STRUCTURAL-GEOMORPHOLOGICAL CHARACTERISTICS OF THE ISLAND OF UGLJAN (CROATIA)

Strukturno-geomorfološke značajke otoka Ugljana (Hrvatska)

doc. dr. sc. Marica Mamut

Department of Geography
University of Zadar
E-mail: mmamut@unizd.hr

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Summary

Ugljan is an island in the Northwestern Dalmatia (Croatia) and belongs to the Zadar archipelago. This island stretches in an almost regular dinaric direction (NW-SE); in this area, Dalmatian type of coast is the most prominent in Adriatic. The basic geomorphological features of the island are represented by a relatively large concordance of the orography with the general geological structures, as well as by the predominance of karst relief on the carbonate lithological base. In terms of geotectonics, Ugljan belongs to the Ravni kotari synclinorium with features disrupted with reversed faults and the formations of shaly structures in the neotectonic stage on the island. The similarity exists between the morphostructural features and the interdependence of the morphogenetic development of Ugljan and the neighbouring land. Today's relief is mostly a consequence of the sea transgression which occured during the Upper Pleistocene and Holocene.

Key words: geomorphological analysis, morphostructural analysis, tectonical structure, Ugljan island

Sažetak

Ugljan je otok u sjeverozapadnoj Dalmaciji (Hrvatska), dio je zadarskog arhipelaga i gotovo je pravilnoga dinarskog smjera pružanja (NW – SE); na ovom području dalmatinski tip obale najizraženiji je na Jadranu. Osnovne su geomorfološke značajke otoka relativno veliko podudaranje orografije s općim geološkim strukturama i prevlast krškog reljefa na karbonatnoj litološkoj podlozi. U geotektonskom smislu, Ugljan pripada ravnokotarskom sinklinoriju sa značajkama poremećenosti reversnim rasjedima i oblikovanjem ljuskave strukture u neotektonskoj etapi. Izrazita je i sličnost morfostrukturnih značajka i međuovisnost morfogenetskog razvoja Ugljana i susjednih kopnenih i otočnih područja. Današnji reljef uglavnom je posljedica izdizanja morske razine koje se dogodilo tijekom gornjeg pleistocena i holocena.

Ključne riječi: geomorfološka analiza, morfostrukturna analiza, tektonske strukture, otok Ugljan.

INTRODUCTION / *Uvod*

Ugljan (51.85 km^2) is an island within the meso-geomorphologic region called *Islands of NW Dalmatia* and is a part of Zadar archipelago. If the surface of all Zadar Islands (366 km^2) is taken into consideration, the island of Ugljan covers 14.2% of the overall area.

Zadar archipelago, with island of Ugljan, has almost regular Dinaric trend. Basic geologic structures stretch from northwest toward southeast. The length of the island of Ugljan is 22km, the width of island ranges from 1 to 6 km. It should be emphasized that here the

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Dalmatian type of coast is the most evident on the Adriatic. It is defined by a series of mutually parallel islands formed by transgression of the sea in the Late Pleistocene and Holocene after glacio-eustatic sea-level rise of 121 ± 5 m (Fairbanks, 1989.), when the parts of the present mainland were divided by channels. At that time Zadar channel separated the island of Ugljan from the mainland, while Middle Channel separated the island of Ugljan from the island of Dugi Otok Island (Fig.1).

The island of Ugljan is the microregion (or the unit) of northwestern Dalmatian macroregion with Velebit littoral slope and archipelago. Geotectonically, the island of Ugljan is a part of Ravni Kotari synclinorium. The synclinorium characteristics on island were disturbed in the neotectonic period with the reverse faults and the formation of imbricated structure. Since the main thrust originated from the northeast, double folds on the island of Ugljan were inclined toward southwest and disturbed by reverse faults, resulting with the basic island asymmetry: laid northeastern and steep southwestern sides of the island. There is a marked resemblance of morphostructural features and interdependence of morphogenetic development of the island of Ugljan and the neighbouring land. Therefore, it is a common relief form since there is a concordance between the geological structures and the terrain morphology. The anticline parts of the folds are ridges and blocks whereas syncline parts of folds are channels and small depressions. The occurrence of straits and passes is mainly determined by the influence of the transversal fault tectonics, of either radial or shear character.

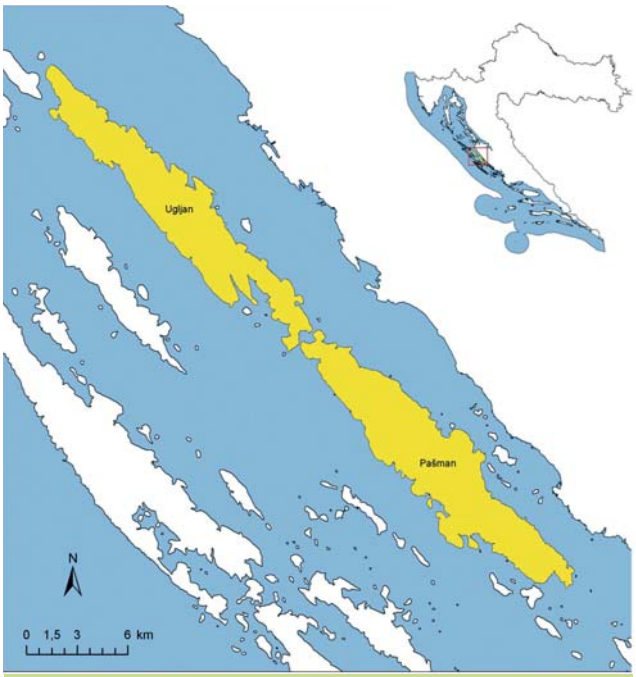

Figure 1. Geographical position of the island in the research

Slika 1. Geografski položaj istraživanog otoka

PREVIOUS STUDIES / *Dosadašnja istraživanja*

The first systematic geologic, including paleontological research of Zadar region, and the island of Ugljan were conducted in the 19th century. This research was the basis for the creation of the first revised geological map of The Austro-Hungarian Empire, made by F. Hauer in 1869. The Legend and Geological map, scale 1:576,000, provides a general representation of stratigraphic-structural relations of The Austro-Hungarian Empire area. Sheet X shows the formation of Zadar region in Triassic, Cretaceous and Eocene.

In 1889. Stache published geological map, scale 1:1,008,000, and in 1912. a map with more information on Dalmatia, with special emphasis on the limestones of Ugljan and Pašmani islands. Northern and Central Dalmatia were more thoroughly studied by R. Schubert (1902., 1905.). All stratigraphic units and their characteristics were shown on 1:75,000 scale maps, with legends. Further researches and mapping of Zadar region were continued by J. Poljak (1930.). He conducted morphological researche and distinguished different types of karts polje (1952.). In the middle of the 20th century numerous authors worked in the Dalmatian region. 1:25,000 scale maps provide detailed lithological and paleontological analyses of deposits and interrelations of certain stratigraphic units. The creation of the mentioned map revealed stratigraphic-structural settings of Dalmatia.

Since 1959. oil boreholes drilling has been conducted on Ugljan Island, and bituminous material and petroleum have been found in the fissures. The age determination of the deposits has been based on microfossil findings of foraminifera and algae.

Basic geological map, 1:100,000 scale, sheets L33-139 Zadar and L33-7 Biograd, with the matching legends (Majcen et al., 1967., 1973. for Zadar and Mamužić et al., 1963. for Biograd) and the works of Prelogović et al (2001., 2003.a, 2003.b) were made based on the recent geological researches of Ugljan island. Using the approach methodologically up to date the island of Ugljan has been researched from the geoecological standpoint for the purpose of creating the Basic geological map of the Republic of Croatia, 1:50,000 scale (Fuček, 1999.).

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Until recently, there have not been many geographical studies on the island of Ugljan It is essential to mention that in some studies this region is studied only marginally within the framework of a broader region analysis. Recently, Zadar islands have become the subject of interest of geographers, mainly those employed at the Department of Geography, The University of Zadar. Ugljan island area has been researched by Magaš, Faričić (1999.). As the part of her dissertation thesis Mamut (2005.) analyzed the geomorphological features of Zadar islands and their geoecological valorization.

RESEARCH METHODS / *Metode istraživanja*

According to the basic geomorphology definition, relief is the result of interdependence of internal and external factors. Those factors form the relief forms that are modified temporally and spatially. Since the aim and the scope of this paper are relief analyses, different research methods were used in order to present a more detailed picture of the complex structures of the investigated area and the interaction between the man and the relief. The applied methods can be divided into the four categories: field observation, geomorphological analyses and syntheses and morphostructural analyses.

In general, the basic method in the geomorphological researches, and in this investigation, is field observation. The determination of relief forms characteristics on the field is more precise in relation to analyses based on topographic maps and aerial photography (unprocessed photography or orthomap). Pedological composition of soils, vegetation, the influence of dominant climate factors and the influences of different human activities, were determined during the field observations. Based on the gathered data, morphogenetic classification of relief and the distribution of specific relief types were made. The photographic documentation compiled while working in the field is also particularly significant.

The basic method used for determination and classification of relief forms was geomorphological mapping. Geomorphological maps are one of the most important end products of investigations made by geomorphologists on the terrain. The author used topographic and orohydrographic maps 1:25,000 scale (sheets Povljana, Rivanjski Channel, Murvica, Nin, Žutski Channel, Gangaro), 1:50,000 scale (sheet Zadar 3), nautical map 1:100,000 scale (sheet Dugi otok - Zadar), geological map 1:100,000 scale (sheets Zadar and Biograd) and accompanying legends (Majcen et al., 1967, 1973, for Zadar and Mamužić et al., 1963 for Biograd). Mapping was done on Pašman and Ugljan Islands on the topographic maps 1:25,000 scale.

A geomorphological analysis encompasses a series of procedures used for the determination of regularity of action of different geomorphological processes on the analysed relief formation. In this investigation qualitative and quantitative analyses were used. Qualitative analyses differentiated relief forms according to their formation, the relations between certain relief forms were shown and spatial-time relations and relief types were determined. Quantitative methods, mainly cabinet work, provided necessary morphometric parameters, their relations, some procedures of morphostructural analyses were carried out and the relief features of the investigated area were presented.

Morphostructural analyses determined relief forms whose formation was mainly influenced by endodynamic processes, i.e. tectonic activity on one side. On the other side the aim of the analyses were to determine the relation of relief forms and geological formation for the purpose of defining structural-geomorphological development, structures and their influences on the direction and dynamics of exomorphological processes. The method implies the comparison of different morphometric maps (hypsometric, the relative relief and slopes inclination maps) with a geological map. Relief units which formation is primarily connected with geological structure and their tectonic dynamics were differentiated based on the morhpostructural analyses.

GEOMORPHOLOGICAL POSITION / *Geomorfološki položaj*

Relief regionalization of the Republic of Croatia was provided by Bognar in 2001. Until then only the following relief regionalization of Croatian territory existed: morphographic-morphometric, structural-geological and natural-geographic-ecological.

Morphostructural, morpholitogene and orographic relief features were the main criteria for the determination of a specific geomorphological regions in the Republic of Croatia. Also an additional criteria, such as hydrographic network, which is in close relation with the abovementioned, was used (Bognar, 2001.). After the orographic typization of relief has been done, it was necessary to develop a classification of the regions based on their size. In the Republic of Croatia four hierarchic taxonomic units were provided: mega-geomorphological, macro-geomorphological, meso-geomorphological and sub-geomorphological units. According to Bognar (2001.) in the Republic of Croatia

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there are hill, island, basin, lowland and submarine types of geomorphological regions.

As previously mentioned, the island relief on the Croatian part of the Adriatic developed during Late Pleistocene and Holocene as the consequence of glacio-eustatic sea-level rise of approximately 120 m. Due to the fact that the Croatian coast is well indented and with numerous islands it was necessary to provide a more detail geomorphological regionalization. The Adriatic archipelago is a part of Dinaric orogen with the prevailing fold-fault-imbricated geological structure, therefore it is justified that the island meso-geomorphological regions are integral part of the macro-geomorphological unit with parts of the neighbouring land area. For sure, at the same time they are a part of mega-geomorphological region of the Dinarides. Structural geomorphological features of the islands were the basis for the determination of mesoregional geomorphological units (Bognar, 2001.).

Zadar archipelago with the belonging sea (channels, straits and passes) is a part of the mega-geomorphologic region of the Dinarides, and from the macro-geomorphological standpoint it is a part of the region of Northern Dalmatia with archipelago. Based on the homogeneity principle of morpho-lithogenic and structural geomorphologic predispositions within the mentioned macroregion, the mesoregion named the islands of northwestern Dalmatia is separated. The following sub-geomorphological regions are part of the abovementioned mesoregion: Dugi otok with Iž – Sestrunj Islands, Ugljan – Pašman, Molat – Premuda and Silba – Olib Islands. Within the sub-geomorphological region of Ugljan – Pašman Islands, Ugljan Island with Rivanj Island and micro-morphological unit of Pašman island with a group of smaller islands (Žižanj, Košava, Gangaro, Kotula Vela, Kotula Runjava, Obun, Šipnata) are differentiated.

GEOLOGICAL FEATURES ON THE RELIEF FORMATION / *Utjecaj geoloških značajki na oblikovanje reljefa*

Tectonics[1]. Zadar Islands consist mostly of Upper Cretaceous and Paleogene carbonate and classic deposits. Folds and faults were generally formed by post-Tertiary tectonics and resemble each other, while the differences are only local. Direction of the structure and the distribution of detached deposits clearly indicate relief tectonic structure, evident in the series of folds of Dinaric trend. The oldest deposits (Cretaceous dolomites) are located in the anticline core, and the youngest ones (Eocene foraminiferal limestone and flysch) create syncline core. Upper Creaceous Rudist limestones are located in the fold limbs. Secondary folds are mainly built of rudist limestones. Numerous folds in this area are upright to recumbent, while overturned folds are rare.

According to their stratigraphic and structural characteristics, investigated islands are determined as part of the Zadar Islands tectonic unit. Main features of this tectonic unit are vertical to inclined folds with secondary folded anticline crests (Škarda), secondary folded limbs (Ist, Molat) and steep limbs (Premuda, Grebena), reverse faults (Dugi otok, Ugljan, Pašman, Iž), plunging anticline axis (Dugi otok, Sestrunj), plunging syncline axis, and partly overturned structures (Dugi otok). There are also brachial-anticline and brachial-syncline formed by horizontal and vertical flexure of folds. These structures are typical for most of the Central Dalmatian islands. Reverse faults on Dugi otok Island are probably the reflection of Cres – Lošinj structure. The most elevated parts of Zadar Islands tectonic unit can be found on Dugi otok, Škarda, Premuda and Sestrunj Islands. Ist Island with Reefs and Molat Island together with Tun Island are probably the extension of Ilovik – Lošinj syncline between Premuda-Škarda anticline and Dugi otok Island on the SW and Sestrunj anticline on the NE side.

Unlike NE coast of the Dugi otok island which is rather low and indented, Dugi otok fault is of reverse character. That refers specifically to the NE littoral area of the Žut Island, which through the series of islets and Sit island forms a connection with Pašman Island.

Pašman island represents the fragmented double fold of Dinaric trend with the main axial plane inclined toward NE, which has also the general direction of island's layer inclination. Along Pašman and Ugljan Islands there are two reverse faults. In the contact zone of the first one, (NE-SW) there are Cenomanian dolomite and limestones in alteration, and Turonian Cenomanian rudist limestones. Along the contact there are series of faults predominantly transversal or reversely inclined, but very steep. Cenomanian beds are mostly inclined toward NE, and along the fault they are horizontal or slightly inclined towards the fault or away from it. Further toward SW, the second reverse fault reduces

[1] "Tectonic structure" chapter is based on the following works: P. Mamužić et al., Basic geological map and Legend, Silba and Molat sheet (Zagreb, 1957, Beograd, 1973); P. Mamužić et al., Basic geological map and Legend, Biograd sheet (Zagreb, 1963, Beograd, 1973); Ž. Majcen et al., Basic geological map and Legend, Zadar sheet, Kuk et. al.: Seismotectonically Active Zones in the Dinarides, Geol. Croat. 53/2, 295-303, Zagreb, 2000, E. Prelogović et. al.: Recentni strukturni sklop prostora Dinarida, Zagreb, 2001, E. Prelogović et. al.: Tektonska aktivnost i klasifikacija struktura pogodnih za naftno geološka istraživanja u prostoru centralnog Jadrana i Dinarida, Zagreb, 2003, E. Prelogović et. al.: Recent structural fabric of the Dinarides and tectonically active zones important for petroleum-geological exploration in Croatia, NAFTA 55, 155-161, Zagreb, 2003,

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the NE limb of the syncline. Along the island, as a part of the mentioned reverse fault, only zone of the Alveolinid limestones from the foraminiferal limestones is preserved. The area to the south of Kali is an exception because Nummulitid limestone is preserved there in a diagonal fault in a relatively lowered southern block. Layers are inclined toward NE. On the southern part of the island reverse fault is marked again, causing the appearance of the Alveolinid limestones zone. Towards SW, transgressively Alveolina limestone lies on the Senonian limestone, and it continuously follows the Touronian carbonates. Along the SW coast of the Ugljan Island, Touronian limestone form anticline marked with Cenomanian limestones and dolomites in alteration. The anticline was found on the steep side of the island, along with Japlenički cape. Toward NW, along with secondary folding, deposits from Cenomanian until Eocene age spread in the open profile across Rivanj and Ugljan Islands.

Structural formation. For the classification of structures and faults according to their importance in the tectonical structure, a division on three basic units is used: Adriatic microplate, Dinarides and Pannonian basin. Within the Dinarides there are four units: Adriaticum, Epiadriaticum, Dinaricum and Supradinaricum. Zadar islands are a part of Adriaticum (Herak, 1986.).

Spatial arrangement and relations between the rocks of different masses are of special significance in structural pattern. Rocks are separated with fault zones of different importance and by classifying them, regional or smaller structural units are determined. Ugljan island, as a part of Zadar archipelago, is situated within the Adriaticum as the part of the following structural units: Susak - Dugi otok and Vis littoral, and Lošinj – Northern-Dalmatian islands (Prelogović et al., 2003.a). Data indicating distribution and relations of rocks forming structural fabric are of special significance for structural pattern analysis.

Great variations of the thickness of layers, facies changes and discordances point to a pronounced tectonic activity, corresponding to the Negoene period. Undoubtedly, Neogene is the key period in the formation of Dinarides. Active fault zones, structural units and structures related to the recent structural pattern are created in Pliocene and Quaternary. The displacements of the Adriatic microplate, which is narrowing, have the greatest influence on the formation of the recent tectonic structure. At the same time, new structures are formed in the Dinarides and Apenines.

The narrowing of the microplate area, especially affected by the recent displacements of Apenines toward NE, creates strong pressures causing the destruction of microplate and the formation of fault system with almost W-E horizontal component of the limb movement. In the Quaternary, the area continues to shrink and new compressive zones are created. Displacements of southern and western parts of the Adriatic microplate directly influence the discrepancy in stress orientation, the direction of structure displacement and seismic activity (Prelogović et al., 2003.a).

Faults. Recent tectonic activity and structure deformation analysis cannot be done without the data on faults. Faults can be arranged according to type, importance in structural pattern genesis and the type of the displacement. Generally, along with the active faults, in the hanging wall the limb of the reverse fault, fault scarps are created (Unije – Susak – Dugi otok fault).

Within structural pattern contact, zones between regional structural unit, Adriaticum and Dinaricum and especially Adriaticum and Adriatic microplate, are particularly important. Contact zone of Adriaticum and Adriatic microplate is 12-35 km wide (Prelogović et al., 2003.a) and it is represented with Unije – Susak – Dugi otok fault (it extends from Kvarner to Kornati Islands) and Susak – Vis fault. Between these faults there are a series of parallel reverse faults of SW to NE vergence, creating borders of certain structures (Prelogović et al., 2003.a).

The area of contact between the Adriatic microplate and the Adriaticum is marked at first with very slightly inclined faulty and reverse-overthurst displacements, mainly between the rock complexes of different characteristics and normal fold. Faults do not reach the surface. Moving from the first faults, the following faults become more steeply inclined, resulting in the more pronounced vertical displacement of upthrown blocks and faults reaching the surface. In that proces they are intersecting Neogene and Quaternary layers. Along some of the structures there are reverse faults of opposing vergence (Prelogović et al., 2003.b). Within the Adriaticum there are faults representing borders of structural units. Those faults are reverse, bending in space and can be followed as independent zones until approximately 20 km of depth on seizmotectonic profiles (Prelogović et al., 2003.b).

Reverse fault Unije – Susak – Dugi otok can be singled out in the Zadar Islands region. It represents a border of a wider contact zone between Adriatic microplate and Adriaticum. The width of the zone is 1.5-3 km, with branches along Kornat Island – 5 km. In the fault hanging wall limb along the open sea side of Dugi otok island there is a significant presence of scarp.

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Inside and outside of the fault zone there are branches and the following faults. The fault plane is inclined at the angle of 28-86° (Prelogović et al., 2003.b).

Aside from this most important fault of the structural fabric, other active faults are also important for the position, relation and displacement of structures. Firstly, faults along the series of local reverse structures. On the surface they are mainly represented by wide zones with a series of parallel faults and also with numerous faults of different inclination. In the relief they are presented as scarp in the hanging wall blocks. Branch of Unije – Susak – Dugi otok fault and its continuation in Hvar fault are of special importance in the contact zone of the Adriatic microplate and Adriaticum. The faults merge at the depth of approximately 15 km. Between Primošten, Rogoznica and Trogir the faults are separated on the surface and underneath the surface they merge with Zadar – Tijesno – Vilaja – Kozjak fault zone (Prelogović et al., 2003.b).

Furthermore, particularly significant are faults bordering local compressive structures. They also form a zone, have branches and reflect in the relief; they are reverse and of opposite vergence. Structure of Zadar region is marked with faults with prevailing horizontal limb displacement. Usually they are reverse and most often dextral. At some places they create relatively wider zones. Local faults within the structures and secondary faults of Rhaetian type contribute to the displacements of the parts of the structures and their fragmentation (Prelogović et al., 2003.b).

Structure. In the Adriatic area, where Zadar islands are situated, the basic features of structural units are elongated reverse structures, in which main reverse faults have SSW vergence. Compression caused the extension of the structures resulting with the reverse faults of opposing vergence along the limbs of the faults. Such structures are obvious indicator of the increased tectonic activity in the region. Along with certain structures there are also upright, recumbent, or overturned (along with the larger fault zones) folds. They are inevitably faulted. Fold layers are mainly slightly inclined (20-30°), and in the fault zones the inclinations are bigger (Prelogović et al., 2003.b). In the Zadar region, the areas of concentration of compressive structures are in the hanging wall of Susak – Vis fault zone starting from Dugi otok and in the hanging wall of Unije – Susak – Dugi otok fault near Dugi otok. Concentration of seismic focuses also indicates compression.

Recent tectonic activity. Displacements of structures, i.e. displacements of fault limbs are very important for the understanding of recent tectonic activity. Displacements determined on the surface depend on initial regional tectonic movements, same as on the spatial arrangement of rock masses. Also, recent relation of stress and possible deformation of structural fabric should be taken into consideration. Compression occurs if the stress orientation is opposite to the direction of structural units and structural fabric. Due to the additional fragmentation of structures, deviations of stress orientation can be observed on the Islands of Ugljan, Pašman and Dugi otok (Prelogović et al., 2003.b). As the result of local stress orientation, the creation of compressive structures has been emphasized.

Movements of the Adriatic microplate play an important role in the recent structural relations. Namely, it is situated between the Apenines, Alpes, Dinarides and Helenides. Besides, it does not create an integral unit (Prelogović et al., 2003.b) but it has been fragmented under strong pressures. Northern Italy and Istrian peninsula form one part, South Adriatic the second one, and among them is the third one different from the others, according to its activity. That third part is located in the wider Zadar region, but according to the stress orientation, structure types and activity zones, it is joining the northern part of the microplate. Since Adriatic microplate area is narrowing, tectonic movements provoke folding of its surface parts and the creation of compressive structures. Rotation of microplate and displacements of the northern part towards NW have also been proven. Aforesaid processes caused relatively stronger compression of the area between Dugi otok and Vis Island. Due to the resistance of Dinarides, towards the Adriatic microplate displacements a wide contact zone of active faults with prevailing reverse displacements is created. On the depths >12 or 15 km the faults are almost horizontal or slightly inclined. As the result of folding caused by compression they are steeper towards the surface.

Neotectonic is also followed by seismic activity. According to KUK et al. (2000) seismotectonic active zones mainly concur with the intersection of faults on the surface. In Zadar region one seismotectonic zone relates to Velebit fault which is 55° inclined in the zone of 10 km. Hypocenters are at the depth of 13 km. The next zone relates to the Dugi otok and Zadar fault, with the inclination of 20-30°. The stronger earthquakes are located outside of these zones; hypocenters are at the depth of 30 km and are probably related with faults which come to the surface at the bottom of the central part of the Adriatic Sea.

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GEOMORPHOLOGICAL ANALYSIS OF THE RELIEF / *Geomorfološka analiza reljefa*

General morphologic features / *Opće morfološke značajke*

Dimensions and morphographic forms of relief are an essential indicator of the general morphological features of relief. Morphometric analyses are based on the selection of parameters showing quantitative and orographic features of relief.

Hypsometric analysis. To define the altitude relations and the forms of relief, a set of hypsometric map of the island has been made.

Ugljan island stretches in the Dinaric direction (NW-SE); this can be seen from the course of isolines (Fig 2). The highest peak of the researched area is Šćah (286 m) on Ugljan island; thus, the altitude above the sea level on the island is relatively low. The transition of the hypsometric levels indicates the difference between the decline of the NE coast and on the S. A mild sequencing of the isohypses from coasts towards the interior is featured in the N and NW parts of Ugljan island, while the southern coast of Ugljan is relatively steep.

The first level on the hypsometric map, the one in the coastal zones, varies in width. Most of the NW part of Ugljan Island's is not higher than 40 m, with an exception of belt up to 100 m. Only a narrow zone of the SW coast is up to 40 m. Altitudes from 40 to 60 meters above the sea level are mostly in accordance with the lower hypsometric level, except for the parts of the coast where the first level is wider. However, this level is the first one of the higher levels dividing the individual complexes of relief.

The level up to 100 m includes a wider zone than the one previously mentioned, facing the Zadar channel, which indicates a mild decline of terrain towards the sea, while on the opposite side of the island this altitude level is as narrow as the previous two.

The altitude level above 100 m defines a secondary ridge in the SE part of Ugljan Island, while the altitudes between 140 and 200 m are featured in the SW of Ugljan Island. On Ugljan Island altutides up to 200 m are featured in forms of peaks Straža (178 m), Kobiljak (177 m), Noršin (145 m), Fratar (183 m), Kobiljak (199 m), Straža (152 m) and Fratar (183 m). The altitude levels above 200 m (200-240 m, 240-300 m) are not very common and include very small areas. On Ugljan Island the highest peak Šćah (286 m) stands out, as well as the second highest Sv. Mihovil (250 m).

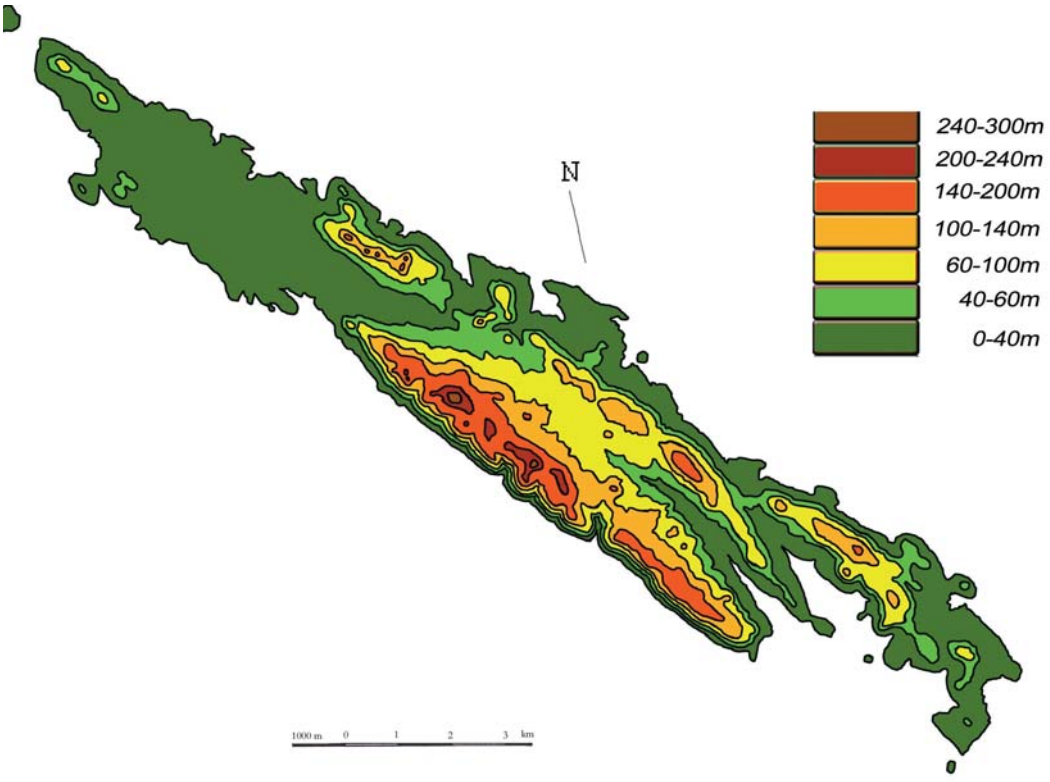

Figure 2. Hypsometric map of the island of Ugljan

Slika 2. Hipsometrijska karta otoka Ugljana

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The analysis of vertical relief dissection. The vertical dissection of the relief is defined by the difference in altitudes of the highest and the lowest point of an area. The term "energy of relief" is also often used and it includes the potential energy of the observed part of Earth's surface. The forms of relief are actually a bordering surface towards the atmosphere and the hydrosphere. Rock formation has its potential energy and, considering the fact that the relief is actually a surface of rock in space, the term "energy of relief" is appropriate. Mass and gravity per unit of area are always a constant in the analysis. Accordingly, energy of relief is defined as an altitude difference between the highest and the lowest point (Δh) within the observed area.

In local terms, the energy of relief is primarily conditioned by the lithological composition, the geologic structure and the intensity of exogenic processes impact. Detailed measurements and statistical analysis of the acquired data single out areas with the highest vertical dissection of relief, i.e. the most intensive denudation, as well as the areas with the lowest vertical dissection, where the dominant process is accumulation. This data is extremely useful in the geoecological valorization of relief, in the geomorphological engineering where it can be useful in defining the slope stability, in pedology where it can be used to determine the solvency of soil, etc.

In regional terms, strong denudation and accumulation appear due to the most recent tectonic movements. The analysis of vertical dissection of relief in a region or certain large area provides an overview of the neotectonical structure, intensity, as well as of the direction of the tectonical movements.

The categories of vertical dissection of relief used in the analysis are those from the geomorphological mapping of Yugoslavia instructions (Instructions for detailed geomorphological mapping of the Socialist Federative Republic of Yugoslavia, scale 1:100.000, 1985).

The category of plains appears in the NW of Ugljan Island which is to be expected since a plateau exists there. (Fig. 3) The largest part of the area belongs to the category of less dissected relief (30-100 m per square km). More prominent relief dissection is evident in the SW and the SE of Ugljan Island, which is a consequence of tectonical movements.

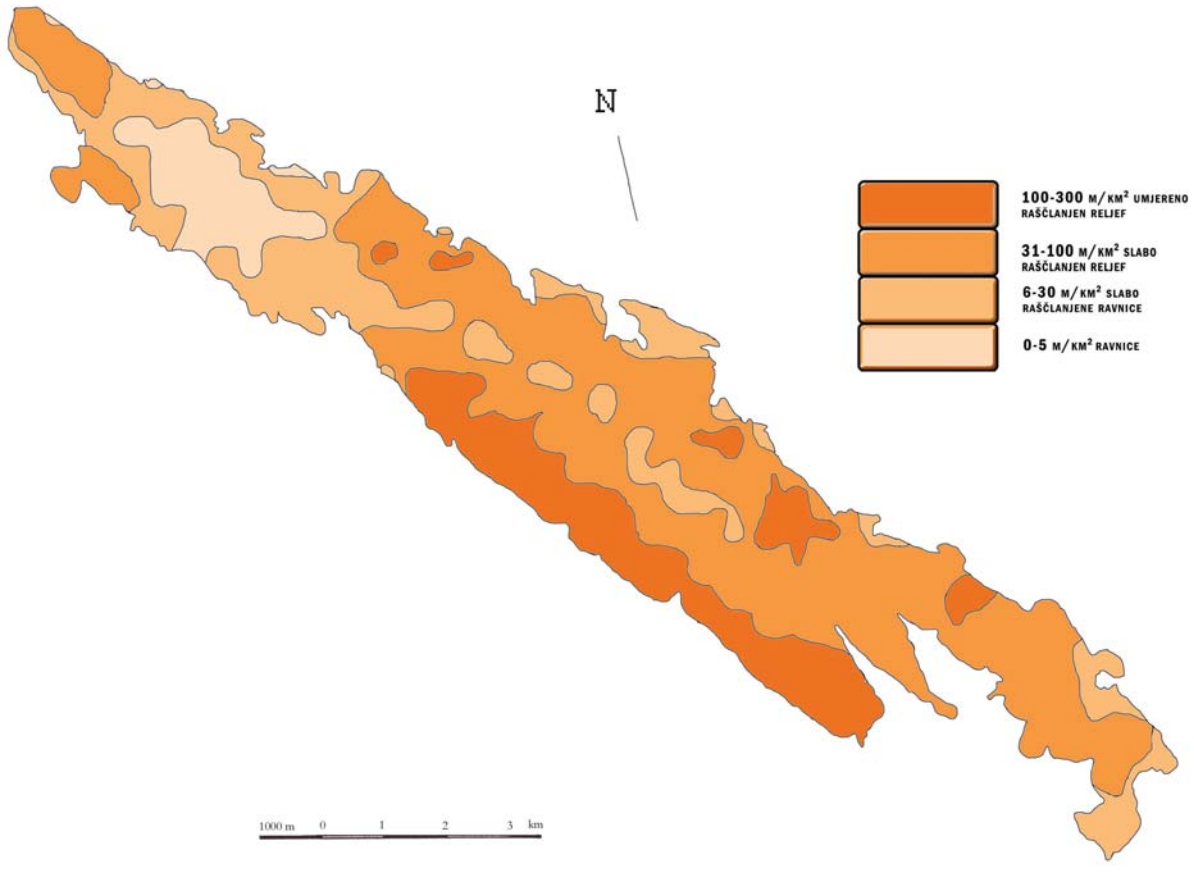

Figure 3. The map of the relative relief of the island of Ugljan

Slika 3.Karta vertikalne raščlanjenosti reljefa

ISSN 0469-6255 (161-175)

Slope inclination analysis. A vertical angle created by an intersection of a surface and a horizontal plain defines the slope inclination. Slope inclination analysis is extremely important in geomorphology and geoecology due to the fact that most of the Earth's surface is uneven. Slope inclinations have different orders of magnitude related to their genesis. If a certain slope has a local character (several meters to one kilometer), the main factors of forming are the exogenic geomorphological processes, while in regional terms (10 to 1,000 kilometers) an inclination is a consequence of endogenous (tectonical) movements.

The slope inclinations are the most dominant factor in activating certain morphological processes in the borders of critical inclinations. Thus, six categories of slope inclinations can be distinguished (Instructions for detailed geomorphological mapping of the Socialist Federative Republic of Yugoslavia, scale 1:100,000, 1985).

Due to the asymmetrical profile island of Ugljan, mild inclinations are featured on the slopes of the SE, while the steeper inclinations are of the SW front of the island. This is also in accordance with the geological structure. Scarps (32-55°) are a feature of reverse faults or steep layers of overturned folds (Fig.4). The steeps on the Ugljan Island are primarily related to the faults, such as the SW slope front of the island of Ugljan , between the Jablanički cape and the cove Prtljug, where the SW anticline limb is steeper than the NE one.

The mildest slope inclinations are primarily related to the bottoms of karst valleys or to synclines – depressions. They are featured in the outermost NW part of the island of Ugljan within the Ugljan karst plateau, as well as in the central valley on the island of Ugljan and the glacis areas around Kali and Sutomišćica (0-2°).

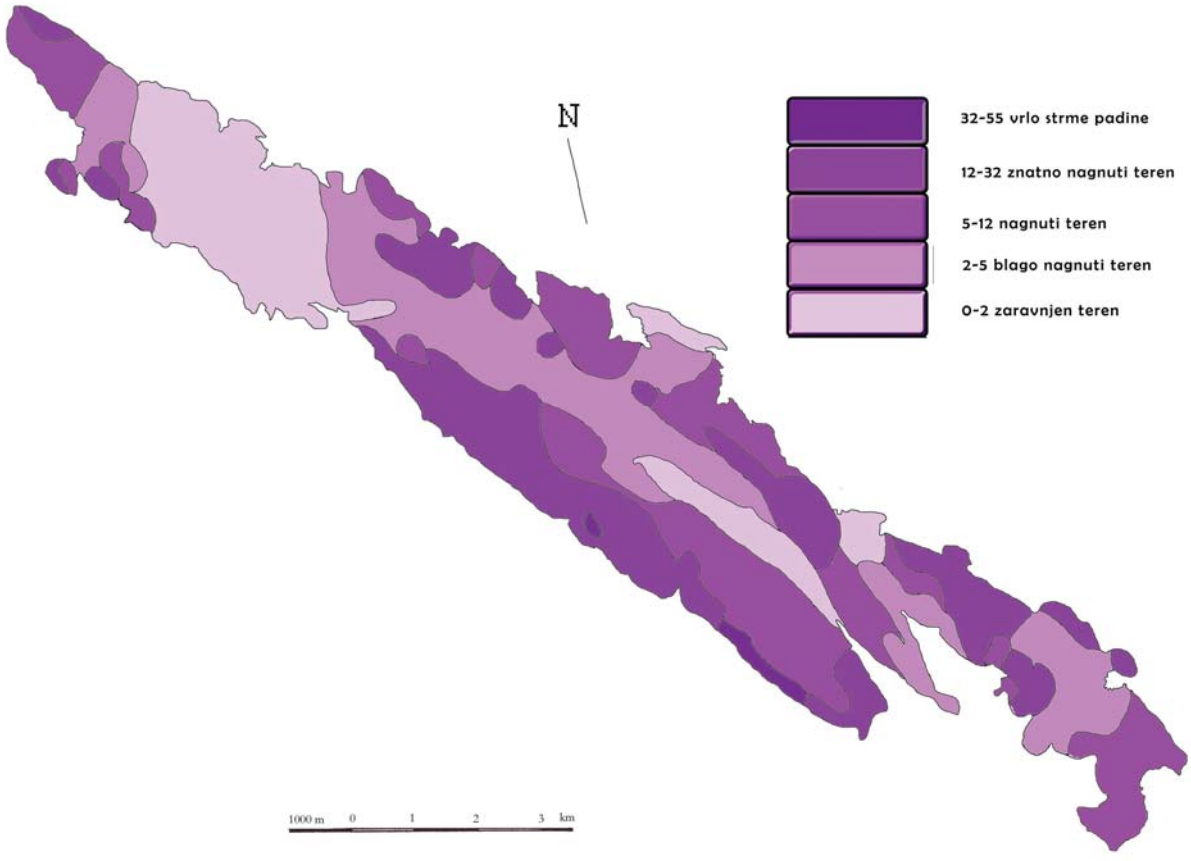

Figure 4. A map of slope inclinations on the island of Ugljan

Slika 4. Karta nagiba padina otoka Ugljana

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Orographic structure / *Orografska struktura*

According to the form, altitude, vertical articulation and inclinations, the island of Ugljan represents an asymmetrical ridge. Orographically, the island extends in the Dinaric direction (NW-SE).

Considering the orographic features, the following types of relief can be distinguished on the island of Ugljan: low asymmetric ridge hills, block hills, depressions or dry valleys, plateaus, coasts, steeps, submerged depressions – synclines, submerged depressions – subsidence, strait – submerged extended depressions.

Ridge hills. Orographically, Ugljan represents relatively low ridge hill (featured asymmetric elevations with steeps or slopes with bigger inclinations by the fault and the more leaning opposite wing or slope) extending in Dinaric direction. Generally speaking, the asymmetry of the island relief structures is prominent, as well as featured with the steep SW (mostly 12-32°, >32°) and leaning NE (2-5°, 5-12°) slopes.

The line of ridge connects a sequence of peaks separated by saddle. Hill elevation of Ugljan is a continuation of the ridge line of Rivanj Island, featured with peaks Lokočina (110 m), Sv. Jelena (98 m) and Vela glava (82 m). Mountain asymmetric ridges of Ugljan Island follows the line of the main ridge featured with peaks Straža (178 m), Šćah (286 m) - the highest peak, Sv. Mihovil (250 m), Kobiljak (177 m), Fratar (183 m) and Kobiljak (199 m), separated by saddles. The continuation can be followed on the asymmetrical ridges of Pašman Island (Fig. 5). Most of the peaks on the Ugljan Island are rounded, with the exception of conic peaks of Sv. Mihovil and Veli vrh (on Ugljan). The highest hill elevations are linearly extended (NW-SE) and have an asymmetric transversal outline, with a steeper southwestern slope front (mostly 12-32° and >32°). Accordingly, the SE parts of the island are characterized by a relatively large vertical dissection with an average of 100-300 m/km² on Ugljan.

A specific activity of tectonic movements in the past has resulted in forming of small linear elevations – asymmetrical ridges, mostly parallel with the main ridges beam mountainous and hilly structures. They have been formed by fault tectonics (reverse faults). They are the most distinctive near the NE coastal front of Ugljan Island. Linear asymmetrical ridges is substantialy lower than the main ridge. The ridge of the lower hill is defined by the round peaks V. Vrh (76 m), Kuranj (150 m), Burnjača (143 m), Trpinje (80 m), Bučolić (139 m), Glavine (177 m), Straža (152 m), etc.

Secondary elevations also have an asymmetric transversal outline – they are steeper towards the SW (12-32°) and milder towards the NE (mostly 5-12°). The relief energy of the ridge is around 30-100 m/km².

Pediments (glacis – accumulation glacis) are mild slopes at the bottoms of ridge hills on the islands. Within the researched area, they are formed on the NE fronts of the island and mostly extend to the coast: on Ugljan Island from Kali to Lukoran. The mentioned pediment has an accumulative origin, meaning they are glacises. The inclination of mild slopes at the bottoms of the elevations are in the categories 0–2° and 2-5°, exceptionally above 5° (on Ugljan). Accordingly, vertical dissection of relief of the glacis is minimal (0–5 m/km² and 5–30m/km²).

Karst dry valleys. This expression usually refers to tectonically conditioned dry karst depressions of the former flows which were lost in the karst underground due to climate shifts or tectonic uplifting. Closed valleys are formed by the merging of several sink-holes along a fault line.

On the island of Ugljan there is one central valley which morphogenesis is predisposed by the reverse fault (NW-SE). It separates the main ridge on the island from the secondary lower asymmetrical ridges near the NE front of the island. Besides the tectonic conditions, the factors influencing the forming of relief in the past were fluvial erosion and corrosion, but today, it is gullying. Thus, it is not surprising that the valley's longitudinal profile is asymmetrical, determined by the forming of the two different parts of the valley – one, so called Draga, oriented towards the SE and the Lamjana cove, and the other with the northwestern orientation, towards the Prtljug cove and the Ugljan plateau.

The main elevations asymmetrical ridges are dissected with a number of gullies and dry karst linear depressions, which were creek valleys during the humid periods of the past. All those linear valley formations and gullies are shorter and with bigger inclination of bottoms on the SW side, while towards the NE they are longer and with milder bottom inclinations.

Plateau. In the area bordered by the coves Činta, Prtljug, Sušica and Muline in the far NW part of the island of Ugljan there is a karst plateau. Its altitude is under 30 meters, and its vertical dissection and slope inclinations are in the lowest categories (0–5 m/km² and 0-2°, respectively).

Coasts. In accordance with the geological structure and the tectonic development, as well as with the lithologic features and the prevailing morphogenic processes, the coasts on the NE fronts of island are mostly low and rocky. Low coasts, formed in the slope correlatives, are related to the contact of pediments with the sea level, and the coves which actually

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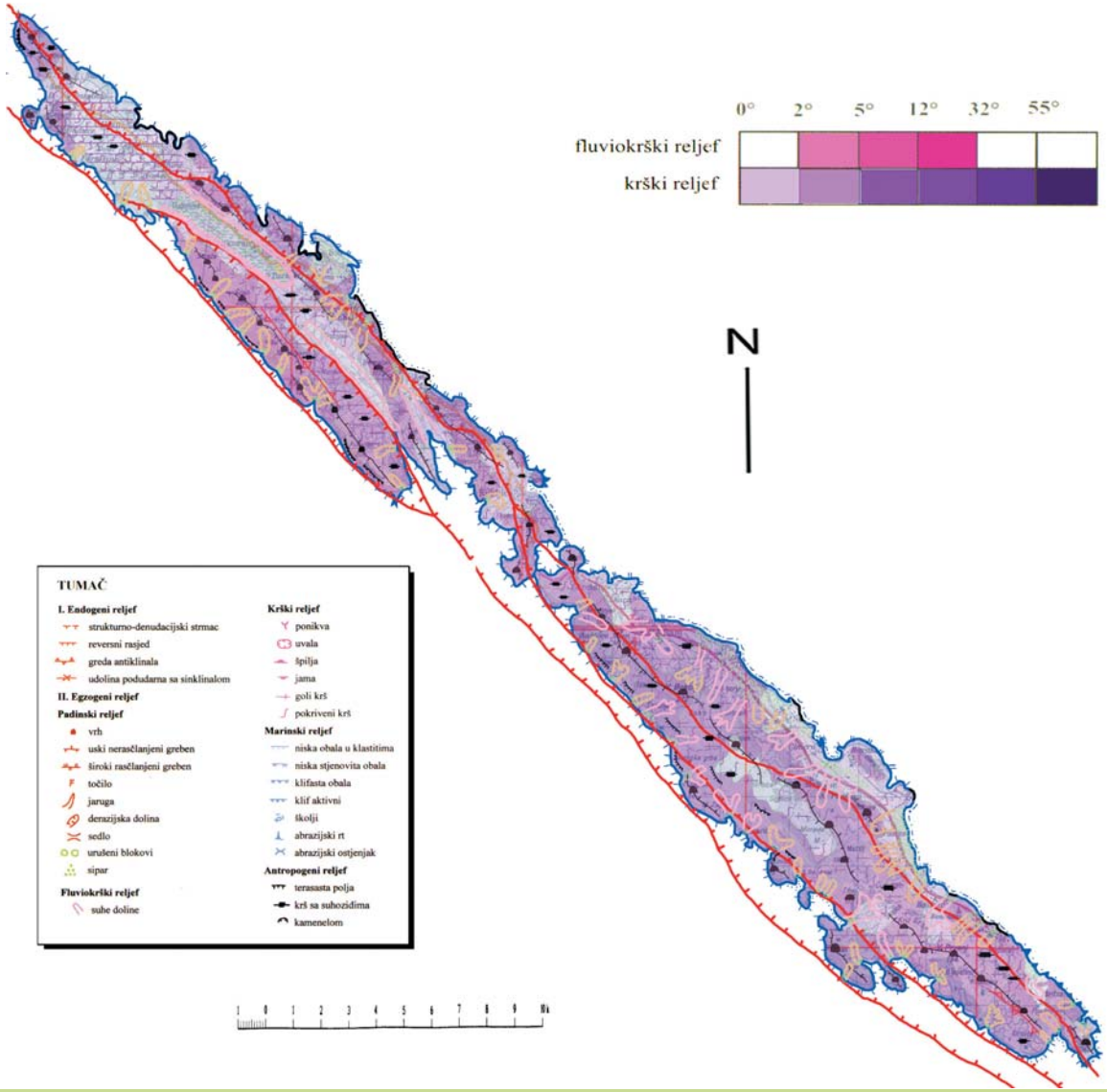

Figure 5. Geomorphological map of the Ugljan and Pašman Islands

Slika 5. Geomorfološka karta otoka Ugljana i Pašmana

represent the endings of karst depressions, gullies and submerged valleys. The erosional activity of waves shaped the torrent accumulations into low beaches. On the SW sides the coasts are high and divided into steep coasts (inclinations 32-55°) and cliffs (inclination >55°). The latter are actually structural and fault steeps.

Structural-geomorphological features / *Strukturno--geomorfološka obilježja*

Morphostructural analysis. This term usually implies a series of related methods with an aim to determine direct and indirect links between relief formations, geological structures and tectonic movements. It must be noted that morphostructures are the forms of relief which are formed due to a combined effect of exogenous and especially endogenous forces and processes. Thus, the purpose of morphostructural analysis is to differentiate those relief forms which were formed primarily due to tectonical processes and movements. In order to perform an efficient morphostructural analysis, a complex approach in research of such processes and movements is crucial. This can be achieved through application and comparation of results acquired by various methods of geomorphological analysis, as well as geological and geophysical researches. That approach provides a reliability in determination of morphostructes and morphostructural elements. All of the above-mentioned represents a general, theoretical and methodological basis of the morphostructural research of certain area (Bognar, pers. com.).

In the morphostructural analysis of the researched area, the applied geomorphological procedures and methods are used, which determine parts of relief formed primarily due to tectonic movements, lithological

ISSN 0469-6255 (161-175)

constitution influence and geological structure (analysis of the relation between relief and geological structure, analysis of the density of dolines).

Relation of relief and geological structure. The researched island has a denudational-tectonic morphostructure (Bognar, 1987., 1990.). Five basic types of morphostructures can be differentiated: asymmetrical ridges with imbricated structure, asymmetrical ridges – anticlines, hill elevations – tectonic blocks, valleys – synclines and depresions – subsidence.

Generally, the relief can be considered as conform, which means that the orographic structure mostly concurs with the geological structure.

Elongated elevations of the Dinaric direction, which were formed into a series of peaks and saddles, were uplifted in the neotectonic period due to fault movements (reverse, radial and horizontal) which were submerged afterwards. This particulary implies the submerging of saddles, while the peaks today appear as small islands (for example Žižanj, Galešnjak, Sit, Gangarol, Rutnjak, Karantunić, Golac, V. Školj, etc.). Taking the submerged slopes into account, those peaks are considerably higher. Hill elevation – anticline of Ugljan, fractioned into blocks by neotectonic movements, has an actual height of 340 – 360 m if the submerged parts of ridges down to 60-70 m of depth are taken into account. The NE seabed of the Zadar channel is very shallow, around 40 – 50 m. This is another fact that emphasizes the asymmetric outlines of island. Thus, they represent conform morphostructure, separated from the continent during the Late-pleistocene-Holocene period.

In broader geotectonical context, Ugljan is a SW part of the Ravni kotari synclinorium, with the submerged flysch valleys appearing as sea channels (Zadar channel, Pašman channel, etc.). The former structure, folded during Eocene-Oligocene epochs (Pirineic orogenous phase), was disturbed by a number of reverse faults, causing secondary folding. In the latest neotectonic period, the further reverse fault movements (all Norhern Dalmatian islands), retrograde movements of geological structures due to the change in stress direction (from SW-NE to generally S-N). It has been determined that the compression structures are bordered with reverse faults of the opposing vergence (the example of the Iž, Ugljan, Pašman and Molat Island). On the mentioned islands, the compression of terrain has caused the "pushing" of limestone from the flysch surroundings; accordingly, limestone rocks move reversely through the Paleogen (flysch) – Neogen strata. Bending of faults is also present, and very common in case of Zadar archipelago. In cases of faults of the bordering structural units, normal faults with the prevailing horizontal side element appears. The example for that is a horizontal strike-slip movement between the structure of Lošinj – Northern Dalmatian islands and the structure Cres – Olib – Rab – Pag – Ravni Kotari (Prelogović et al., 2003.a).

In terms of structural genesis, the researched island is characterized by a predominantly fold-imbricated structure, partially disturbed by recent movements and transversal faults. One of the consequences was a detachment of the islands of Rivanj and Sestrunj from Ugljan island, as well as a detachment of Ugljan from Pašman Island, representing a double fold which was fractioned by a right lateral slip movement in the far SE of Ugljan Island. Bathymetric maps of the researched area implying such connection. It can be assumed that these islands were initially folds which were later fractioned by faults. As these transversal faults intersect with older reverse faults, they are obviously a consequence of recent tectonic events. It is especially evident in the orography of the secondary ridge of Ugljan Island which is deformed along the right lateral fault (ENE – WSW), in the vicinity of the village Kali. The NW part of the secondary ridge, following the line Orjak (136 m) – Glavina (137 m) – Vrh (177 m), etc. is shifted in comparison to the far SE part of the ridge (Sv. Pelegrin (92 m), Straža (152 m), Vrh (123 m) etc.) by approximately 300-500 m (Prelogović et al., 2003.b).

Considering the hypsometric fact that the highest parts of the researched island are those by the SW fronts, as well as the morphography which implies the transversal asymmetry of the island's relief, it can be concluded that the intensity of rising during the recent tectonic phase was primarily related to younger reverse faults: along the central valley area of Ugljan Island, the reverse fault follows the SW front of Pašman Island. This also influenced the orientation and the intensity of the exogenous forming of relief, primarily fluvial erosion during the more humid stages of Pleistocene and Holocene, when the dry karst depressions were active, as well as gullying, which influenced the forming of series of proluvial fan on the NE fronts of both islands, which today form pediment-glacis between Tkon and Dobropoljana on Pašman Island and between Kali and Sutomišćica on Ugljan Island.

Most of the correlatives are connected to the parts of island's front which have the most elevated terrain in their background. It is a clear fact since it is known that the intensive denudation as well as the necessary accummulation of correlatives is related to the rising of the islands' highest parts.

The plateau in the vicinity of the settlement Ugljan represents a particular form of relief. The genesis of

ISSN 0469-6255 (161-175)

the plateau indirectly implies the influence of tectonic movements on the development of relief. Namely, tectonics (forming of scales and the appearance of smaller overthrusted structures along the reverse) have conditioned the appearance of a flattened structure, which also contributed to the processes of corrosion in the far NW on Ugljan Island.

Valleys density analysis. Research of valley density is commonly used in differentiating structural and morphostructural relations. The density of valleys is determined by an overall length of all types of valleys, regardless of their genesis; it evenly includes the valleys formed by active and periodical streams, dry valleys, karst valleys, derasion valleys and gullies (Mamut, 1999.).

The bottoms of valleys and the gullies on Ugljan are almost typically longer, with milder inclination and higher density on the NE parts of islands, while on the SW parts they are shorter and steeper. The prevailing direction of valleys on island is NW-SE. They are mostly derasional valleys and gullies, and in lesser extent dry valleys.

The development of valleys was influenced by the geological structure; thus, linear valleys over 500 m long were developed near the faults (coves G. Lamljana and D. Lamljana on Ugljan Island).

Morphostructure classification. The classification of structurally geomorphological relief units has been based on the results of the morphostructural analysis derived from the analysis of the relations between relief and geological structure of terrain and tectonic movements. The classification is binary.

The geotectonic evolution which started in Cretaceous, as well as the neotectonics and the glacio-eustatic changes in sea level, divided the researched area of the Ugljan and Pašman archipelago into smaller structurally geomorphological units. Using the analysis of the morphostructural data, topographic maps and the elements obtained via geomorphological mapping, three types of morphostructural units can be distinguished – positive, negative and neutral.

Positive morphostructures on researched island are mostly represented by the main and secondary linear hilly elevations, as well as block structures of smaller islands and, less commonly, peninsulas. Those smaller block structures, which can most commonly be identified as islands and islets, were formed primarily as a result of faulting along the transversal faults which have fractioned the parts of hill elevations anticlines (V. Školj, Golac, Bisaga, Karantunić in the vicinity of Ugljan Island;) or the asymmetrical block elevations – scales (Jidula, Galovac, Ošljak i Mišnjak near Ugljan). On Ugljan island, the anticline ridge is a scale of the SW part of the island, as well as the scale of the secondary ridge on the island.

Glacis, as parts of hill, represent positive morphostructures elevation foots. They were formed by reverse faulting which caused the fragmentation of rock mass by the fault, as well as by the processes of denudation and the parallel backwards movements of the slopes. There is one negative morphostructure on Ugljan island: a valley – depression in the central part of the island.

The Ugljan plateau represents a neutral morphostructure with a genesis related to the allochtonous tectonics due to the neotectonic stage of development and the processes of corrosion in the researched area.

CONCLUSION / *Zaključak*

The island of Ugljan belongs to the sub-geomorphological region of the Zadar archipelago within the Northern Dalmatian macro-geomorphological relief unit.

From the lithological point of view, this area is marked with a shift of deposits varying from Mesozoic to Cenozoic (Cretaceous – Holocene), and structurally it is a part of the SW Ravni Kotari synclinorium with submerged flysch valleys which today appear as channels (Zadar channel, Middle channel).

Based on the results obtained through the analysis of general morphological features, the following orographic units were distinguished: low asymmetric mountain beams, hill blocks, valleys or dry valleys, plateaus, coast, steeps, submerged depressions – synclines, submerged depressions – originated by subsidence, gate – submerged linear depresion. Morphostructural analysis has determined the relations of relief and geological structure; also, the analysis of valleys density was used to classify the structurally-geomorphological elements. Positive morphostructures are mostly represented by main and secondary elevations and block structures of smaller islands or, less commonly, peninsulas. Neutral morphostructure is the Ugljan plateau – thrust.

Contemporary relief formation on the Ugljan Island is related with the exogenous processes, especially slope processes (weathering and gullying). Besides the recent slope processes, those which were ocurring during periods of cold climate were also very significant (pedimentation processes).

The dominance of carbonate rocks and their microtectonic fragmentation enabled extremely strong processes of karstification which have conditioned the

ISSN 0469-6255 (161-175)

forming of the exokarst (bare and covered karst), endokarst (caves) and fluviokarst (dry valleys) relief formations. The Late-Pleistocene-Holocene sea ingression, which occurred approximately 20.000 years ago, was the main factor in forming the coast of the researched island. Morphogenetically, it can be divided into rocky (prevailing), accumulative and anthropogenic type.

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