88	427	3.31	510	3.82	1.71
311	3.50	329	2.00	346	3.88	363	2.50	411	2.25	428	4.56	511	4.03	1.45
312	2.25	330	3.50	347	4.25	364	2.75	412	3.50	429	2.77	512	3.16	3.06
313	2.50	331	3.50	348	8.05	365	2.25	413	4.03	430	3.29	513	3.20	1.26
314	2.50	332	5.50	349	2.25	366	6.70	414	5.17	431	3.70	514	3.51	3.16
315	4.00	333	2.50	350	3.17	367	4.58	415	3.49	432	3.00	515	3.23	1.65
316	3.00	334	4.25	351	4.50	368	2.50	416	3.57	433	3.13	516	3.26	0.92
317	4.00	335	5.68	352	2.25	369	3.00	417	2.63	434	3.17			
318	2.00											601	3.15	1.65

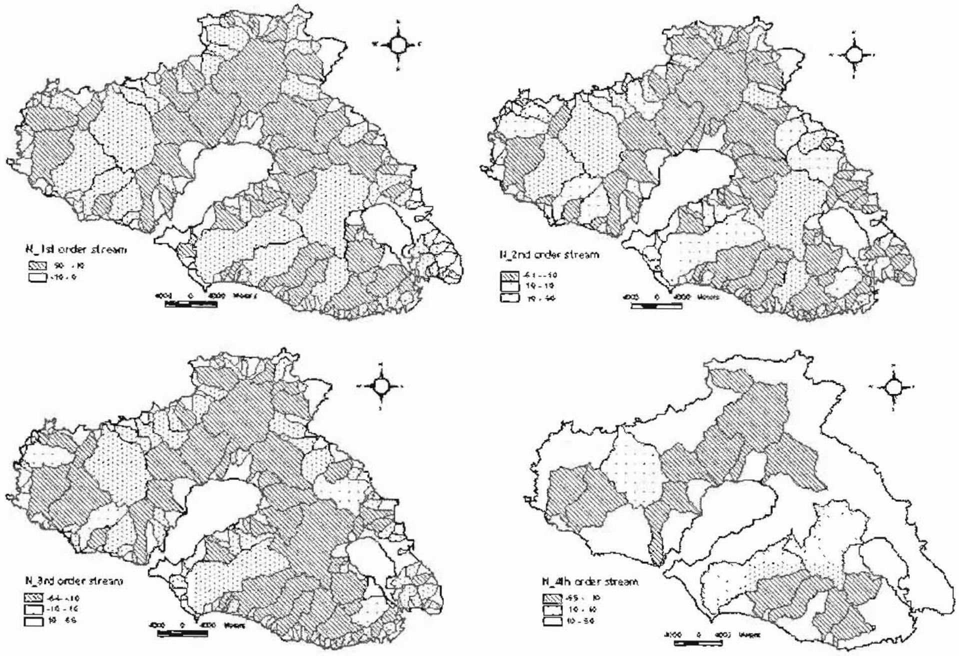

Fig.9. Maps showing the divergence values of the number of streams of 1st, 2nd, 3rd, 4th and 5th order basins.

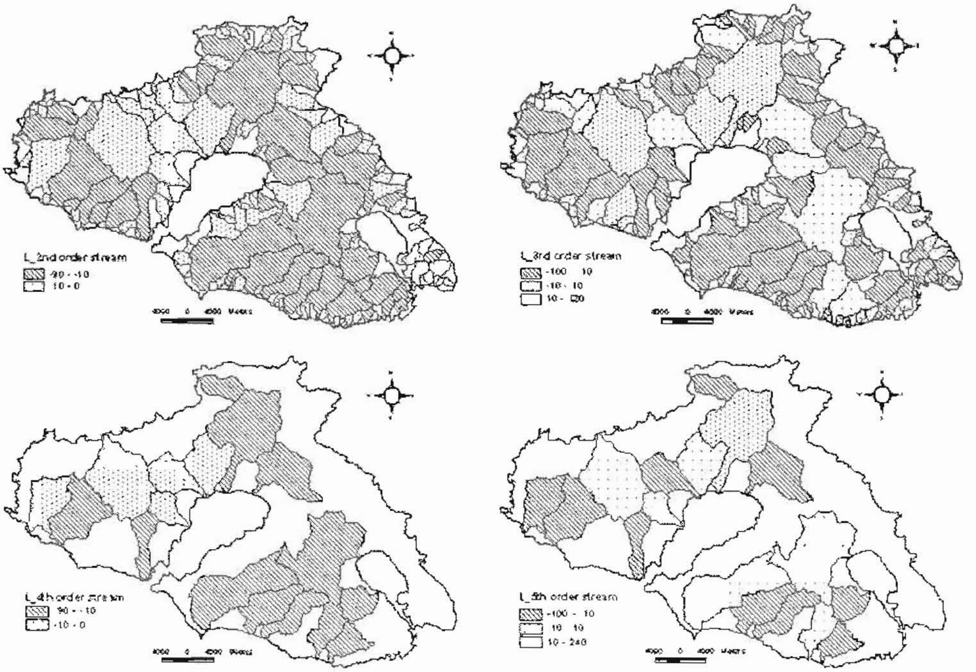

Fig.10. Maps of the drainage basins of the island showing the divergences of the length of the streams on 1st, 2nd, 3rd, 4th and 5th order basins.

Table 3. Total amount of drainage basins and basins' areas of the 3rd, 4th and 5th orders.

	3rd order basins	*4th order basins*	*5th order basins*
Total basins' number	351	82	18
Minimum area (Km²)	0 28 Km²	1.49 Km²	18 78
Maximum area (Km²)	18 61 Km²	38 74 Km²	94 62
Mean area (Km²)	2 68 Km²	10 52 Km²	40.88
Number/basins' area < mean area	233/310 Km²	56/355.53 Km²	6/408.42 Km²
Number/basins' area > mean area	118/360 8 Km²	27/517 68 Km²	12/327 48 Km²
6th order basins / Area (Km²)	91 3 Km²		

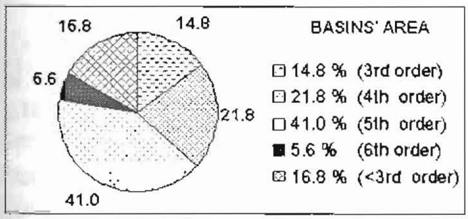

Fig.11. Diagram showing the percentage of covered area per order of drainage basins.

The bifurcation ratio (Rb) of the 6th order basin is 3,15, of the 5th order basins ranges from 2.91 to 4.42 while the mean is 3.73, the *Rb* of the 4th order ranges from 2,17 to 5.43 while the mean is 3.53 and the Rb of the 3rd order ranges from 2 to 8 with mean 3.74 (Table 2). Higher values show the basins 335, 348 and 366 with Rb 5.88, 8.05 and 6.70 respectively. According to HORTON (1945) an ideal value of Rb is 2. Values between Rb=2 and Rb=5 show a well-developed drainage network. Values significantly higher than Rb=5 show a higher creation of streams due to lithologic or tectonic factors.

Basin area

The area of the 6th order basin is 91.3km². The smallest area of 5th order basins' is 18.8 Km² (basin 508), the largest is 18.8 Km² of basin 508 and the mean value is 41.97 Km². As for the 4th order basins the mean value is 10.52Km² while the smallest area is 1.49 Km² (basin 423) and the largest area is 38.70 km² (basin 414), the smallest 3rd order basin is 0.3Km² (basin 319) and the largest is 18.63 Km² (basin 335) while the mean value 2.68Km².

The mean divergence of is-area values from theoretically expected values of 5th and 6th order basins has been evaluated (HORTON 1945). Histograms of figure 8 present these values in correlation to mean length values of streams of the corresponding orders.

Negative divergence values of basins' area indicate their young stage of evolution. Correlation of basins' area with branches' length of the corresponding order indicates the degree of erosion. Negative divergence of area and positive divergence of branches' length of the corresponding order indicate downcutting (ΛΥΚΟΥΔΗ, Ε. 2001). In contrary positive divergence of area values and negative divergence of length values of corresponding branches indicate advanced state of evolution or occur due to behavior of lithologic structures (mass movements, slops instability etc.). In the case of Lesvos island positive divergence of area values and negative divergence of

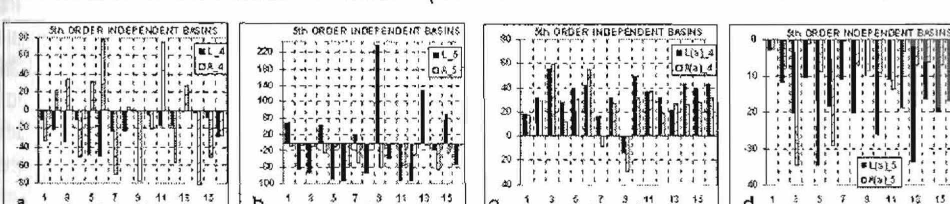

Fig.12. Diagrams showing the deviation of the mean length and mean area of 4th (a) and 5th order streams (b) on the 4th and 5th order basins as well as the deviation of the mean cumulative length (c) and mean cumulative area of 4th and 5th order streams (d) on the 4th and 5th order basins respectively.

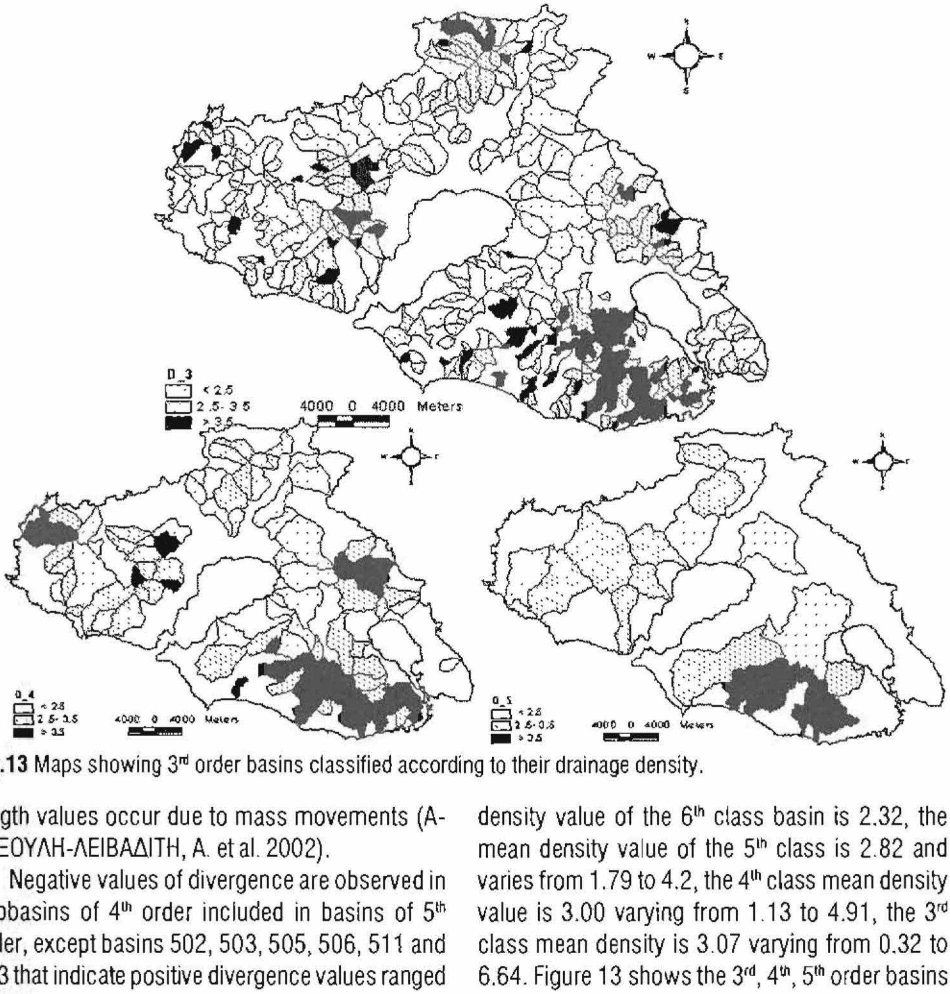

Fig.13 Maps showing 3rd order basins classified according to their drainage density.

length values occur due to mass movements (ΑΛΕΞΟΥΛΗ-ΛΕΙΒΑΔΙΤΗ, A. et al. 2002).

Negative values of divergence are observed in subbasins of 4th order included in basins of 5th order, except basins 502, 503, 505, 506, 511 and 513 that indicate positive divergence values ranged from 22% to 77.43% (Fig.12a). In this basins negative values are observed in addition to length values of the corresponding branches. Area divergences in 5th order basins are all negative, while in 37% of the cases a positive divergence in branches' length is observed (basin 509 up to +239%, basin 513 up to +13.25% and basin 515 up to +70.65%) (Fig.12b).

Drainage density and channels' frequency

The drainage density D values of the island's basins vary from one basin to the other as well as significantly among basins of different orders. The density value of the 6th class basin is 2.32, the mean density value of the 5th class is 2.82 and varies from 1.79 to 4.2, the 4th class mean density value is 3.00 varying from 1.13 to 4.91, the 3rd class mean density is 3.07 varying from 0.32 to 6.64. Figure 13 shows the 3rd, 4th, 5th order basins classified according to their density values. Most of the basins showing the highest density values are found in the southern part of the island, the Agiassos area, which consists of greenschist while the rest of high density value basins are spread over the rest of the island. In general the drainage density is directly influenced by lithology of the underlying rocks. Also other factors and particularly climate, altitude, tectonic structure, area and inclination of the slopes influence drainage density.

Channel frequency values (F) present similar

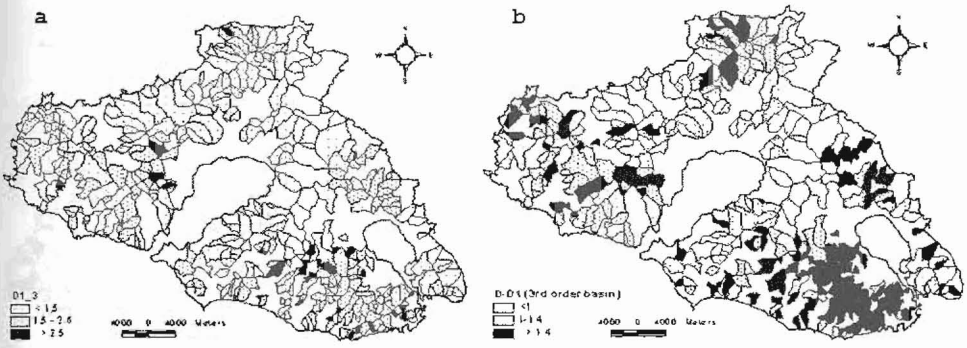

Fig.14. Maps showing the 3rd order basins classified (a) according to their 1st order drainage density and (b) the difference D-D1.

picture to drainage density (Fig.15). The frequency value of the 6th order basin is 3.34, the 5th order basins' mean channel frequency value is 8.71 and vary from 3.75 to 17.51, while the 4th order basins' mean F is 7.26 and vary from 0.57 to 20.23 and the 3rd order basins' mean F is 8.69 and vary from 1.43 to 35.17. A high correlation between D and F is expected due to mutual dependence from the area, the total number of streams and their total length. Streams' number and length are as well correlated to each other. Channel frequency F and channel density D are influenced by the same factors. The values of the channel frequency are usually higher than those of the drainage density.

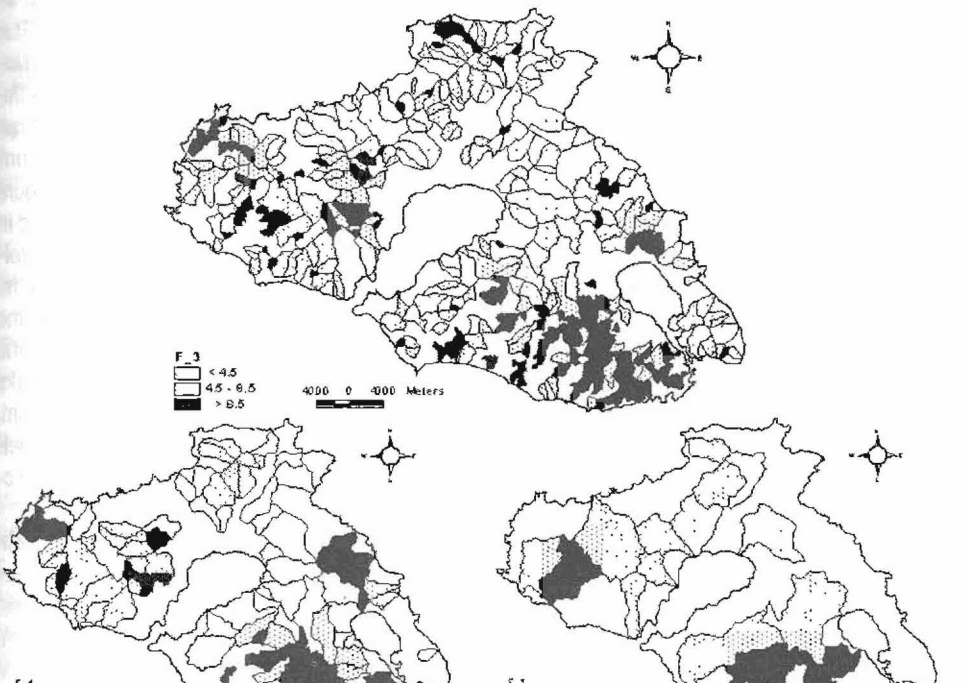

Fig.15. Maps showing the 3rd order basins classified according to their drainage frequency.

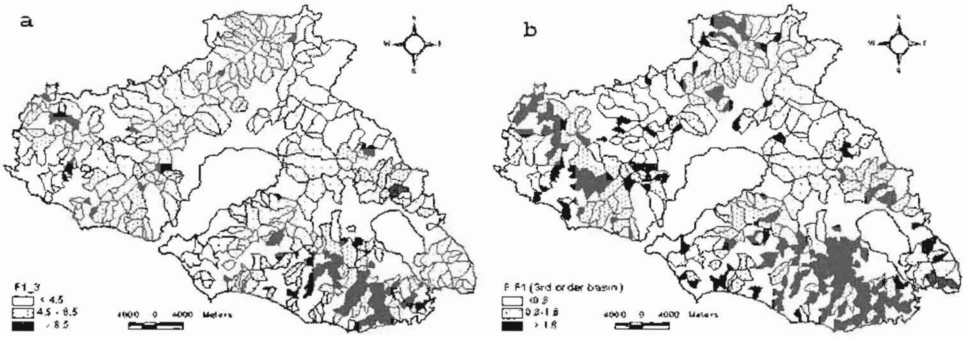

Fig.16. Maps showing the 3rd order basins, (a) classified according to their 1st order drainage frequency and (b) the difference F-F1.

From a comparison between values D and D1 (Fig. 14) as well as values F and F1 (Fig. 16) it has been concluded that basins situated on Mio-Pleistocene volcanic rock show significant formation of new number and bigger length of streams of the 1st order. According to PARKER (1976) and MELTON (1957) (from ASTARAS 1980) these parameters indicate that frequency and density of those basins occurs due to new formation of streams of the 1st order. According to CLOCK (1931,1932) and PARKER (1976) (from ASTARAS 1980) this leads to the conclusion that the drainage network is in a young stage of evolution.

The constant of channel maintenance C has in general low values. They vary from 0.15 to 3,16. The highest values are observed in basins of acid volcanic rocks (Fig. 17). The correlation of D, F, D1, F1 and C indicates that the basins are in a young stage of evolution. The lava from volcanic activities formed a primary relief on which formation of drainage networks occurred, preserving yet young stage features. Besides, field observations identify recent uplifting movements.

Higher values of drainage density and channel frequency are observed for 3rd, 4th and 5th order basins on metamorphic rocks located in the southern part of the island (Fig.15). In contrary, lowest values are observed in basins located on acid volcanic rocks between Antissa, Filia and Agia Paraskevi. Values D1 and F1 are compared to values D and F to define, weather high values occur due to the increase of the number or length of 1st order streams. The comparison showed that F1 and D1 values are higher on basins consisting of volcanic rocks.

DISCUSSION AND CONCLUSIONS

The quantitative geomorphical analysis of Lesvos' island drainage networks is studied. The shape of the island is almost triangular, with two very deep gulfs at the southern part alongside the base, i.e. the gulfs of Geras and Kaloni. Three mountainous bulks are distinguished: mount Olympos in the south, mount Ordimnos and mount Lepetimnos in the north. The relief of the island in general is smooth but the area consisting of volcanic rocks has most intensive relief. 30% of the area dips less than 30%, and only the 5% of the island has inclination higher than 65%. From the above mentioned mountains the drainage networks of the island spring and grow radiantly around them. These directions indicate that the drainage networks are controlled mostly by lithology, and secondary by the neo-tectonic activity.

The lava from volcanic activities during Miocene-Lower Pliocene formed a primary relief on which formation of drainage networks occurred, preserving yet young stage features. The drainage network in the eastern part of the island constructed by metamorphic rocks of Upper Paleozoic-Triassic age is developed on a descendant drainage network intensively affected by tectonic

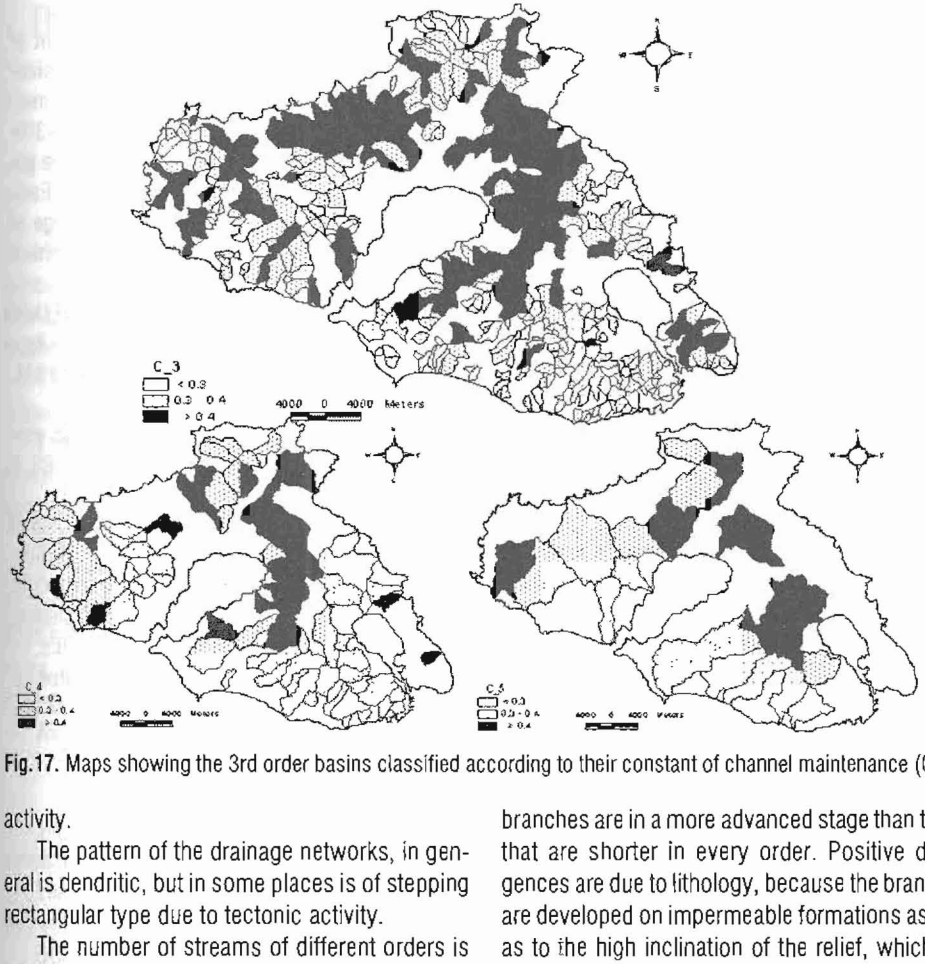

Fig.17. Maps showing the 3rd order basins classified according to their constant of channel maintenance (C).

activity.

The pattern of the drainage networks, in general is dendritic, but in some places is of stepping rectangular type due to tectonic activity.

The number of streams of different orders is general less than theoretically expected, showing negative divergences.

Mean bifurcation ratios, Rb show a well-developed drainage network.

The mean length of streams of all the orders is shorter than the theoretically expected in most basins, showing negative divergences. Longer mean stream length (positive divergence) is observed, as an exception in some basins, which reaches up to 133% longer (basin 430). Shorter streams, at smaller orders and longer at bigger ones, show that these basins are in stage of transition to a higher order. This results to the smoothing of the network with fewer divergences. These branches are in a more advanced stage than these that are shorter in every order. Positive divergences are due to lithology, because the branches are developed on impermeable formations as well as to the high inclination of the relief, which are caused by recent uplifting movements.

Negative divergence values of basins' area indicate their young stage of evolution. Correlation of basins' area with branches' length of the corresponding order indicates the degree of erosion. Negative divergence of area and positive divergence of branches' length of the corresponding order indicate downcutting. Positive divergence of area values and negative divergence of length values of corresponding branches indicate slops instability due to mass movements etc.).

The drainage density and the channel frequency show a high variation. Most of the basins showing the highest density values are found in the southern part of the island, the Agiassos area, which consists of greenschist while the rest of high density value basins are spread over the rest of the island. They depend directly on lithology of the underlying rocks, but this can be clearly recognized only where the other factors and particularly climate, altitude, tectonic structure, area and inclination of the slopes, are uniform.

The constant of channel maintenance C has in general low values.

The correlation of D, F, D1, F1 and C indicates that the basins are in a young stage of evolution.

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