UNIVERSITY OF NOVA GORICA
GRADUATE SCHOOL

UVALA
– CONTRIBUTION TO THE STUDY OF KARST DEPRESSIONS (WITH SELECTED EXAMPLES FROM DINARIDES AND CARPATHO-BALKANIDES)

DISSERTATION

Jelena Ćalić

Mentors: dr Andrej Kranjc
dr Andrzej Tyc

Nova Gorica, 2009

UNIVERZA V NOVI GORICI
FAKULTETA ZA PODIPLOMSKI ŠTUDIJ

UVALA – PRISPEVEK K ŠTUDIJI KRAŠKIH GLOBELI (Z IZBRANIMI PRIMERI IZ DINARIDOV IN KARPATO-BALKANIDOV)

DOKTORSKA DISERTACIJA

Jelena Ćalić

Mentorja: dr Andrej Kranjc
dr Andrzej Tyc

Nova Gorica, 2009.

Hereby I declare this thesis is entirely my author work.

Izjavljam, da je doktorsko delo v celoti moje avtorsko delo.

Acknowledgements

Let me start this list of acknowledgements with my sincere gratitude and respect to all the people who have established the post-graduate program of karstology at the University of Nova Gorica. This excellent idea and successful realization have been a significant step in further improvement of the position of karstology in the system of geo-sciences.

My PhD studies would not have been possible without the scholarship that I was receiving from the Slovene human resources development and scholarship fund (Ad Futura). I am very grateful to the kind people from the Ad Futura team, and to the Government of the Republic of Slovenia for establishing such a fund. Part of the scholarship was covered by the Slovene Ministry of higher education, science and technology.

I am very grateful to my supervisors, Dr. Andrej Kranjc and Dr. Andrzej Tyc, who have supported and encouraged me from the very beginning of this research. Their suggestions and comments have been of immense help for me.

It has been more than a decade since I first met the great people from the Karst Research Institute in Postojna. Their energy and team work have been an inspiration to me ever since. I am using this opportunity to thank all of them for the past and future field trips, discussions, literature, and above all their kindness.

To my dear colleagues and co-workers at the Geographical Institute "Jovan Cvijić" of the Serbian Academy of Sciences and Arts in Belgrade, thank you all for your support and understanding during the finalization of this thesis. Special thanks to Dragoljub Štrbac, for transferring to me a part of his huge knowledge on geographical information systems.

I sincerely thank Dr. Ugo Sauro and Dr. Francesco Ferrarese for hosting me at the University of Padova, and for showing me the methods and results of their research of dolines.

I am very grateful to Dr. Jože Čar for his valuable instructions regarding the structural-geological mapping and for the company in fieldwork in the uvalas of Trnovski Gozd.

To my caving friends from the Speleological Section "Velebit" from Zagreb, especially to Ana and Darko Bakšić, Petra Bajo, and Andrej Stroj, thank you for your company in the field and for interesting, wide-ranging karstological discussions.
My sincere thanks to Dr. Sanja Faivre and Dr. Neven Bočić from the Geographical Department of the Faculty of Science and Mathematics, University of Zagreb, for providing me the literature related to the Croatian part of the Dinaric karst.

For a number of valuable favours during my studies in Slovenia, I sincerely thank to Staša Mesec, Miha Staut, and the family Rapaić from Ljubljana.
I thank Ms. Nataša Pregl for translating the Summary to Slovene language.

And finally, very special thanks to my very special family – Predrag and Tomislav, together with my parents Gordana and Petar, who have all been so supportive and full of understanding regarding my work and my frequent absences.

Uvala – contribution to the study of karst depressions, with selected examples from Dinarides and Carpatho-Balkanides

Abstract:

Uvalas are a particular type of karst closed depressions. While other types of closed depressions – dolines and poljes – are regularly listed and relatively well defined in overviews of karst surface morphology, the uvalas are either excluded or their vague identification is stressed. The leading idea of the thesis is to start a systematic study of uvalas, in order to obtain the clear meaning of the term uvala and prevent its abandoning in karstology and general geomorphology. Within the study, 43 examples of uvalas have been selected. The studied uvalas are located in the Dinaric karst and karst of the Carpatho-Balkanides. All the case examples have been digitally processed in the same way. Creation of high-resolution digital elevation models enabled quantification of morphometrical parameters, generation of inclination maps and cross-sections, as well as application of descriptive, exploratory and inferential statistical analyses. Formation of the geographical information system of the studied uvalas was done using raster-based and vector-based GIS software packages. In 12 studied uvalas, detailed structural-geological mapping has been carried out, which revealed dominant development of uvalas along tectonically broken zones of regional scale. Several delicate issues related to the position of uvalas in the system of karst closed depressions are discussed: terminological problems, genetic issues, relation to other geomorphological processes (fluvial and glacial), as well as some directions for future research. A revised definition of the term uvala is suggested, leaving the opportunity for further discussions and upgrades.

Key words:

karst surface morphology, karst depression, uvala, geographic information system, Dinarides, Carpatho-Balkanides

Uvala – prispevek k študiji kraških globeli

z izbranimi primeri iz Dinaridov in Karpato-Balkanidov

Izvleček:

Uvale so značilna vrsta zaprtih kraških globeli. Medtem ko se druge vrste zaprtih globeli – vrtače in polje – redno pojavljajo v pregledih kraške površinske morfologije in so tudi precej dobro opredeljene, so uvale potisnjene ob rob ali pa je poudarjeno, kako težko jih je natančno opredeliti. Glavni namen disertacije je začeti s sistematsko raziskavo uval, da bi pridobili jasen pomen izraza uvala in preprečili njegovo popolno izginotje iz krasoslovja in splošne geomorfologije. V okviru študije smo izbrali 43 primerov uval. Te uvale se nahajajo na Dinarskem krasu in na krasu Karpato-Balkanidov. Vsi vzorčni primeri so bili digitalno obdelani na enak način. Oblikovali smo digitalne modele reliefa z visoko ločljivostjo, s čimer smo omogočili količinsko opredelitev morfoloških parametrov, pripravo kart naklonov in presekov ter uporabo opisnih, raziskovalnih in inferencialnih statističnih analiz. Z uporabo rastrskih in vektorskih programskih paketov GIS smo vzpostavili geografski informacijski sistem uval, vključenih v raziskavo. Dvanajst izbranih uval smo podrobno strukturno-geološko kartirali, pri čemer smo ugotovili, da so uvale nastajale zlasti vzdolž tektonsko porušenih con na regionalni ravni. Obravnavali smo več občutljivih vprašanj, povezanih s položajem uval v sistemu zaprtih kraških globeli: terminološke probleme, genetske probleme, povezavo z drugimi geomorfološkimi procesi (fluvialnimi in glacialnimi) ter nekatere smernice za nadaljnje raziskave. Predlagali smo spremenjeno definicijo termina uvala, pri čemer dopuščamo možnost nadaljnjih razprav in nadgradnje.

Ključne besede:

kraška površinska morfologija, kraška globel, uvala, geografski informacijski sistem, Dinaridi, Karpato-Balkanidi

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. Introduction

Closed depressions are generally considered the most characteristic feature of karst surface morphology. In a great number of references, especially in south-eastern Europe, three forms are usually listed in classifications of karst surface depressions: doline, uvala, and polje. On the other hand, in western European and north American literature, uvala is often either excluded from such classifications, or it is given a marginal importance.

Dolines are mostly regarded as "diagnostic" karst landforms. Most of the usual definitions say that dolines are depressions "circular to subcircular in plan form, and vary in diameter from a few meters to about one kilometer" (Ford & Williams, 1989). On the other hand, the definitions of polje are usually more complex, but most authors agree that poljes are closed large depressions in karst, with flat bottom covered with unconsolidated sediments, and situated very close to the local water table.

The definitions of uvalas, however, differ to a considerable extent. In most references, uvalas are defined as karst depressions which are formed due to coalescence of several dolines. Occasionally, the genetic factor is not included at all, and uvalas are mentioned only as forms whose size is "in between" those of dolines and poljes. Sometimes the authors quote Jovan Cvijić, who introduced this term into the karstological literature (first in 1893, and more precisely in 1899), but unfortunately with erroneous theory on genesis – that the uvalas are transitional evolutional elements between dolines and poljes. This mistake had a critical impact on the subsequent usage of the term uvala: as the cyclic theory on karst evolution (that dolines evolve into uvalas, and uvalas into poljes) was abandoned, uvalas were gradually losing the status of an established form of karst surface relief. This is maybe best illustrated in the explanation of uvala in the Glossary of a well known karstological internet portal *speleogenesis.info*: "The term was introduced to describe features assumed to be the second step in a 3-stage process of polje development, in which dolines were supposed to coalesce into uvalas. This mechanism is no longer accepted and the term uvala has fallen into disuse." (definition taken from Lowe & Waltham (1995)).

The starting idea of this work is that there are substantial reasons for re-introducing of uvalas into modern karstology. This requires thorough geomorphological analysis which would help in correction of previous erroneous views and hopefully lead towards re-definition of the term uvala.

The general objective of this thesis is to turn the attention of karstological scientific community towards uvalas – a “forgotten” and often misinterpreted form of karst surface relief.

The initial hypothesis is that there is a type of karst surface depression which is by size larger than a doline and usually smaller than a polje, but differs from these two forms also in morphology and combination of genetic factors, which gives it a status of a particular karst relief form. It is a widely accepted fact that all karst features are formed by combination of corrosion and mechanical erosion, as well as more or less prominent influence of lithological and structural elements. For various features, various elements are considered dominant – for example, tectonic movements are often considered a dominant factor in formation of poljes, while lithology is of great importance in the development of forms like karren and kamenitzas. One of the goals of the thesis is to estimate roles of those particular factors in formation of uvalas.

The objectives can be summed up in several points:

- to give a detailed overview of usage of the term uvala, from its introduction to nowadays; covering various attitudes (references that approve the term, as well as those who disapprove or ignore it)
- to pinpoint about 40 uvalas (the final number is 43) in the Dinaric and Carpatho-Balkan mountains, which present various types of this feature, in different lithological, structural and geomorphological conditions
- to carry out detailed structural-geological field mapping of some of the selected uvalas (12 examples), which has lead to valuable answers about the influence of tectonics in their formation
- to carry out morphometrical analyses of all the studied uvalas
- to create a Geographical Information System which has comprised all the significant data about the studied examples, and allowed easier statistical processing and comparison. Even more important function of the GIS is to serve as a basis for future research in this field.
- to suggest a classification of the studied uvalas and to offer a revised definition aimed at re-establishing of the uvalas in the system of karst closed depressions.

It was very important to establish a precise and consistent database, not only for the research within this thesis, but, even more important, for the future studies of this subject which are yet to come and are expected to be much more extensive and detailed. We opted for precise georeferring of cartographic input in order to obtain the most accurate positioning of the study areas. All the examples have been methodologically processed exactly in the same way, to make the comparisons fully reliable.

Due to the previous poor coverage of uvalas and uvala-like features in karstological literature, it was impossible to encompass in this work all the segments necessary for their detailed study, i.e. to apply all the methods which are usually used for the study of other kinds of karst depressions.

Particular attention has been paid to the development of fundamental background and standardization of initial methodological procedures which will in future be upgraded with more detailed research techniques from various disciplines of geo-sciences. In some way, it can be said that considerable part of the work is related to *organization* of the research, in comparison to the detailed research itself, and that, subsequently, due to limited extent of the thesis, some aspects of the issue had to remain open for future studies. Particular section (8.10) is dedicated to the ideas for further research on this matter.

Instead of the intention of giving the final solutions and answers, it would be more appropriate and more realistic to say that this is the introductory research into the problem of karstic uvalas.

2. Overview of definitions and classifications of dolines and poljes

Regarding the fact that dolines and poljes are generally recognized forms of karst surface relief, and uvalas are usually mentioned "in between" the two, it is necessary to outline the basic scientific opinions on these "boundary elements". The references in this overview are listed in approximately chronological order.

2.1. Dolines

In great majority of references, doline is regarded as a surface relief form which determines karstic relief – a "diagnostic" karst form. Dolines are circular to sub-circular depressions of karstic origin, whose diameters are in most cases several tens of meters, but can reach even several hundreds of meters.

First occurrences of this term in literature date back to middle 19th century (elaborated by Gams 1973), when Austrian authors accepted the word "dolina" from Slovenian language. This word has much wider meaning in many Slavic languages, denoting any low-lying part of relief (mostly a fluvial valley), but the inhabitants of the Kras region use it for medium-sized karst depressions, because such depressions are the only low-lying relief forms in the area (fluvial valleys are completely missing). For this reason, the Slavic word "doline", although used in most part of the world for this form of karst relief, is not used in Slavic languages scientific terminologies (e.g. the word "vrtača" is used in Slovenian and Serbian, "ponikva" in Croatian, "lejek" (or "lej krasowy") in Polish, "závrt" in Czech, etc.).

Cvijić (1893, 1895) gave the first scientific elaboration of dolines in his capital work "Das Karstphänomen". Although many overview references (e.g. Sweeting 1972, Ford & Williams 1989, 2007; and many others) stress Cvijić's morphographic classifications of dolines (bowl-shaped, funnel-shaped and well-shaped), it must be said that this is only his sub-classification of "normal", solutional dolines. The initial Cvijić's classification, which is somehow "hidden" because of unsystematic organization of the chapters, distinguishes: (1) "normal" dolines (equivalent to the present term "solution dolines"); (2) abysses; (3) alluvial dolines. Abysses are steep-sided dolines which continue downwards into caves. Although this doline type is not present in contemporary classifications, it is worth to stress Cvijić's awareness of the link between dolines and vertical shafts, which is recently again in the focus of attention (Šušteršič, 1994; White, 1988; Sauro, 2003). The greatest Cvijić's mistake in classification of dolines is his negative attitude towards collapse as a doline morphogenetic process.

One of the most detailed systematical overviews of dolines ever, but especially for the time of middle 20th century, is the work of Cramer (1941). He reviewed virtually all up-to-date published references on dolines and extensive terminology of karst surface forms in several languages, i.e. regions – German, "Dinaric" (covering south-Slavic languages), French, Italian, and selected terms from other languages (native expressions from central America, Morocco, Greece, Hungary, etc.). Cramer distinguished five types of dolines: collapse, solution, suffosion, alluvial and "schwund" dolines (seemingly a sub-type of suffosion dolines). Collapse and solution dolines occur on bare karst, while other types are developed in covered karst.

Jennings (1985) allows that dolines can reach "several hundreds of metres in horizontal dimensions" and states that "Increasing size is usually accompanied by complexity of form, which takes them into other categories of closed depressions". In the classification, he differentiates the following types: solution doline, collapse doline, subsidence doline, subjacent karst doline (in formations overlying karst rocks), and alluvial streamsink doline.

Ford & Williams (1989; 2007) stress that it is true that the dolines are the indicators of karst, but also that their absence on carbonate rocks does not mean that karst is not developed. In the first edition of their book (Ford & Williams, 1989), four types of dolines are distinguished (solution, collapse, subsidence, suffosion), while in the second edition (2007), there are six types: solution, collapse, dropout, buried, caprock, and suffosion. Solution dolines may be formed by two types of initiation: (1) point recharge and (2) drawdown. Point recharge development involves the development of proto-conduits in previously covered limestone, and initiation of dolines when proto-caves reach a breakthrough stage (towards a spring or other conduit) and become points of surface waters recharge. Drawdown dolines are formed in limestone without caprock, with already developed vadose conduit network, so the recharge of atmospheric waters is diffuse, depending on soil cover (Ford & Williams, 2007; Fig. 2.1. by Sauro, 2003).

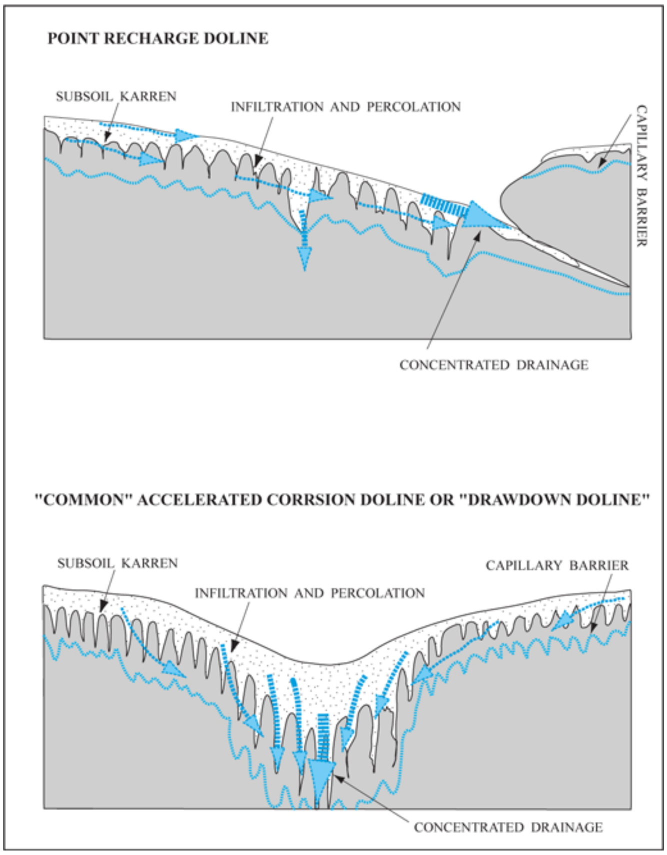

Fig. 2.1: Two types of solution dolines (defined by Ford & Williams 1989 and 2007; Figure by Sauro, 2003)

Sauro (2003) introduced an additional genetic type of solution dolines – inception dolines (apart from point recharge and drawdown dolines, defined previously by Ford & Williams, 1989). Inception dolines evolve in the conditions where a hanging karst aquifer exists over an impermeable rock layer. If there is an outlet in an impermeable layer, or a pre-existing void in the underlying karstic rock, the hanging aquifer focuses its drainage toward that point, which is a triggering factor for doline development (Fig. 2.2).

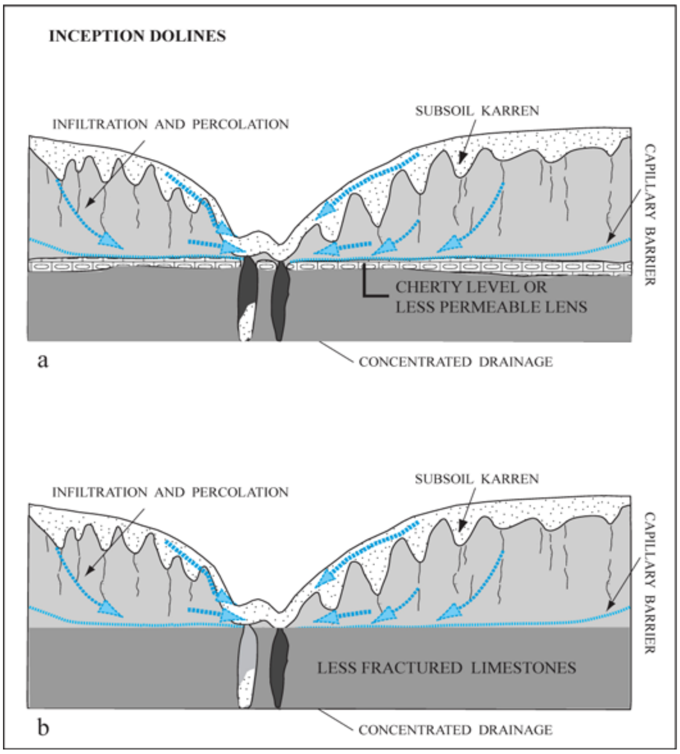

Fig. 2.2: Inception dolines – new sub-type of solution dolines, besides point recharge and drawdown dolines (Sauro, 2003).

Close connection between dolines and pre-existing underground conduits was focused also by Šušteršič (1994). He stressed the role of vertical shafts (domepits) in the development of dolines, supporting the idea that dolines are "reproductions of the underground karst voids on the surface", or more precisely, features that develop when underlying caverns (domepits) intersect with the surface which is being lowered by karst denudation.

Several intricate questions regarding dolines are discussed by Sauro (1995); for example, general lack of very small dolines (less than 10-15 m diameter) in limestone areas is explained by the stage of "cryptodoline", which in fact exists in rock, but is still filled with debris and sediments. Chains of dolines along dry valleys and structural and stratigraphical contacts are discussed as well. The author also explains the examples of forms of mixed origin (e.g. glacio-karstic) and polyphase development (Sauro, 1995). Extensive and systematic overview of all karst surface depressions, particularly dolines, was given by the same author within the Encyclopedia of caves (Sauro, 2004; in Culver & White, 2004). Classifications by different criteria is given (according to shape, geomorphological / topographical settings, hydrological behavior, and, of course, genetic processes), as well as overview of other geomorphological processes (apart from karstic) that can take part in doline evolution: weathering (including frost shattering and soil forming), slope processes, overland flow, sediment trapping and evacuation.

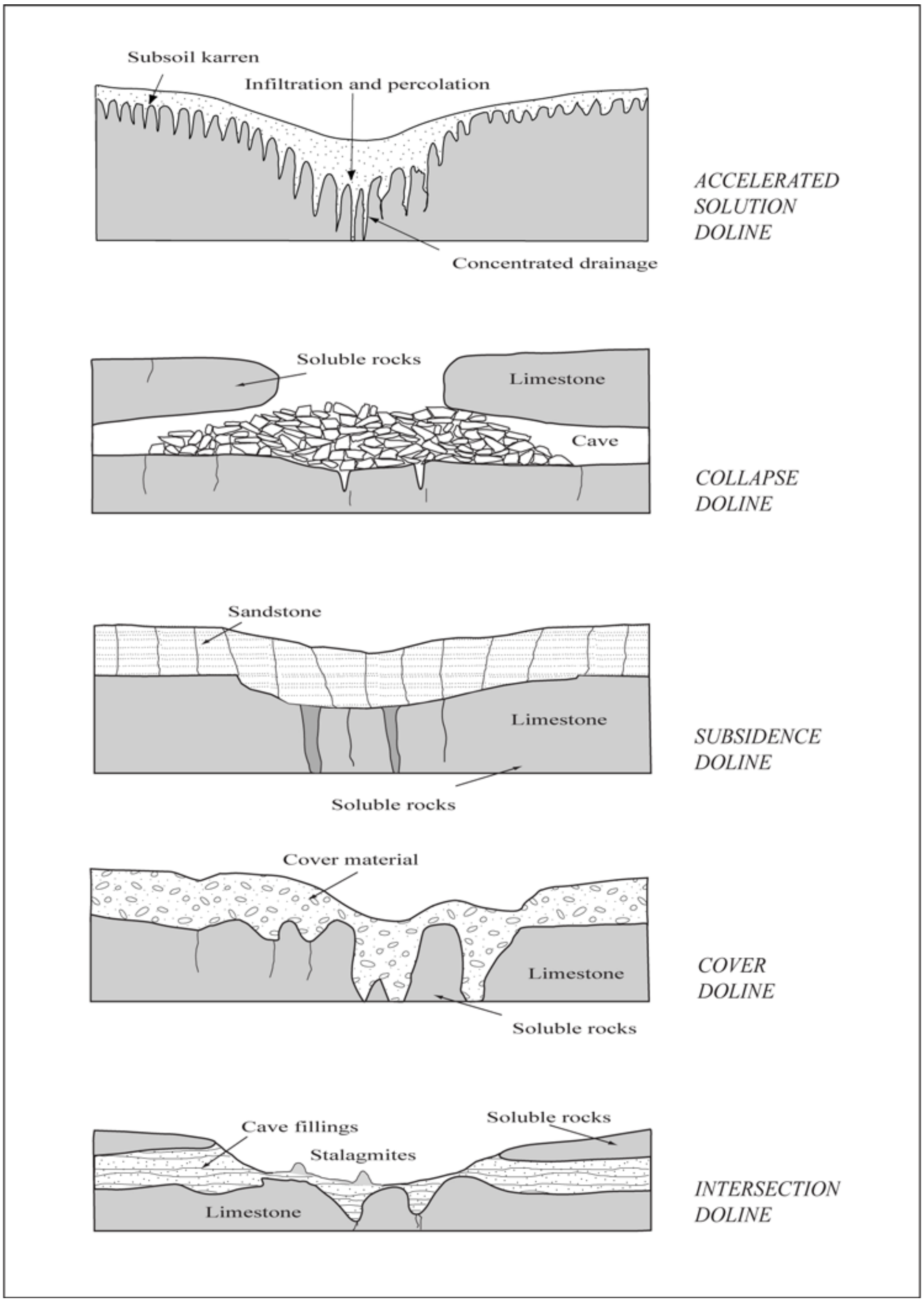

Fig. 2.3: The main categories of dolines (Sauro, 2003)

One of the milestone articles related to doline morphogenetic processes is that of Gams (2000). Without entering the issue of classifications, some other important and delicate questions are discussed – general limestone solution dynamics, doline slope development, global climatic restraints of the doline distribution, as well as the initial factors of doline development, especially the “local accelerated solution”.

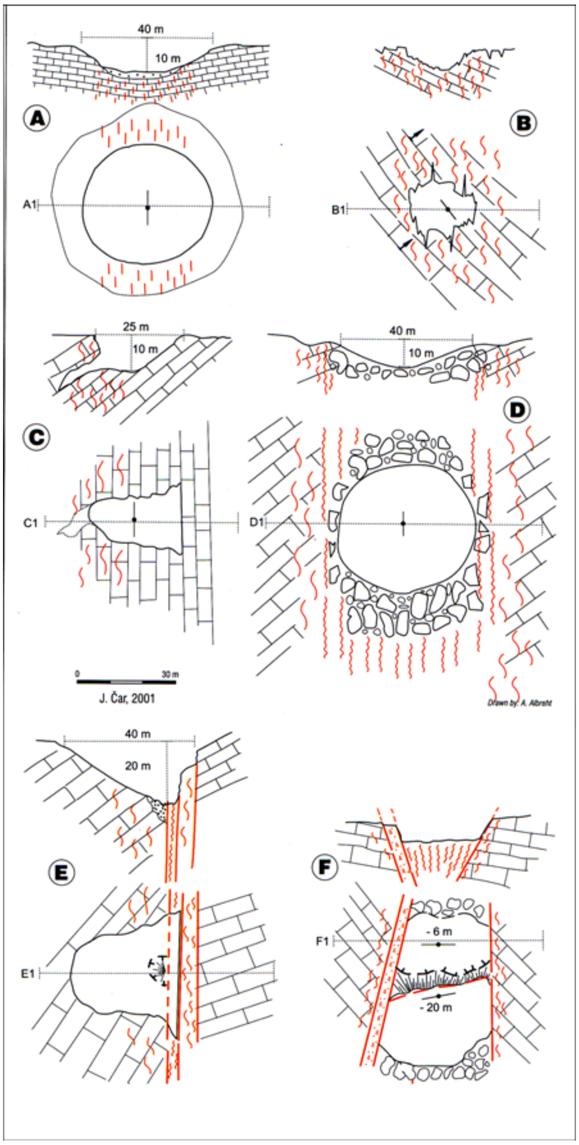

Fig. 2.4: Structural classification of dolines (Čar, 2001)
(A – stratification doline; B – Fissure doline; C – Bedded-fissure doline; D – Broken doline; E – Near-fault doline; F – Fault dolines)

Classification of dolines according to their position within the structural pattern is elaborated by Čar (2001), who differentiates six basic types: stratification dolines, fissure dolines, bedded-fissured dolines, broken dolines, near-fault dolines, and fault dolines; as well as two additional, more complex types: contact dolines and reproduced dolines. A particular type comprises broken collapse dolines, which are transitional features between classical collapse dolines (above horizontal cave

passages), and broken dolines (dolines in broken zones). Various positions regarding tectonically fractured zones (crushed, broken, fissured) result in specific forms and particular dynamics of development.
By application of precise field measurements and mathematical and statistical processing, Šušteršič (2006) determined that small-sized solution dolines demonstrate a regular shape, which can be approximated by a "paraboloid that hardly differs from a cone". Doline slopes consist of three zones – central zone (C), intermediate zone (S), and outer zone (Z). Intermediate segment is variable during the doline growth, while central and outer segments remain constant in size (inert).

2.2. Poljes

Although the Dinaric expression "polje" was occasionally used in literature since the second half of the 19th century (e.g. Mojsisovicz, 1880; cit. by Gams, 1978), it was Cvijić (1893, 1895) who made the first scientific introduction of the term. This first official definition states that the polje is "a great karstic depression, of vast flat bottom, with sharp angle between floor and slopes, and its longer axis is always clearly defined, parallel with bedding strike". Cvijić claims that the most typical poljes are situated in Bosnia and Herzegovina. Two main classifications are by the criteria of shape (elongated; circular; irregular) and hydrographical function (dry; seasonally flooded; lake poljes). In the same study, Cvijić explains the dimensional relation between dolines and poljes: "...there are transition forms between poljes and dolines. Smaller of these transitional forms, not exceeding 1 km in diameter, are called dolines, and bigger are called poljes" (Cvijić, 1893, 1895).
Penck (1900) also discussed that sometimes it is difficult to define whether some forms are big dolines or small poljes. He stressed that the sharp morphological line between floor and slopes of poljes (sharp angle) exists due to sediment infills of sand, clay, rarely gravel, that are brought to poljes by rivers. According to Penck, some large dolines on Mt.Orjen in Montenegro have functioned like poljes during the ice ages (they were hydrologically active). On the other hand, some large poljes, like Nevesinjsko polje in Herzegovina, are not flat, so numerous ponors divided it into several smaller depressions, which are again of similar dimensions as great dolines. As opposed to dolines, which are present almost everywhere on karsts, poljes are

more rare, they are not a "essential inventory" of karst, and are present only where parts of terrain have been uplifted or subsided (Penck, 1900).

Among the first authors who indicated that poljes are not essentially karstic form, but only the inliers of normal fluvial landscapes in karst terrains was Roglić (1955, 1974). He stressed the role of lateral (marginal) corrosion in the areas covered with impermeable sediments. These sediments suspend the normal karstic development, which is vertically oriented, and guide the corrosion into horizontal direction, to attack the margins of a polje. Roglić stresses the strength of the corrosional process, which is "very powerful and can be very fast", helped with the organic matter in stagnating water and biochemical processes.

Slovene karst terminology (edited by Gams, 1973) offers the following definition of a polje: "The largest karst depression with flat bottom and karstic outflow. In its typical form it has a sinking river and steep slopes".

Gams (1978), in one of the most cited papers on the issue of polje, gives a review of most relevant definitions of karst poljes in glossaries of karst terminology of that time. The most usual hydro-geomorphological and genetic elements from these definitions are: "large (largest) depression, flat bottom, steep slopes sharply rising from the bottom, karstic outflow, sinking river, inundations, selective erosion, tectonic control" According to Gams, the flat bottom (either of limestone or covered by alluvium, or formed in impermeable sediments) is the only indisputable element in the definitions. The main processes in poljes are (1) selective erosion (denudation of impermeable sediments); (2) marginal (lateral) corrosion if bottom sediments are impermeable; (3) subsoil corrosion and/or suballuvial corrosion (depending on the type of bottom deposits).

The expression "large" depression is often questionable. Gams (op.cit.) indicates that "Size of a "large depression" or "largest depression" is a subjective matter and depends on the country and also on the author". He advises that a definition of polje "has to be precise, so that without knowing the size of foreign poljes or the size of karst depressions in known karst areas, a person can recognize the form as a polje and distinguish it from uvala, blind valley and karst valley".

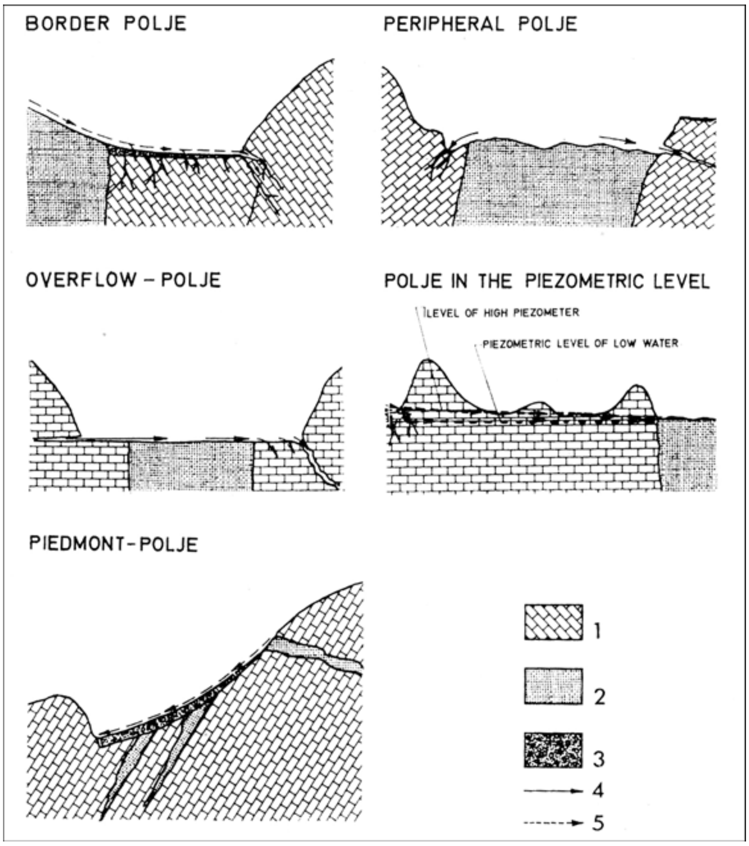

Fig. 2.5: Types of poljes suggested by Gams (1978)

Gams finally lists the minimal characteristics required for the status of a polje: (1) flat floor, either in rock (which can also be terraced), or in unconsolidated sediments, or alluviated, or covered by fluvisoils; (2) closed basin, with a steeply rising marginal slope at least on one side; (3) karstic drainage; (4) if all the mentioned characteristics are present, the flat floor must be at least 400 m wide. Considering the importance of the flat floor in all the definitions, Gams also points to some problems which may arise – "Especially questionable is the separation of a great basin into a polje and uvala when the flat floor is not continuous.", or "(…) we cannot be precise about the proportion of the floor which needs to be flat if we call the form a polje".

Waltham (1981) made a very interesting case study of Matienzo depression in Spain, which has all the basic characteristics of a polje, but the author is cautious in usage of this term, due to some characteristics which are different from the Dinaric poljes ("The flat, flood-prone, cave-drained floor of the Secada part of the Matienzo depression suggests that it could be called a polje. However the valley lacks the sharply defined slope edges typical of the classical Yugoslavian poljes, and there is no guiding element in the structural geology, so the term can only be applied loosely.”).

Silvestru (1995) gave one of the overviews of previous polje definitions, favouring some simple, clear ones like “inliers of fluvial landscape…”. He offered a new definition, stating that “a polje should be an ante-Quaternary enclosed depression with a predominantly flat, alluviated bottom, in large massive limestone area” (p.506). Silvestru gives less significance to present hydrological function, considering it to be of secondary character and stating that “it *may* drain a temporary or permanent karst stream” (italics by J.Ćalić), as well as to the size, which he considers irrelevant. It is somewhat unusual that Silvestru considers only poljes to be true karst depressions, thanks to their flat bottoms (“truncated shape (…) mostly achieved by alluviation”), as opposed to dolines and uvalas, which “display a predominantly conical shape”.

One of the largest documented poljes is the Jiloca polje in the Iberian Range, with the area of 705 km^2. Initiated as a half-graben which deformed a Pliocene regional erosional surface, it continued to develop as a karst polje, which deepened about 300 m by corrosion processes (Gracia et al., 2003). In a relatively recent phase of development, the polje was hydrographically captured by headward erosion of the Jiloca River, and turned into an “open polje”, with external drainage.

Ford & Williams (2007) condensed the classification given by Gams (1978) to only three typical cases – border polje, structural polje and baselevel polje.

Border poljes have the allogenic water input. They abound in floodplain deposits, with active processes of lateral planation and alluviation. Structural poljes are dominated by bedrock geological controls, because polje floors are made of impermeable rocks, thanks to intensive tectonic activity (faulting). Local water tables (relating only to polje floors) are near the surface, but the hydraulic gradients steepen on polje margins, at the contact with limestones. Therefore waters drain from the basins through series of ponors. When quantities of waters are too large for capacities of ponors, the flooding takes place.

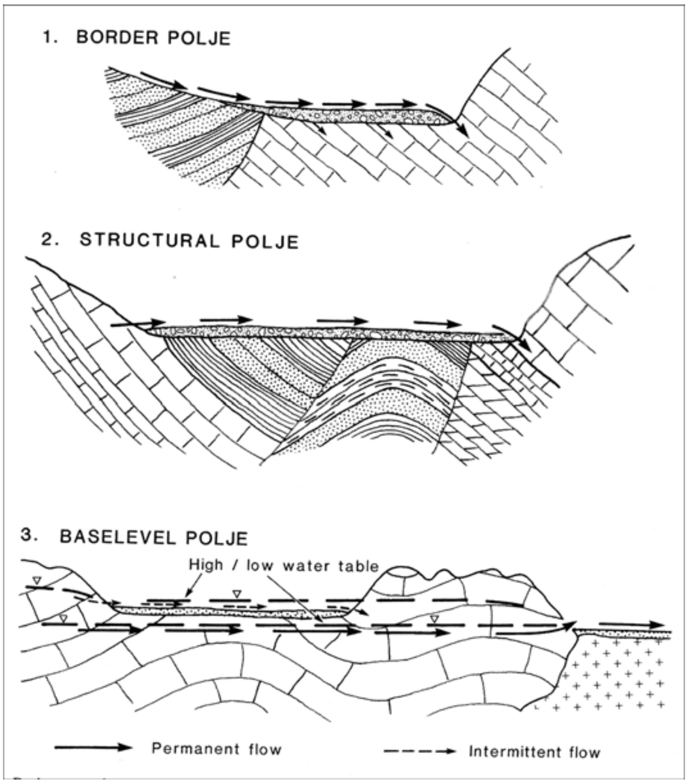

Fig. 2.6: Types of poljes according to Ford & Williams (2007) (condensed classification of Gams, 1978)

Most Dinaric poljes belong to this group. Baselevel poljes are formed where denudation lowering of karst surface has reached the regional water table. In a way, these poljes are “windows on the water table”, because they are flooded during the water table oscillations. The processes are then not directed vertically, but laterally. Thanks to the fact that they do not depend either on allogenic waters or geological controls, “they can be considered the purest kind of polje” (Ford & Williams, 2007).

3. Usage of the term *uvala* – an overview

3.1. Regional usage

The word "uvala", denoting a geomorphological form, exists in the language of people in Croatia, Bosnia, and Serbia. In the region of Lika and western Bosnia, as well as in some parts of Serbia, it means a depression in relief (usually a karstic depression of bigger dimensions than a doline), while along the Croatian coast, the term uvala denotes a small gulf on a sea shore. This dual meaning is a significant problem in scientific usage of the term "uvala". In Slovenia, people mostly use the terms "draga" and "dol" for the relief forms of this kind. In the Alps of Slovenia, there are forms partially similar to uvalas, which are called "konta" and will be briefly discussed further in this chapter. In Croatian part of the Dinaric karst, where karstic uvalas are present in great number, there are various popular expressions for such a relief form. In the regions of Gorski Kotar and Lika, especially on Mt.Velika Kapela, people use both the words "uvala" and "draga". On the northern part of Mt.Velebit, this form is called "duliba", while on southern Velebit, there is also the word "korito". In western Bosnia, the word "uvala" is abundantly used for features of this kind. No precise counting has been carried out, but it can be said, undoubtedly, that in the regions of Lika and western Bosnia dozens of toponymes contain the word uvala, and it is properly used for the relief forms of this kind. In Montenegro, relief forms which we consider uvalas are mostly called "do" and "ubli" (the latter can be etymologically linked to the word "uvala").

3.2. History of the karstological term

The term uvala, denoting a form of karst surface relief, was introduced into karstological literature by Jovan Cvijić. Cvijić first mentions uvalas in his capital work "Das Karstphänomen" (1893, translation to Serbian published in 1895). However, in this work, the uvalas are not introduced "officially" – the word is only mentioned twice, without the intention of stressing its meaning. In the chapter on dolines, under the sub-title "Deviations from normal size and shape", Cvijić describes the "dolines with huge diameter" (250 m in average, with maximums up to 600 m), and states that "Such dolines are called *do* and *uvala*, and most settlements in western Montenegro are situated in them”. The second occurrence of the term uvala is within a subtitle in the chapter on poljes: “Poljes, and uvalas similar to poljes in Montenegro”. Unfortunately, the term uvala is not mentioned anywhere in the further text.

In some later works, like “Glacial and morphological studies on mountains of Bosnia, Herzegovina and Montenegro” (Cvijić, 1899, 1900a), the word uvala appears as already established term. Describing the glacial traces on Mt.Treskavica in Bosnia, Cvijić states: “...Jezero is the deepest (...) karst uvala, that was transformed into a lake thanks to numerous springs”. Further in the text, many karst depressions are classified as uvalas (Crno Polje on Mt.Prenj, Gvozd on Mt.Čvrsnica, Carev Do on Mt.Maglić, etc.).

Cvijić made the first more precise analysis of uvalas in his paper about karst poljes of western Bosnia and Herzegovina (1900b, 1901). This is actually the paper in which he introduced the idea that the uvalas evolve into poljes (inspired by W.M.Davis’ concept of erosional cycle): “The difference between them is this: poljes are deeper, their bottoms are flat and without dolines, covered with thick sediments; poljes have characteristic hydrographic features, which are missing in uvalas. But the upper main characteristics of these forms show the direct relation between uvalas and poljes; uvalas are the initial forms, from which poljes evolve”. A great number of uvalas are mentioned, mostly within the ridges between poljes. The most interesting example is the Grahovo area, which “consists of small poljes and uvalas” and is described with a lot of details. Finally, Cvijić concludes that “... numerous Grahovo basins are in various stages of development, and therefore no other area is so convenient for studies on poljes development”. He additionally states that in Grahovo area one can see “(1) uvalas, from which poljes are formed: Vlasulje, Korita, Isjek; (2) transitional type between uvalas and poljes, and uvala bottoms in poljes: Vedro and Marinkovačko polje, and the flat portion of Grahovsko polje; (3) coalescence of uvalas and poljes, and formation of large poljes of irregular shape; it is clearly visible that all poljes of irregular and strange shape could have been formed by coalescence of uvalas to poljes”. In the same work, after the regional outlines, there is a chapter on genesis of karst poljes, in which the “transitional process” doline-uvala-polje is described with more details. The role of denudational process in formation of karst depressions is stressed, stating that “Denudation is a steady process, which lowers the bottom of uvala; the ridges between its dolines are being washed away, and small flat surfaces are developed at the bottom of uvala" (Cvijić, 1900b).

Finally, in one of his latest works "La géographie des terrains calcaires", published only in 1960, Cvijić repeats the opinion on transitional role of uvala, even stating that "uvalas are nothing else but large dolines, with diameters from 500 to 1000 m (...)". He admits that W.M.Davis' concept of erosional cycle is hardly applicable to karst, "because karst erosion does not act by same regulations as normal erosion", but claims that karst requires special definitions of evolution of every single form, thus we need to "prove and, if possible, explain the transition from one to another, and connect it to underground hydrography" (Cvijić, 1960).

We have presented Cvijić's contributions more in detail, for two main reasons. On one hand, he introduced the term uvala, which requires particular attention. But on the other hand, by linking the uvalas to the incorrect idea of karst cycle, Cvijić indirectly contributed to partial disregard of the term after the concept of karst cycle was generally abandoned.

In this review of usage of the term uvala, the references are grouped by their type, to: (a) textbooks, encyclopedias, and dictionaries; and (b) particular scientific papers and regional studies. In this way, it is possible to stress the impact of "educational" literature, which subsequently has a great influence on usage of the term.

3.3. Textbooks, encyclopedias, and dictionaries

Within this group of references, there are both karstological and general geomorphological publications. One may notice that general geomorphological (physical-geographical) references usually use very simplified definition of uvala, which mostly means size and/or basic genesis ("coalescence of dolines"). On the other hand, karstological sources mostly put up a kind of complex discussion, commenting also the cyclic concept of evolution.

Sweeting (1972) in "Karst landforms" included uvalas into the chapter on dolines ("... dolines evolve or become bigger; as they grow they sometimes coalesce and such coalescent dolines are known as uvalas. Uvalas are hollows with undulating floors made up of more than one doline." Further on in the text, the author mentions a discussion on karst terminology, organized in 1962 by the Slovenian Geological and Geographical Society, where "several different types of uvalas were recognized: (a) elongated uvalas or *dols*; (b) uvalas composed of a number of adjoining basins (or *vrtačasta uvala*); (c) periodically inundated uvalas; (d) waterlogged uvalas". In the section on tropical karst, it is stated that elongated depressions known as *glades* in Jamaica, are roughly similar to uvalas. In the chapter on karst poljes, the author considers that the concept of cyclic evolution of karst landforms (from doline through the uvala to the polje) is incorrect (Sweeting, 1972).

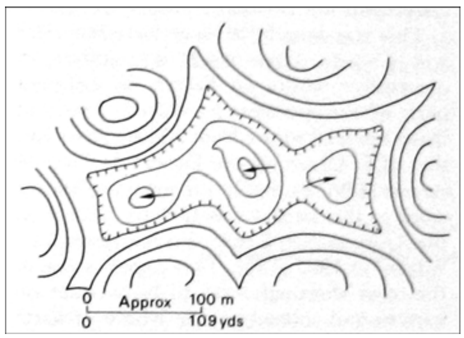

Fig. 3.1: Glade (uvala) south of Chanal, Northern Chiapas, Mexico (sketch by A.Gerstenhauer; Sweeting, 1972)

The Encyclopedia of Geomorphology, edited by Fairbridge (1968), contains the entry *uvala* ("...a series of joined or coalescent dolinas, often elongate and marking a former subterranean stream channel or series of collapsed sinkholes. It does not necessarily contain a stream at the present time. An uvala is generally of the order of 1 km in length; it is thus intermediate in size between a doline and a polje"). It is interesting to notice that this is the only definition that associates the uvalas with coalescence of *collapse* dolines, and also contains a hint on unroofed caves ("marking a *former* subterranean stream channel"). In the same Encyclopedia, uvala is also mentioned under the entries *blind valley*, *doline*, *geomorphic maps*, *karst*, and *polje*.

In "Slovene karst terminology" (edited by Gams, 1973), evolution of uvalas is not discussed, it is just mentioned that they are smaller than poljes, and bigger than dolines, usually with dolines at the bottom. The sub-types are *dolasta uvala* (elongated), and *vrtačasta uvala* (uvala with dolines). In "Serbian karst terminology" (Gavrilović, 1974), where Cvijić influences are much stronger, the entry Karst uvala (*kraška uvala*) contains the cyclic concept ("It is a transitional type between a doline and a karst polje"). On the other hand, this entry contains an incorrect citation – that this term was scientifically defined by Cvijić in 1889, although it was not before 1900 (Cvijić, 1900b, 1901). In "Contribution to the Croatian karst terminology" (Roglić, 1974), the term uvala is criticized for being the same as the term for small coastal gulf in the Adriatic. The explanation contains the disapproval of the cyclic concept ("The concept of cyclic relief development is generally abandoned, so the term "uvala" will in future get the meaning which corresponds to it linguistically"). It is very surprising that Roglić had such an antagonistic attitude towards the term uvala, because, apart from western Bosnia, it is Croatia where the term originated linguistically. In the mountains Velika Kapela and Mala Kapela, as well as Lika region, this term is used in people's language, and it constitutes a great number of toponymes, as opposed to all other regions where its usage is restricted only to scientific (karstological) terminology.

Trudgill (1985) states that "Simple, conical-shaped depressions, or dolines, are thought to coalesce, forming compound features termed *uvalas* (Sweeting, 1972; Jennings, 1971). The author Cvijic suggested that this led to the formation of poljes, but as discussed by Sweeting (1972, p.192) and in this book on p.105, poljes have a rather different scale and mode of origin".

Jennings (1985) defines uvalas as complex forms "having uneven floors with more than one low point, but no extensive flat areas". The formation is often due to "intersection of dolines", and elongated shape can be a consequence of location along the strike of steeply-dipping limestones. Jennings gives some examples of uvalas from New Zealand, Tasmania and Morocco.

In "Geomorphological field manual" by Dackombe and Gardiner (1983), there are no uvalas and poljes among the geomorphological mapping symbols.

"Geomorphology" by Chorley et al. (1985) gives a brief, yet a compound definition: "The uniting of several adjacent dolines produces a more complex uvala, but the largest class of karst closed depressions, the polje, cannot be attributed to such growth."

Small (1970) in his textbook on geomorphology explains the karst forms through the case study of Grands Causses in France: "The basic form is the small round or elongated hollow (referred to locally as a 'sotch') which is comparable with the 'doline' of the Jugoslavian karst (...) In many areas closely adjoining sotchs have amalgamated, through lateral extension, to give larger depressions comparable with the 'uvalas' of the Karst proper."

White (1988) approves usage of a particular term for features sized between dolines and poljes, but favours the expression *compound sink* instead of *uvala*: "I have used the terms *sinkhole* and *doline* interchangeably (...). For features of intermediate size, I use *compound sink* or *valley sink* rather than *uvala*; the uvalas of the Adriatic karst are similar to compound sinks".

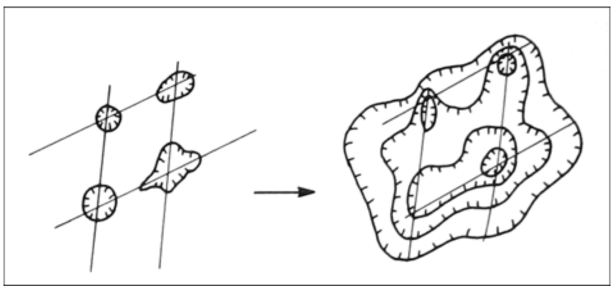

Fig. 3.2: Evolution of compound sinks (White, 1988)

Regretfully, one of the most cited publications related to karst, the "Karst Geomorphology and Hydrology" by Ford & Williams (1989), mentions uvalas in completely incorrect way. Discussing Cvijić's early ideas on karst, it is stated as follows: "In his 1893 monograph he suggested a genetic sequence involving amalgamation from dolines to uvulas to poljes, but it was not until 1918 that he published his considered opinion on the morphological evolution of karst (…)" (p.452). First of all, the word uvala is written incorrectly, as uv***u***la (in the Index there is again the incorrect plural form, *uv**uals**;* probably a typing mistake). Furthermore, Cvijić did not suggest a genetic sequence dolines-uvalas-poljes in his 1893 monograph, but only in 1900 (Cvijić, 1900b, 1901). In the new edition of this book ("Karst Hydrogeology and Geomorphology", Ford & Williams, 2007), the above-mentioned citation is repeated (p.391). It is again with erroneous reference (Cvijić 1893 instead of Cvijić 1901) and incorrectly spelled (uvula). Uvala-type depressions are not recognized under any other term or expression (such as, e.g. "compound depression" in some other references) – dolines and poljes are the only mentioned karst depressions. Only in the citation of a regional study by

Racoviță et al, it is stated “doline clusters on the plateau surface are set within larger enclosed basins (thus constituting uvalas, i.e. compound closed depressions)” (p.346), without any additional details, or using of the term elsewhere. We can suppose that such an approach in these major karstological references has probably contributed to decreasing usage of the term uvala.

The “Encyclopedic Dictionary of Physical Geography”, edited by Goudie et al. (1994), defines the uvala rather briefly, without mentioning a cyclic concept (it is not mentioned under the entries doline and polje, either): “Uvala: A depression or large hollow in limestone areas produced when several sinkholes coalesce.”

Lowe & Waltham (1995), in “A Dictionary of Karst and Caves”, stress only the cyclic concept, and by disapproving it, discard the whole notion of uvalas: “Uvala: A multi-coned closed depression; now little-used term of Croat, Serb or Bulgarian origin. The term was introduced to describe features assumed to be the second step in a 3-stage process of polje development, in which dolines were supposed to coalesce into uvalas. This mechanism is no longer accepted and the term uvala has fallen into disuse.”

Waltham et al. (2005) again stressed the disuse of the term uvala in the Glossary of sinkhole terminology, within their book on karst engineering (“Uvala – Closed depression with multiple sink points (now little used)”).

A “Glossary of cave and karst terminology”, published within the book by Gillieson (1996), offers a simple definition of uvala, without any genetic details: “Uvala: A complex closed depression with several lesser depressions within its rim”.

In East European literature, uvala is usually listed in all classifications of karst surface forms. One of the distinctive examples is the book by M. Pulina (1999), where it is stated that, beside karst dolines, there is also a composite form, uvala, and that the development of big groups of dolines can lead to formation of large karst depressions (“Obok pojedynczych lejów występują formy połączone *uvala* (serb.), a rozwój większych skupień lejków może prowadzić do powstania dużych depresji krasowych”, p.51). Furthermore, in the contribution about karst and caves in the Geographic Encyclopedia of the World (Wielka encyklopedia geografii świata), Pulina & Andrejchuk (2000) even introduce the term uvala into cryokarst terminology, as *glacier* *uvalas* ("(....)inne, połączone z kilkoma lejkam, tworzą *uwala lodowcowe*"). The term uvala is an entry also in the terminology of Panoš (2001).

Also in French references, there is a broad acceptance of uvalas. In one of the major references, "Précis de Karstologie" by Salomon (2000), the closed karst depressions are listed as "dolines, ouvalas et poljés". Apart from mentioning formation by coalescence of dolines, the author describes a number of other conditions which favour formation of uvalas, and finally concludes that uvalas are rather rare phenomenon because it is a rare case that so many conditions are fulfilled ("La rareté relative du nombre d'ouvalas indique que ces conditions ne se réalisent que peu souvent"; p.46).

The Lexicon of Cave and Karst Terminology (US Environmental Protection Agency, 2002, p. 201-202), offers three definitions of uvala: (1) definition by Lowe & Waltham (1995), cited above in the text; (2) definition by Sweeting (1973): "Large closed depression formed by the coalescence of several dolines which have enlarged towards each other. Typically, the floor is irregular, being a combination of doline floors and degraded slopes of the individual hollows"; (3) definition from the "Glossary and Multilingual Equivalents of Karst Terms" (UNESCO 1972): "A Yugoslavian term for an elongated closed depression in karst that is commonly dry or with periodical small sinking streams or inundations. They are generally a few hundred metres long and may be considered as a small polje". The definition (3) is generally the least correct, overlooking the hydrological function and emphasizing only the size.

Two fundamental encyclopedias on karstological issues were published in 2004. The one edited by J. Gunn (2004) does not contain the entry Uvala, but the term is mentioned within the entry Dinaric Karst (in the sense of origin of the term), and within the entry Doline ("Individual dolines may merge to form compound closed depressions (known as uvalas) and large dolines may subdivide internally into smaller second generation basins").

Sauro (2004) contributed a broad, all-encompassing chapter on karst closed depressions in the Encyclopedia of Caves, edited by Culver & White (2004). This chapter offers one of the best explanations of uvala-type features, although the term itself is mentioned only as a synonym: "The large closed depressions that do not show a doline morphology are also referred to as *uvala*". Among closed depressions which are sized from several hundreds of metres to a few kilometres, the author distinguishes *compound hollows* (which are formed by coalescence of dolines), and *polygenetic sinks* ("which evolved through both the karst process and another morphogenetic process"). Depending on the nature of that other process, polygenetic sinks can be divided to tecto-karstic hollows, fluvio-karstic hollows, and glacio-karstic hollows.

In a comprehensive monograph dealing with most aspects of cave geology, Palmer (2007) briefly covers also the karst surface landforms. The term uvala appears together with dolines and poljes in the section on closed depressions (also in the Index), but with the awareness of general vague notion of the term (p.30): "*Uvalas* are compound sinkholes containing multiple depressions. The term *uvala* is used in a variety of ways and is sometimes applied to youthful poljes or to dry valleys floored by sinkholes. This term needs to be more clearly defined or abandoned entirely."

3.4. Scientific papers and regional studies

Of course, it would be impossible to list and discuss all the papers that mention to some point the subject of uvalas. Some of the most significant, as well as those that report about uvalas in various karstological settings, are listed below.

Katzer (1909) used both the words *uvala* and *karstmulde* (German term for the same form) in his discussion pointed towards negation of the existence of uvalas. Katzer states that uvalas are formed either without the influence of tectonics, which makes them only a kind of solution dolines, or they are formed along tectonic lines, which makes them a kind of poljes. From that, Katzer infers that the term uvala is "not morphologically convincing". He continues that the term is used in people's language in western Bosnia, for the depressions larger than dolines and smaller than poljes, but "not uniformly". However, in further discussion, where he debates against the cyclic evolution of karst landscapes, he states: "Uvala cannot be formed from a doline, neither can polje be formed in such a sequence. These are three various forms in karst, each formed for itself, and not three various stages of evolutionary cycle".

Cramer (1941) defines the uvalas as dolines lined up in a valley ("zu Talungen vereinigte Dolinen"), and he offers a similar explanation within the terminological list from various regions ("Dinarische Karstgebiete: Uvala – Dolinentalungen in Bosnien und Herzegowina").

One of the most important papers that deals with genesis of uvalas and their relation to dolines and poljes, is that of Poljak (1951). Mentioning and analyzing a great number of uvalas in Croatia and western Bosnia, Poljak disapproves the cyclic theory on their evolution, and stresses the influence of tectonics on their genesis and development. It seems that this is the first (and one of the very few) papers which argues with the cyclic concept not only generally, but with plenty of detailed examples and analyses. Poljak strictly differentiates those uvalas that were formed by coalescence of dolines (calling them *ponikvaste uvale*; dolined uvalas, uvalas with dolines), from the "regular" uvalas, whose main genetic factor is tectonic activity. It is well noticed that one of the strongest arguments in favour of tectonic influence is the fact that karst levelled surfaces completely lack uvalas, regardless of the fact that they are often pitted with dolines. Although Poljak in some statements goes to other extreme, completely disregarding the role of karst erosion in formation of uvalas ("they are of tectonic importance, and not erosional like dolines"), this paper is of utmost importance in the study of uvalas.

Šerko (1948) gives a broad list of 228 various large karst depressions on the territory of the former Yugoslavia, categorizing them as poljes, uvalas, or transitional forms between polje and uvala ("really small polje, or a larger uvala").

Gams (1978) covers some questionable issues related to distinguishing the uvalas from the poljes ("According to modern views, an uvala is different from a polje not in its size, but in terms of the flatness of its floor").

Cocean & Petrescu (1989), in their paper about uvalas on Apuseni Mountains, express the view that uvalas are the classical form of karstic relief, which is by dimensions situated between dolines and poljes, but has a specific genesis influenced both by tectonics and corrosion, as well as modified by fluvial erosion. They differentiate three types of uvalas: (1) uvalas resulting from tectonics; (2) uvalas of fluvial origin; and (3) uvalas formed by coalescence of dolines. It is stressed that the uvalas of the third type are very rare, and that there is a plenty of conditions that need to be fulfilled for that course of development.

Rusu (1990) discusses the uvalas within his paper on principal types of karst depressions. He explains the genesis and evolution, and suggests a classification of *depressions de capture karstique*, which are in fact blind valleys that protrude more or less into karst. Rusu argues that uvalas of fluvial origin, as defined by Cocean & Petrescu (1989) should be in the category of *depressions de capture karstique*, instead of a type of uvalas. Additionally, he offers a classification of uvalas by shape, to circular (formed in tectonized zones), linear (formed along a linear series of dolines), elliptical (formed in former affluent basins), meandering (following a form of a "primary valley"), and lobate (convergence of multiple elements).

Petrović, D. (1994) classifies uvalas into karstic and polygenetic. Karstic uvalas are formed by coalescence of dolines, and have two sub-types: those with dolines on the bottom, and those with flat bottom, where all ridges between former dolines have been lowered, and only flat bottom remained. Polygenetic uvalas can be fluvio-karstic and glacio-karstic, depending on the type of process which took part in their genesis. In formation of fluvio-karstic uvalas, Petrović presumes the existence of a "pre-karstic" river, later disorganized by karstic erosion; dolines at its bottom are coalescing into an uvala. However, Petrović avoided the intricate question of evolving of uvalas into poljes, so this issue remained open in this paper.

Habič (1978) mentions that there are two types of uvalas, *vrtačaste uvale* (uvalas with dolines), and *dolaste uvale* (uvalas in a form of *do*, elongated). In one of his later works (Habič, 1986), he extensively discusses the problems of definitions and origin of uvalas, with some very bright remarks. He theoretically allows the cyclic evolution in the sense of Cvijić, but stresses that these cases are very rare, and generally the whole model must be revised. He opts for keeping the term uvala, but in revised context ("The notion of uvala, which is adopted in karstology, has to be preserved, but not in the initial, narrow cyclic model"). Habič notices that in some karst depressions (uvalas) the dolines are in fact secondary features, formed *after* the formation of the whole depression. In a small Contribution to the karst terminology, given in the appendix to the paper, Habič explains the term úlaka, a local expression from Notranjska region ("asymmetrical shallow uvala, in the foothill of steeply inclined hillsides or conical hills").

In the paper about the relief of western Suha Krajina region, Habič (1988) gives the information (including morphometry) on 13 uvalas ("kraški doli – uvale") of the region, stating that great number of uvalas distinguishes this area from other karst areas in Slovenia. The elevations of bottoms of these uvalas gradually decrease, following the decrease of water table level from Ribnica polje to the Krka valley.

Gams (1974, 2004) in his monographs about Slovenian karst lists a great number of Slovenian uvalas, discussing at the same time their evolution and genetic factors. In a paragraph titled "Is uvala a young karst polje?" it is stated that the cyclic model is rather questionable (Gams, 2004). Uvala is defined as follows: "Karst surface depression bigger than a doline, with undulating bottom, which is usually not flooded, and not cultivated". The author gives a series of examples of depressions in Slovenia which are considered uvalas, as well as those that trigger debates about their classification.

Numerous limitations of the term "uvala" are outlined by Šušteršič (1986). Some of the opinions are too radical – for example, that after rejecting Cvijić's cyclic model there are no grounds to retain any component of the whole terminology. Šušteršič states that the great problem related to uvalas is that their definition is in fact negative – karst depressions which are neither dolines nor poljes. He approves the Poljak's (1951) definition of karst uvalas, considering it clear and correct, but reminds of a problem that they are only "a droplet in a flood of other different examples". A very useful suggestion which evolved from these arguments is that "we first have to make an inventory of uvalas, and after that discuss about their genesis and classifications" (Šušteršič, 1986).

Kunaver (1983) discusses the issue of "konta" – type of large karst depressions in Pre-Alpine plateaus in Slovenia, stating that they are uvala-like depressions. Kunaver mentions the opinions of previous researchers of high-mountain depressions, some of which have used the term uvala for those of irregular shape (e.g. Haserodt, 1965, who also analyzed their shapes and observed that their bottoms consist of a number of smaller flat-bottomed depressions and funnel-shaped dolines). Kranjc (2006) classifies kontas either as large dolines or as high-mountain uvalas.

There is a very interesting paper by M. Frelih (2003), discussing differences between uvalas and poljes, through a case study of the depression Lučki Dol in Dolenjska region in Slovenia. After a detailed analysis of geological, geomorphological, and hydrological characteristics, it is concluded that Lučki Dol is not an uvala, but a small karst polje.

Brief terminological discussion on status of uvalas among karst depressions is given by Gostinčar (2009). She explains the reasons why she uses the term "kraška kotanja" (karst depression) instead of the term "uvala": "This relief form (uvala) is defined morphologically, but not genetically. (…) Due to the fact that the term is used for genetically various relief forms, we have chosen another term, which has a morphological meaning, but does not have any genetic implication".

Bočić (2009) distinguishes particular type of fluviokarstic depressions which he calls "dolinaste uvale" (possible translation could be "valley-floor uvalas"). They are situated along dry valleys, or in reshaped blind valleys in fluviokarstic areas.

In morphometric study of dolines of the Candaglia Plateau (Venetian Forealps), it is said that "the wide Candaglia depression was excluded from analysis because its form differs from other considered dolines. It is the large elongated uvala resembling in some characteristics a small polje" (Bondesan et al. 1992). Similarly, in some other morphometric studies of dolines, the uvalas and compound dolines are explicitly excluded from the investigation (Péntek et al., 2007). It is of course understandable that irregular features are excluded from particular studies which aim to define the rules of regularity, but on the other hand, this implies the need for particular studies of irregular forms as well.

Nicod (2003a), in the discussion of special cases of poljes, states that many poljes are in incipient stage, and mentions blind valley and "uvala in extension" among examples. In his book on the Dinaric karst (Nicod, 2003b) he mentions uvalas within the chapter on terminology, as well as in the "small toponymic vocabulary" at the end of the book.

Sauro (2003) discusses the uvala Agugliana in eastern Lessini mountains (Venetian Prealps), which has a floor in basalts and some characteristics of contact karst.

Ravbar & Šebela (2004) discussed that the periodical lakes in Upper Pivka basin in SW Slovenia might be defined as „karst depressions – uvalas periodically filled with water".

Existence of "uvala-like depressions" in evaporites (salt diapirs of Zagros Mt, Iran) was reported by Bosák et al. (1999a).

Large shallow karstic depressions up to 1100 m long and 600 m wide in central Ebro basin (Spain) were identified as uvalas by Soriano and Simón (1995).
Balák et al. (1999, 2003) refer to the uvala Hedvábná in the northern part of Moravian Karst, on the plateau above the caves Macocha and Amaterska. Later research of Balák indicate that Hedvábná could also be interpreted as unroofed cave (pers. comm. by A. Tyc), while Bosák et al. (1999b) suggest that this is a doline.
Generally, there are numerous papers in which authors classify some of the studied features as uvalas, without detailed discussion about terminology (e.g. Nicod 1980; Salomon & Pulina 2005, Papadopoulou-Vrynioti 2004, etc.).

4. Methodology

In the overall methodology of this study, it is possible to distinguish several chronological steps of work. Subsequent to checking and analyzing the most important literature references, large-scale topographic maps were used to identify a number of most conspicuous examples of uvalas in the study areas. Majority of the localities have been visited in the field, in order to get the idea on their forms and dimensions, and to carry out the necessary geomorphological observations and mapping where needed. Photo-documentation was made as well. Based on map analyses and fieldwork, the total of 43 examples of uvalas were selected for the research, keeping in mind to include a variety of cases, which differ by their dimensions, geological and topographical settings, as well as by morphological characteristics. Out of 43 examples, 12 were selected for detailed structural-geological field mapping applying the method of Čar (1982, 1986, 2001). Selection of these 12 examples was based on the diversity of uvalas and the accessibility of particular locations. Some interesting uvalas in the Dinarides had to be excluded from the detailed field survey due to the danger of the landmines. Digitizing of contours and creation of digital elevation models marked a starting point of digital processing, which subsequently included quantification of morphometrical parameters, creation of inclination maps and cross sections, statistical analyses, as well as formation of the geographical information system.
The most important methodological issues are discussed more in detail in the further text.

4.1. Cartographic input

The basic input element of the whole study, both for field mapping and processing of digital data, have been topographic maps. Without doubt, the ideal option would have been to choose maps in the scale 1:5.000 or 1:10.000, which show a number of details in relief. These scales are, for example, a requirement in morphometric analyses of dolines (Bondesan et al., 1992). Unfortunately, it was very difficult to obtain such maps for all the studied areas. They either do not exist at all (for example, 1:10.000 maps in Serbia were made only for populated areas, and karst areas of our interest are unpopulated), or are very difficult to reach, “buried” in cadastre offices and overwhelmed by bureaucratic procedures. The fact that the studied uvalas are dispersed all over the area of more than 100.000 square kilometres, in 5 countries, discourages all the attempts for obtaining 1:10.000 maps from numerous municipal cadastre offices. Therefore we decided that 1:25.000 maps are used in the study, except for the examples from Slovenia, where larger scale maps are easily available. Contour interval of 10 m is not the best solution, but it is the only possible in these circumstances. We are aware of the fact that even the elevation differences less than 10 m, which are in this case invisible, can significantly affect the morphometrical parameters.

4.2. Definition of basic parameters

The problem which occurs prior to digital processing and morphometric analyses is precise definition of parameters which will be either measured or calculated.

4.2.1. Measured parameters

4.2.1.1. Perimeter line

Even in morphometric analysis of dolines, which are much simpler and much more regular forms than uvalas, there are some problems in definition of perimeter line (Bondesan et al., 1992). The perimeter of the highest closed contour is considerably smaller than the perimeter of the line that encircles the area morphologically influenced by the doline (a theoretical water divide, or topographical divide) (Fig. 4.1).

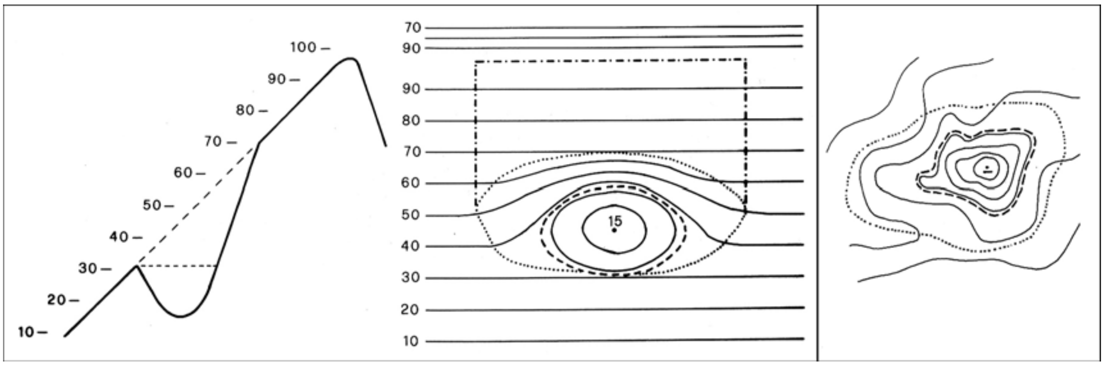

Fig. 4.1: Several ways of defining a perimeter line for a doline:
dashed line – perimeter of the closed depression; dotted line – portion of slope influenced by the doline; dash-and-dot line – water divide
(Bondesan et al., 1992; parts of Figures 1 and 11)

Perimeter line is for sure the most important among measured parameters of a depression, because almost all other measured and, subsequently, calculated parameters rely on it. This line is the very basic definition of a feature. When determining the size of the polje, its flat bottom (rather easy to delineate) is taken into account in most cases (e.g. Gams, 1978). In the study of dolines, questionable determinations of perimeter line are more common, but still relatively rare, so in methodological papers it is often suggested to leave the "difficult" examples out of the total examined population, if possible (e.g. Bondesan et al., 1992). Šušteršič (1994) also discusses the issue of doline perimeters, stating that this definition is crucial in the study of dolines. He advocates abandoning of both topographical divide and highest closed ("overflow") contour as possible perimeter lines of dolines. Instead, he claims that in the field it is relatively easy to detect the perimeter line of the doline ("It is marked by an abrupt change of the slope, though small in its value, dividing the "normal karst surface" and the area influenced by slope processes…"; p.129).

Fig. 4.2: Delineation of perimeter line (red line) for: a) dolines (sharp change of slope inclination), and b) poljes (flat bottom). Location of (a) is in Marinkovci, close to Bosansko Grahovo in Bosnia, while (b) is flooded Fatničko polje in Herzegovina

The same author (Šušteršič, 1986) states that in delineation of a karst depression, one should take into account "the outmost limit of processes triggered by the depression formation", or "the true karstic mass removal area".

Although this argumentation is highly convincing and clear in case of dolines, it is necessary to stress that for uvalas, it is very difficult to apply the same practice. In great majority of uvalas, it is impossible to notice the "line" of the abrupt change of slope inclination. It may be visible only in a small number of cases, and only in small segments of the perimeter. Instead, in many cases the line of considerable change of inclination is at the same time a topographical divide of regional scale. The line of karstic mass removal area (in the sense of Šušteršič, 1986) is difficult to detect, and thus, being highly subjective, very questionable for statistical operation. If we express it as a number (exact length of perimeter), we have to give it a numerical justification (how we reached the value), which is almost impossible.

At this initial stage of the research of uvalas, we do not have a solution for determining the *exact line* which encompasses the limit of depression-forming karst processes. Having that in mind, we have to discuss the other possibilities for uvala perimeter determination, being aware of their disadvantages, as well as certain advantages:

a) highest closed contour (HCC)

- disadvantage: length of HCC perimeter is usually too small to express the real size of a depression
- disadvantage: association of "overflowing", characteristic for fluvial system and not essential to karst (cf. Šušteršič, 1994)
- disadvantage: shape of HCC perimeter is often more irregular than the overall perception of a depression
- advantage: this is the only perimeter line (in case of uvalas) which can be defined completely objectively, and has a "mathematical justification". Or, as explained by Waltham (1981), "At a minimum, the depression below this level must have been excavated and then transported away by the underground karst drainage".

b) topographical divide (only theoretically!)

- disadvantage: this is the largest possible perimeter, usually with least irregularities, and most probably overestimating the "real" size of a depression
- disadvantage: topographic divides have no importance for karst process (again, association with fluvial system, the principles of which are irrelevant in karst)
- disadvantage: this method of determination is less objective than HCC method; some rules of "drainage area" delineation have to be overlooked

because of karstic morphology (e.g. areas with dolines), and sometime selection of ridges may be arbitrary (see next point). This introduces a touch of subjectivity, but only at some segments

- advantage: area within the topographical divide is in majority of cases very close to overall perception of the uvala. The closest ridges are taken as divides; more distant higher ridges are chosen only if the area in-between is considerably and constantly inclined towards the depression.

Despite many disadvantages and few advantages, highest closed contour and topographical divide have to be accepted as two variations of uvala perimeter (symbol **Pc** for HCC, defining minimal uvala area; and **Pd** for topographical divide, defining maximal uvala area), until a distinct method is developed for definition of true karst mass removal area. For each uvala in the analysis, almost all selected parameters are defined both taking the highest closed contour and the topographical divide as perimeter. The length of the each perimeter is always expressed as the length of its orthogonal projection.

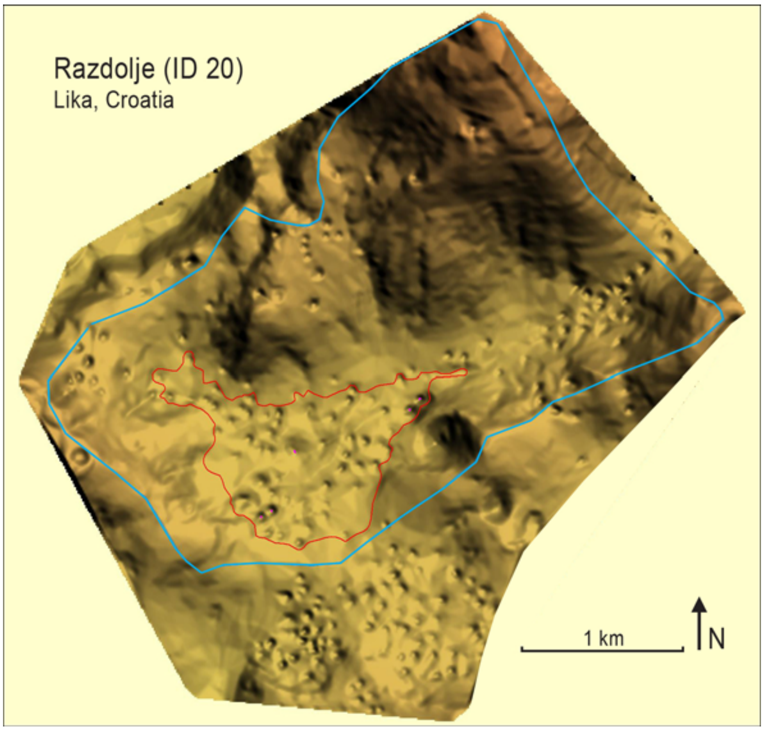

Fig. 4.3: Razdolje uvala (ID 20) defined by highest closed contour at 700 m a.s.l. (red line) and topographical divide (blue line). Pink dots mark the lowest points, at 675 m a.s.l.

4.2.1.2. The lowest point

On large-scale topographic maps, used in morphometric studies of dolines, the altitude of the lowest point within the doline is very often numerically indicated. Since only 1:25.000 topographic maps have been used in this study for great majority of case examples, no spot heights at the depression bottoms have been available. During the process of digitizing, we considered that the bottom of each depression is situated at the elevation which is lower than the lowest closed contour by half of the contour interval. This means that the elevation of the bottom points has always been set 5 metres lower than the lowest closed contour. Although this might not be true in reality, we considered that the possible mistakes would not affect the overall dimensions of the uvalas, taking into account their sizes which significantly exceed those of average dolines.

23 out of 43 case examples have more than one lowest point. Therefore, in selection of parameters for morphometrical analysis, we had to skip all the parameters which are essentially related to the lowest point position. These parameters are axes of length and width (in Bondesan et al., 1992, marked LAXI and WAXI; and in Williams, 1972, marked L and W), the adjoining semiaxes, as well as the computed parameters which include any of these.

4.2.1.3. Other measured parameters

All the parameters of this category have been measured either from the digital elevation models, or from topographic maps 1:25.000, from which the models have been created. The method of DEM creation is described further in the text. In selecting the exact parameters for morphometric analysis, Bondesan et al. (1992) have been the principal reference. Greatest number of symbols is kept the same as in that reference, while some of the symbols have been changed due to some different characteristics between dolines and uvalas. Due to the above-mentioned problem of perimeter definition, all the parameters related to the perimeter have been split to two sub-categories: those referring to the highest closed contour, marked with letter **c**, and those referring to the topographical divide, marked with letter **d**.

Tab. 4.1: Measured parameters

Parameter	Explanation
Pc	perimeter (highest closed contour)
Pd	perimeter (topographical divide)
Ac	planimetric area, bordered by the highest closed contour (Ac) and topographical divide (Ad)
Ad	
DMAXc	maximum diameter – linking two most distant points of the perimeter(s)
DMAXd	
DMNRc	minor diameter – longest segment linking two points of the perimeter(s) and perpendicular to DMAX
DMNRd	
DDIRd	maximum diameter direction (azimuth); measured only for DMAXd
V	volume of the depression below the highest closed contour
Emin	elevation of the doline bottom
Ec	elevation of the highest closed contour
Emaxd	elevation of the highest point along the topographical divide

Linear parameters are expressed in meters, surface parameters in square kilometers, and elevation parameters in meters above sea level. The symbol Emin is equivalent to FMIN from Bondesan et al. (1992). The volume has been calculated only for the part of depression below the highest closed contour, because topographical divide does not follow a single plane below which the volume could be calculated.

4.2.2. Computed parameters

Similarly as for the measured parameters, most of the computed ones have been split to two sub-categories due to dual perimeter definition. Most of the parameters have been taken from Bondesan et al. (1992). Instead of elongation ratio RL/W, which includes axial parameters referring to a single bottom point, we have used the relation DMAX/DMNR, marked with ELONGc and ELONGd. Elevation difference between the lowest point and the highest closed contour is marked HUV instead of HDOL.

Tab. 4.2: Computed parameters

Parameter	Explanation
HUV	uvala depth (from the lowest point to the highest closed contour)
HBAS	basin depth (from the lowest point to the highest point of topographical divide)
CEQUc	equivalent circumference (circumference of the circle with area equivalent to planimetric surface of the uvala)
CEQUd	
ISINc	sinuosity index (ratio between Pc or Pd, and circumference of a circle with area equivalent to planimetric surface of the uvala)
ISINd	
DIDEc	ideal diameter (diameter of the circle with area equivalent to planimetric surface of the uvala)
DIDEd	
DAVEc	average diameter (arithmetical average of DMAX and DMNR)
DAVEd	
RH/Dc	cross section ratio (HUV/DAVEc)
RH/Dd	cross section ratio (HBAS/DAVEd)
ELONGc	elongation ratio (DMAX/DMNR)
ELONGd	
VDVP	volume development (ratio between volume of the uvala and volume of a cone with a base equivalent to planimetric area of the uvala, and height equivalent to uvala depth)
HVOL	volumetric depth (V/Ac)

4.3. Digital processing

In order to perform numerous morphometric operations and to constitute a Geographic Information System, the relief of all the study areas had to be transferred to a digital format. This has been done by digitizing the contour lines and elevation points from topographic maps, thus transforming the contours to vectors with attributed elevation. The *Intergraph MicroStation 95* software has been used for this purpose, with the additional help of the applications *I/RAS B*, *I/RAS C*, *MRFClean*, and *GeoVec*.

The files were exported to .dxf format and then imported to the raster-based GIS software *Idrisi Andes*, which was used to produce square-grid digital elevation models. This software creates raster files by triangulation between the contour

vectors (TIN function, constrained triangulation). A grid of 10 by 10 m was chosen as the most appropriate, showing enough details in relief (e.g. particular dolines within the uvalas, escarpments indicating tectonic structures, etc.). In cases of the study areas for which 1:5000 topographic maps were available, we opted for a 5 by 5 m grid DEM (uvalas Hrastov Dol and Ravan in Slovenia). Each DEM was smoothed by applying the filter (type: mean, size: 3x3).
Subsequently to creation of digital elevation models, *Idrisi Andes* was used also to produce maps of slope inclinations, to calculate volumes of the uvalas, and to extract the selected cross-sections. Slope inclination maps were made in grid resolutions of 10 x 10 m, and 20 x 20 m. Although the program allows for calculation of average inclination for the whole processed area of each case example, we did not include this information into the study, because of the complexity of uvala slopes and problematic definition of the perimeter. As already mentioned above, volumes were calculated only for the part of depression below the highest closed contour, using the Overlay module from *Idrisi* for creation of the mask which excludes the area out of the HCC. The numerical version of the histogram, specifying the exact number of grid cells of particular elevation, was used for calculation of the volume.

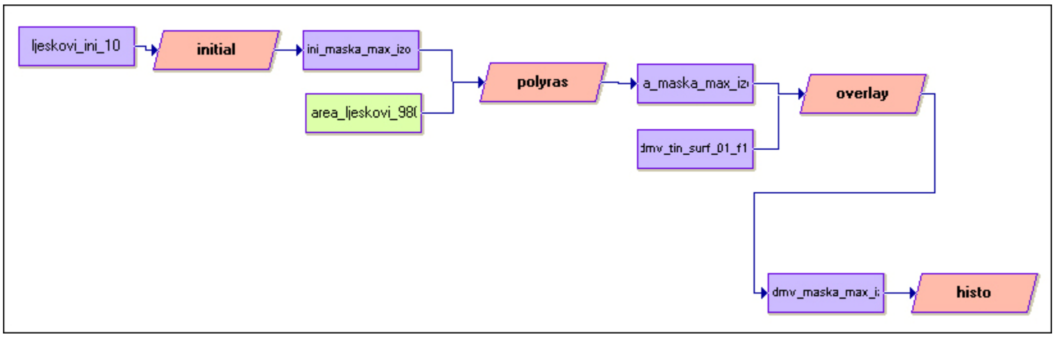

Fig. 4.4: Macro-model designed in Idrisi Andes, for extraction of highest closed contour area, and subsequent volume calculation

Digitizing and raster processing was done in Gauss-Krueger coordinate system (kilometer square grid), because all the topographical maps for the studied areas are made in that coordinate system, in three meridian zones (5th zone with central meridian 15ºE; 6th zone with central meridian 18ºE; and 7th zone with central meridian 21ºE). Projection is Transverse Mercator, while map datum is D-48 Slovenia.

The software package *Global Mapper 7* was used for imaging (visualization of digital elevation models) and coordinate conversions. Thanks to its good-quality visual performances, it was helpful in precise definition and digitizing of topographical divides, as well as the parameters DMAX, DMNR and DDIR. In *Global Mapper*, the highest closed contours of each studied uvala have been transformed to Keyhole Markup Language (.kmz format), developed for use with Google Earth (available at http://earth.google.com/). The files are written on a CD which is the Appendix 1 to this thesis.

4.4. Structural-geological mapping

For determination of the influence of structural and tectonic elements on the formation of uvalas, the structural mapping following the method of Čar (1982, 1986, 2001) has been used. Out of 43 case examples, 12 have been mapped in this way. The essence of the method is detection of three types of fractured zones in rock outcrops (crushed, broken and fissured zone, together with transition zones between them), as well as measuring dip orientation and dip angle for a series of fissures and bedding planes. The distinction between the three zones was first explained in a study of the ponor area of Planinsko polje, Slovenia (Čar, 1982). **Crushed** zone is a complex of highly tectonically damaged rock along the central (longitudinal) zone of a fault. It abounds in cataclastic rock fragments, tectonic clay, tectonic breccia, mylonite (especially in dolomites), and other outcomes of strong mechanical stress along a fault. Tectonic breccia in limestones consists of angular rock fragments cemented by reddish mixture of clay and calcite. It is characterized by higher resistivity to erosion and smaller water permeability. **Broken** zone lies in the outer sides of the crushed zone, and is characterized by systems of chaotically distributed fractures which split the rock into blocks of various sizes (from several centimeters to as much as several meters). Blocks in the broken zone are rather loosely connected, and moved in various directions, but their inner texture is not tectonically damaged. Broken zones often contain calcite veins and infiltrated terra rossa. They are highly porous and well permeable. **Fissured** zones are the outer continuation of broken zones, containing systems of fissures (joints) along which there has been no tectonic movements (or they are insignificant). Therefore, bedding is undisturbed and well visible, in accordance with the bedding of broader surroundings. Fissured zones are well permeable and, together with broken zones, they represent the main hydrological routes (Čar, 1982). In some faults, the crushed zone is not developed, so only broken and fissured zones are present (Čar, 2001).

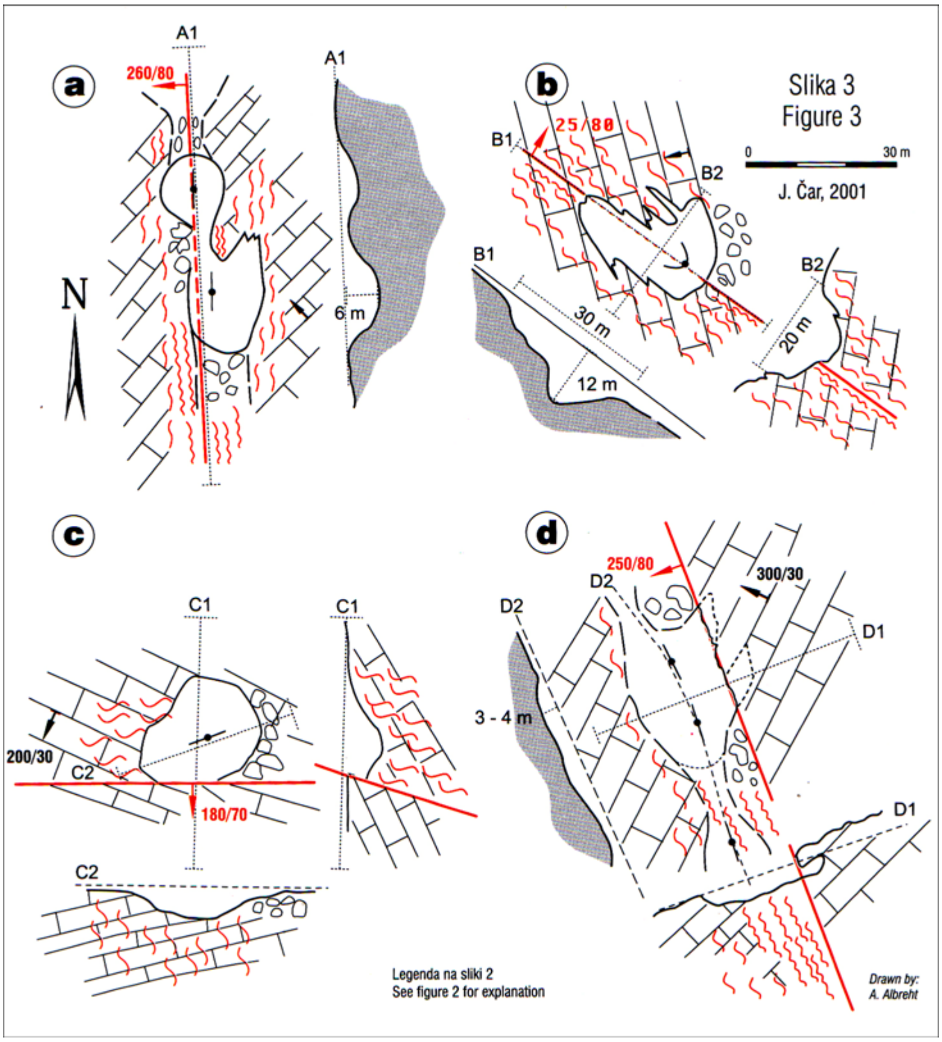

Fig. 4.5: The method of structural mapping developed by J. Čar, applied for the study of dolines (Čar, 2001)

Apart from cartographical presentation, the results of structural mapping are also expressed as stereonet projections, using equal angle projection on lower hemisphere (poles of planes). Shareware software application *StereoNett 2.46* (Duyster, 2000) was used for this purpose.

Digital elevation models have been very helpful in detecting some of the structural elements (e.g. faults and fault zones), or in proving and additional emphasizing of the data collected in field mapping. Combination of all these observations and measurements gives valuable insight in structural guidance of various karst features development, including uvalas.

4.5. Statistical analyses

The sample size of 43 studied case examples of uvalas allows for a certain amount of statistical data processing. The exact number of examples was reached in some way subjectively, but at the same time having in mind some statistical practice and theories (e.g. as explained by Lehmann (1999), Student's small-sample theory categorizes samples of up to 30 as small samples, which we aimed to overcome). In morphometric analysis of dolines in the Classical Karst of Trieste, presented in Bondesan et al. (1992), it is said that statistical analysis of large dolines was of little significance, due to the small example of just 21 dolines of that category. We hoped to get some reliable results by doubling this number. Furthermore, some recent studies of karst depressions also used approximately 40 case examples (Šušteršič, 2006; Stepišnik, 2006). The sample in this thesis contains selected examples of uvalas, without the exact idea about the size and distribution of the overall population in the studied area.

Applied statistical procedures can be categorized to three groups of statistical analyses: descriptive statistics, exploratory statistics, and inferential statistics.

Descriptive statistics are used to summarize and describe a collection of data. Within this group, we applied the measures of central tendency – the mean and the median, as well as a measure of dispersion (standard deviation) referring to the mean value.

Exploratory statistics, used for data analyses aiming to formulate hypotheses for testing, were applied through the cluster analysis and multidimensional scaling.

Among the methods of **inferential statistics**, we have used the confirmatory data analysis – chi-square test for independence; as well as correlation analysis – identifying a number of correlation coefficients to detect linear relationship between particular variables. Chi-square test was used to process the nominal (categorical) sets of data, while correlation analysis was applied to the data measured on interval scale.

Descriptive and inferential statistics were performed with the help of *MS Excel*, and in exploratory statistics, the software *Statistica 6* was used.

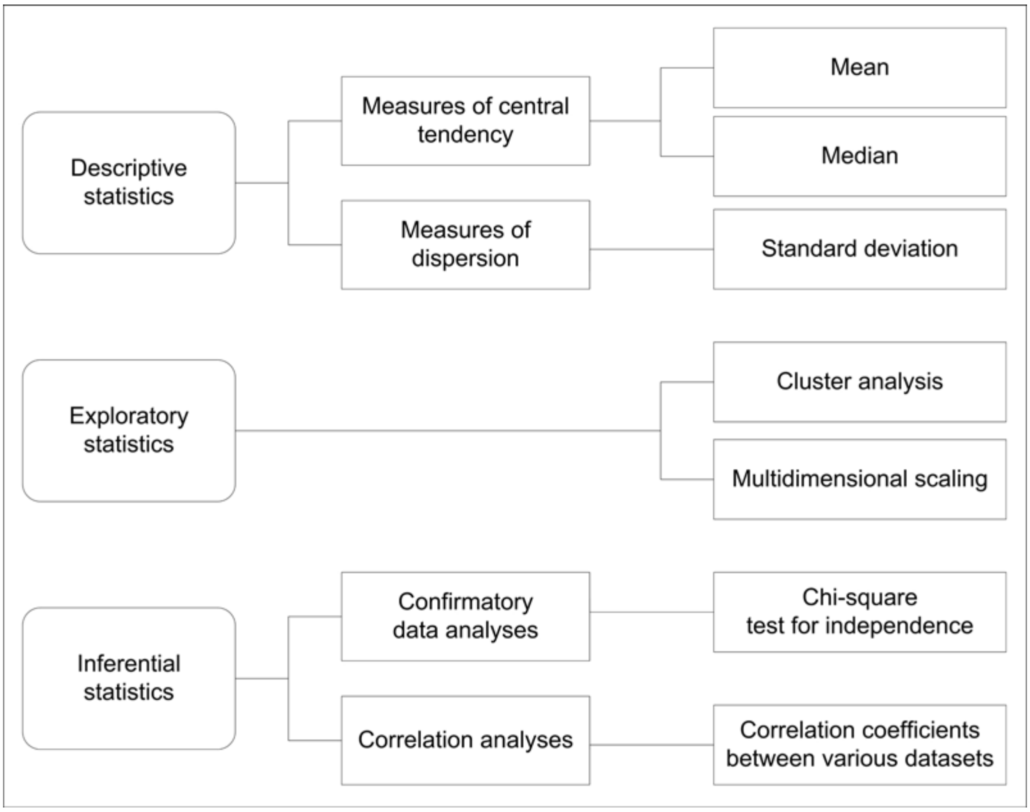

Fig. 4.6: Applied statistical procedures

4.6. Geographical information system

Geographical information systems can be either vector based, or raster based. Raster based GIS used in this study has already been explained in the chapter 4.3 (Digital processing).

Formation of vector based Geographical Information System of the studied uvalas has been done using the software *GeoMedia Professional 04* (designed by the *Intergraph Corporation*). The data storage space is defined in geographic Lat/Long coordinate system, geodetic datum WGS 84, while the output maps of the overall studied area are made in Lambert Conformal Conic projection.

The system comprises all the relevant information obtained during the study:

- exact locations of uvalas, defined both by the highest closed contours and topographical divides
- elevation data
- morphometric data, both measured and calculated
- orientation of long axes diameters

- nominal data referring to qualitative parameters (dominant lithological elements, morphology of the bottom, presence of hydrological elements, vegetation, indications of Pleistocene glaciation processes).

Within the system, sets of data are organized as a relational database. Each group of data (e.g. elevation parameters of uvalas) enters a system separately, and is subsequently linked to other groups through relational models. In this way it is easier to make inputs into the system, to make updates and corrections, to extract the needed data, to combine certain parts of the database, etc. The primary key attribute is always the ID number of an uvala, which is of course unchangeable throughout the study. The database can be accessed and updated both through *GeoMedia* and *MS Access*.

5. Selected field examples

For the purposes of this study, it was necessary to select a certain number of case examples. We decided to choose the area of Dinaric karst, as the area of typical development of temperate karst, and the region where the term uvala originated. On the other hand, we opted also for a part of Carpatho-Balkan mountain range, for both karstological (karst characteristics) and historical reasons (Cvijić explorations). Karst of the Carpatho-Balkanides in Eastern Serbia differs to a great extent from the Dinaric karst – the limestones are of much smaller thickness, and are distributed in small patches, causing frequent occurrences of contact karst and fluviokarst features.

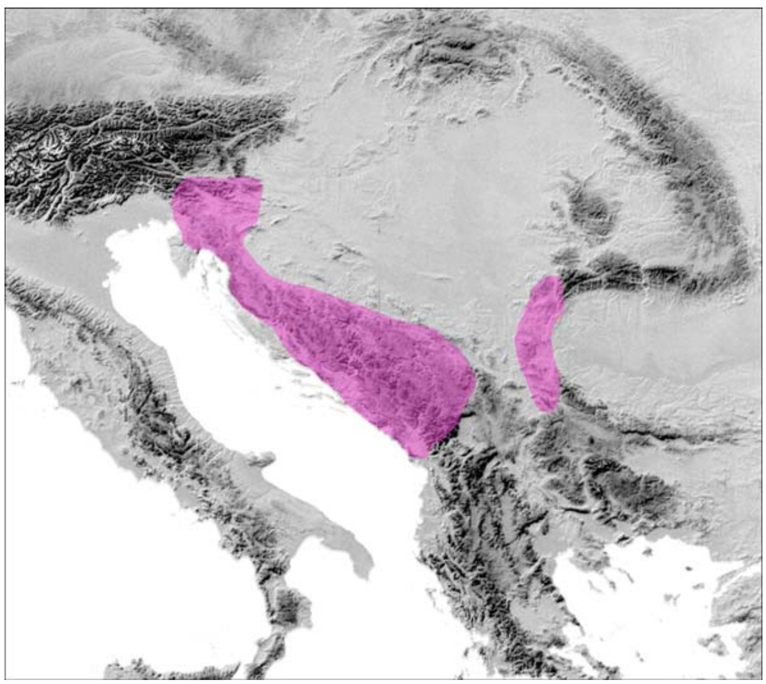

Fig.5.1: Areas of research

By searching through the literature and topographic maps, as well as from observations in the field, the final list of 43 karst uvalas was established. All case examples are listed in Tab. 5.1. The locations are divided by countries just for easier orientation, without the intention that the countries are equally represented.

Tab. 5.1: Uvalas included in the study

country	ID	uvala	location	closest municipal center
Slovenia	**1**	Kanji Dol	Trnovski Gozd, Črni Vrh	Idrija
	2	Mrzli Log	Trnovski Gozd, Črni Vrh	Idrija
	3	Hrastov Dol	Dolenjska, Suha Krajina	Ivančna Gorica
	4	Ravan	Bloke Plateau, Metulje	Bloke
	5	Grda Draga	Mt.Snežnik, Mašun	Ilirska Bistrica
Croatia	**6**	Lomska Duliba	Northern Velebit	Senj, Otočac
	7	Veliki Lubenovac	Northern Velebit	Senj, Otočac
	8	Bilenski Padež	Central Velebit	Senj, Otočac
	9	Brizovac	Central Velebit	Karlobag
	10	Crni Dabar	Central Velebit	Karlobag
	11	Ravni Dabar	Central Velebit	Karlobag
	12	Došen Duliba	Central Velebit	Karlobag
	13	Konjsko	Southern Velebit	Karlobag
	14	Duboke Jasle	Southern (SE) Velebit	Gračac
	15	Duboki Dol	Southern (SE) Velebit	Gračac
	16	Glibodol	Mt.Mala Kapela	Brinje
	17	Mala Kapela	Mt.Mala Kapela	Brinje
	18	Čorkova uvala	Mt.Mala Kapela, Plitvice	Plitvička Jezera
	19	Jasenova Korita	Trnavac - Homoljačko polje	Plitvička Jezera
	20	Razdolje	Krbavica - Krbavsko polje	Plitvička Jezera
	21	Vagan Mazin	Mazinsko polje	Gračac
	22	Vagan Popinski	Southern (SE) Velebit	Gračac
	23	Poljica	Imotsko polje	Imotski
Bosnia and Herzegovina	**24**	Rupa	Mt.Grmeč	Bosanski Petrovac
	25	Materića uvala	Mt.Lunjevača	Drvar
	26	Crljivica	Mt.Osječenica	Drvar
	27	Klekovačka uvala	Mt.Klekovača	Drvar, Potoci
	28	Razvala	Mt.Dinara	Livno
	29	Ždralovac	Mt.Velika Golija	Livno, Glamoč
	30	Poljanica	Mt.Cincar	Livno
	31	Ljubodol	Hrbina	Livno, Kupres
Montenegro	**32**	Vuči Do	Oputne Rudine	Nikšić
	33	Baljački Do	Oputne Rudine	Nikšić
	34	Štrpca	Banjani	Nikšić
	35	Broćanac Nikšićki	Katunski Kras	Nikšić
	36	Ljeskovi Dolovi	Katunski Kras	Nikšić
	37	Ubaljski Do	Katunski Kras	Nikšić
	38	Dragomi Do	Katunski Kras	Kotor, Cetinje
	39	Ilinski Do	Katunski Kras	Kotor, Cetinje
	40	Dolovi	Mt.Lovćen	Cetinje
Serbia	**41**	Veliko Igrište	Mt.Kučaj	Paraćin
	42	Baševica	Tepoš Plateau, Mt.Vidlič	Pirot
	43	Ovča	Tepoš Plateau, Mt.Vidlič	Pirot

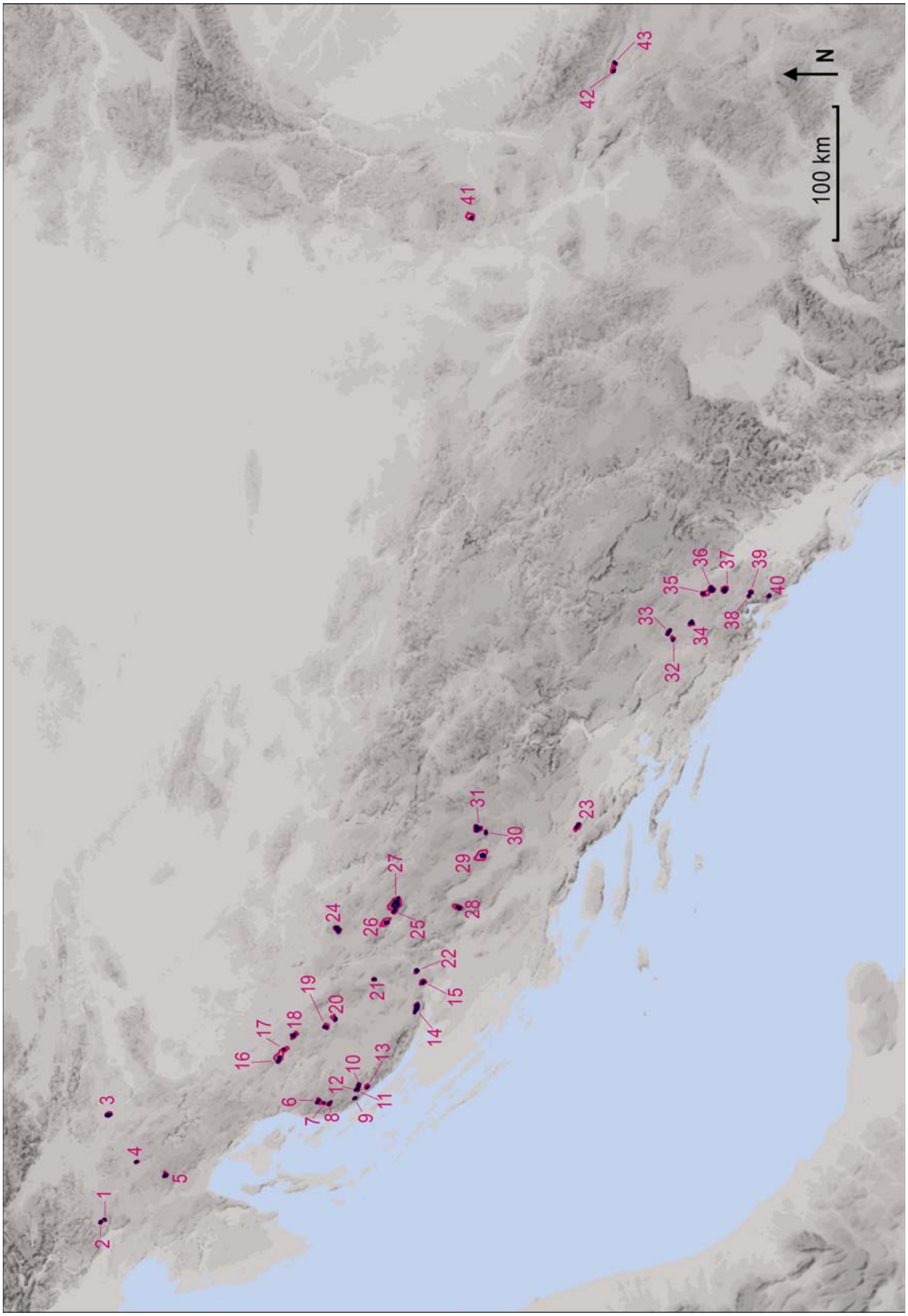

Fig. 5.2: Overview map of the studied uvalas, marked with ID numbers (see in landscape page orientation)

During selection of field examples for the study, the depressions had to meet at least two of the following morphographic requirements: (a) irregular shape of perimeter (either the highest closed contour or topographical divide); (b) one of the diametres exceeding 1000 m; (c) multiple swallows within a closed contour, with diameter exceeding 500 m. This does not mean that these are the main characteristics defining the uvala, as the issue of definition will be discussed further in the text. The mentioned requirements were the approximate criteria chosen *before* the study in order to avoid possible "mixing" of various kinds of depressions.

Selected examples are situated at various elevations (Fig. 5.3), in the complete elevation span in which uvalas occur within the studied areas.

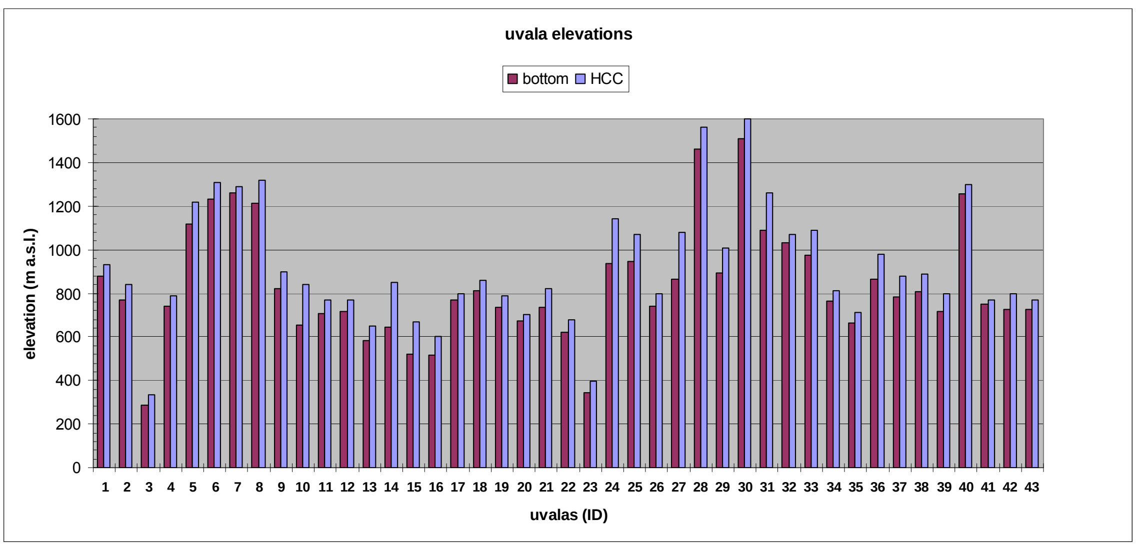

Fig. 5.3: Elevations of the studied uvalas (lowest points and highest closed contours)

Considering the fact that majority of the studied uvalas are located in the Dinarides (40 out of 43), and that orientations of uvalas mostly follow the general tectonic patterns, the rose diagram with orientations of major diameters (DDIRd values, referring to DMAXd parameter; see chapter 4.2.1) shows dominant Dinaric pattern (Fig. 5.4). Three uvalas located in the Carpatho-Balkanides are left within the rose diagram data sample, because their share generally does not influence the complete diagram outline.

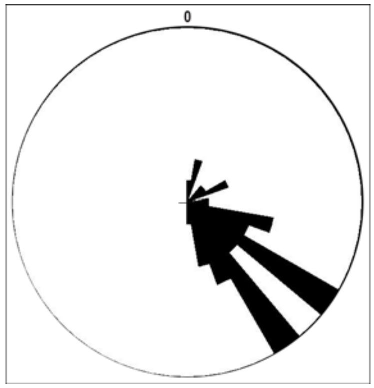

Fig. 5.4: Rose diagram of orientations of uvala major diameters (on the scale 0º-180º)

In the further text, each case example of uvalas will be separately described, both for the main characteristics and the position within the broader morphological unit. Unfortunately, the regions in which some of the uvalas are located are very poorly covered in the available geomorphological literature. The lack of published references has, in some cases, inhibited the appropriate geomorphological outline of the location. Whenever possible, we opted for a comprehensive overview, including the approximate interpretation of morpho-stratigraphy of the region (in the sense of Sauro, 2002). In the cases where the previous studies are missing, it was not possible to carry out the overall geomorphologic study of each area, so only the general ideas on relief evolution are made.

Morphometric data are only sporadically included in overviews of case examples, in order not to be too overwhelming for the text. Values of selected parameters (Pc, Pd, Ac, Ad, HUV, HBAS) are listed within the figures of digital elevation models, so that the reader can easily get the basic idea about uvala dimensions. In the DEM figures, the lowest points of uvalas are marked with pink dots, the highest closed contour is the red line, while the blue line represents the topographical divide. For more detailed morphometrical data, the readers are kindly asked to refer to the Appendix 2, where all the measured and computed parameters are listed in a table.

5.1. Dinaric karst

In many references, the Dinarides are considered a southern branch of the Alpine-Mediterranean orogenic belt, stretching from the Southern Alps in the north-west to the Hellenides in the south-east. According to Coward and Dietrich (1989), the inland part of the Dinarides belongs to the internal units of the Alpine chain, containing oceanic crust and sediments affected by Alpine metamorphism, while the belt along the Adriatic Sea is a part of the external units, consisting of sedimentary nappes only slightly affected by Alpine metamorphism. One of the crucial factors in the formation of the Dinarides was the motion of the Adriatic microplate: moving towards the north-east, with anticlockwise rotation (Coward and Dietrich, 1989; Battaglia et al. 2004). Strong compression during the Tertiary (starting from the Late Eocene), has resulted in the uplift of the Dinarides. According to Pamić et al. (1998), fold, thrust, and imbricate structures strike in NW-SE direction, and the dominant tectonic transport direction is towards the south-west. The same authors add that "The southwesterly vergence of the Dinaridic NW–SE-trending folds and thrusts, which were formed during this main deformational event, suggest a north- to northeast-dipping subduction".

Among many geotectonic interpretations of the Dinaric belt, one of the most cited is Herak (1986), in which four structural units are distinguished: Adriaticum, Epiadriaticum, Dinaricum, and Supradinaricum (Fig. 5.5). Adriaticum is in fact the Adriatic carbonate platform, placed in between the Apenninic and Dinaric structural complexes. Epiadriaticum refers to the interplatform labile belt, which is a transition between the Adriaticum and the Dinaricum (Dinaric carbonate platform). Compression from the north-east and south-west causes continental subduction of the Adriaticum under the Dinaricum, and there are subsequent gravitational displacements as well (Herak & Tomić, 1995). The fourth structural unit within this system, from the Dinaricum towards the north-east, is called the Supradinaricum. It contains some elements of the pre-Alpine basement, incorporated into the recent structures of the area known as the Inner Dinaric belt (Herak, 1986).

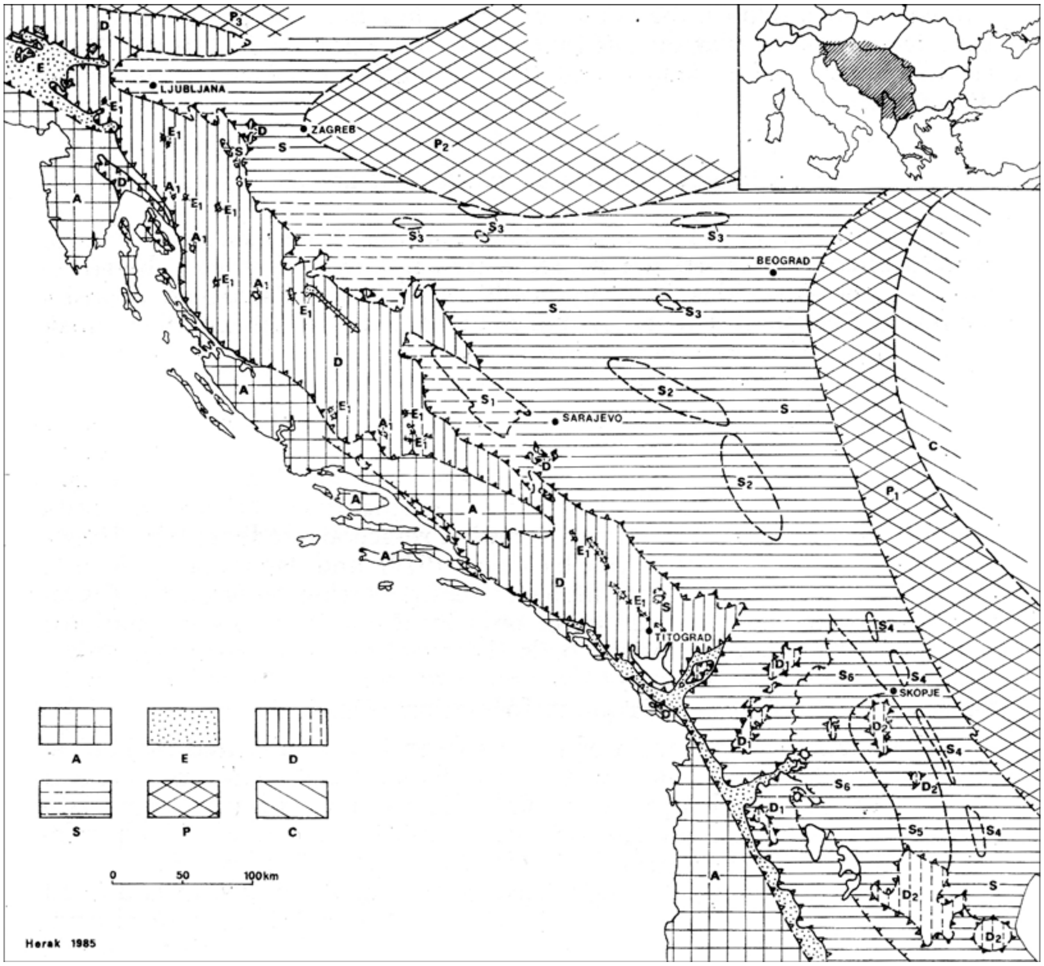

Fig. 5.5: Simplified general tectonic map of the Dinarides (Herak, 1986)

A – Adriaticum (with tectonic windows A1); E – Epiadriaticum (with tectonic windows E1); D – Dinaricum; S – Supradinaricum; P – Paradinaricum; C – Carpatho-Balkanides

Although the cited concept is relatively widely accepted among the geologists studying the Dinaric area, there are also opposing concepts, supporting the model of only one carbonate platform (Adriatic; AdCP), existing on the Adria Microplate during the Mesozoic (Vlahović et al., 2002, 2005). According to these authors, deposits which can be attributed to the AdCP range from the top of the Lower Jurassic to the top of the Cretaceous, while the formation of the Dinarides took place during the tectonic events which culminated in the Oligocene-Miocene. For that reason, and due to the fact that the Dinarides to a large extent consist of the rocks not originating from the AdCP (from the Middle Permian to the Eocene, i.e. more extensive in time span than the AdCP), Vlahović et al. (2002, 2005) consider that the term Dinaric carbonate platform should not be used.

Anyhow, since our study is not directly related to the sedimentological issues of the Dinarides, the presented short review of the main concepts is sufficient for the basic understanding of paleogeography of the area.

Carbonate deposits of the Dinarides are 4500 up to 8000 m thick (Tišljar et al., 2002). Depth of the zone of vertical karstification varies regionally, but it is considered that on average, karstification reaches deeper below sea level towards the south-east (Gams, 1969). The very first occurrences of karstification date back to the phases of emersion during the existence of the Adriatic (or Adriatic and Dinaric; see above) carbonate platform. These episodes have been characterized by bauxite deposition, like Kimmeridgian bauxites in the Nanos area in Slovenia (Dozet et al., 1993). Other dry phases have been reported as well (e.g. Matičec et al., 1996), although, of course, not uniformly and simultaneously along the Dinarides, but in particular smaller areas and in various periods of time. Detailed stratigraphy of bauxites in the Dinarides was given by Grubić (1964, cit. by Milovanović, 1965). After the strongest phase of tectonic uplift of the Dinarides, during the Neogene, few authors (e.g. Nicod, 2003b) mention the karstification of tropical type, with formation of coalescent depressions and residual relief forms like "glavica" and "hum". However, the articles referring to this period of paleokarstification in the Dinaric karst are very scarce. The features that link, perhaps in most apparent way, the period of pre-Quaternary karstification(s) and present karstic relief are unroofed caves. Up to now, they have been most systematically studied in Slovenia (Mihevc et al. 1998; Mihevc, 2001, 2007; and others), and there are reasons to believe that the spread of such studies in other parts of Dinaric karst will give most valuable new notions on ancient karstification phases.

With the advance of the Quaternary, particularly Pleistocene, the Dinarides have been subject to certain degree of glaciation (most of the high mountains) and wide spread of periglacial processes (great portions of areas below the Pleistocene snowline). Glacial traces have been reported on a number of mountains exceeding the elevation of 1000-1200 m a.s.l. (Cvijić, 1899; Milojević, 1937; Roglić, 1958; Šifrer, 1959; etc). In most cases, the glaciers of cirque or valley type have used the previously formed karst depressions for ice accumulation and transport. In lower areas, the periglacial environments have played a major role in the development of new and re-shaping of previously existing karst closed depressions. Many authors assign considerable importance to this process (e.g. Habič, 1991; Šušteršič, 1994; Gams, 2000).

Although particularly the Kras region in south-western Slovenia (and part of Italy) is the real "locus typicus" of the term karst (Kranjc, 1998), we can undoubtedly say for the whole Dinaric region that it is a world-wide recognized specimen of karst geo-system and cradle of karstology as a science. Roglić (1969) differentiates two main types of karst in the Dinarides – "deep" karst and fluviokarst.

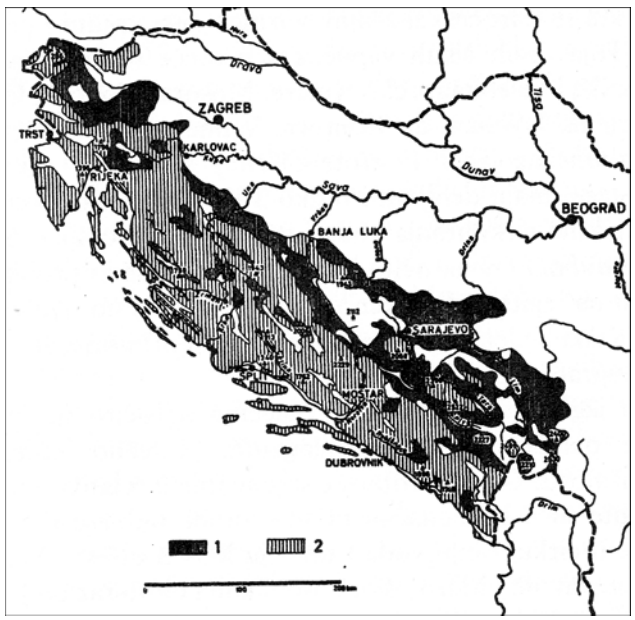

Fig. 5.6: Dinaric karst, according to Roglić (1969) (1 – fluviokarst; 2 – deep karst)

The regions consisting of relatively clean Upper Jurassic, Cretaceous and Paleogene limestones are characterised with full development of all karstic forms to considerable depth in the carbonate sequence. Roglić (1969) calls this belt "high" karst or "deep" karst (Fig. 5.6). He also stresses the role of other type of karst – fluviokarst – in the general landscape of the Dinarides ("extensive areas composed of Lower Mesozoic dolomites and impure limestones (…) with combined processes of corrosion and slopewash").

To conclude about the karst evolution in the Dinarides, it may be good to cite Milovanović (1965): "The Dinaric holokarst is formed in the discontinuous and genetically complex succession of various karstification phases, and consists, as a whole, of the combination of recent karst and stratigraphically various paleokarsts".

5.1.1. Uvalas Mrzli Log and Kanji Dol, on Trnovski Gozd

Trnovski Gozd, mountain range within a wider morphological unit Trnovsko-Banjška Planota, constitutes the area of High Karst in south-western Slovenia. Macro-structurally, Trnovski Gozd lies in the region of contact between the units of Dinaricum and Epiadriaticum (Herak, 1986). This is the area of mountainous karst surrounded by lower non-karstic areas. "Conical shaped summits and intermediary ouvalas developed by limestone weathering and by superficial and karst debris washing off" (Habič, 1991). Uvalas Mrzli Log and Kanji Dol are situated in eastern part of Trnovski Gozd, in the orographic units Križna Gora and Javornik. Lithologically, this area consists mainly of Upper Triassic Norian-Rhaetian dolomite, with local occurrences of limestones of the same age, as well as Jurassic limestones (Čar, 1997).

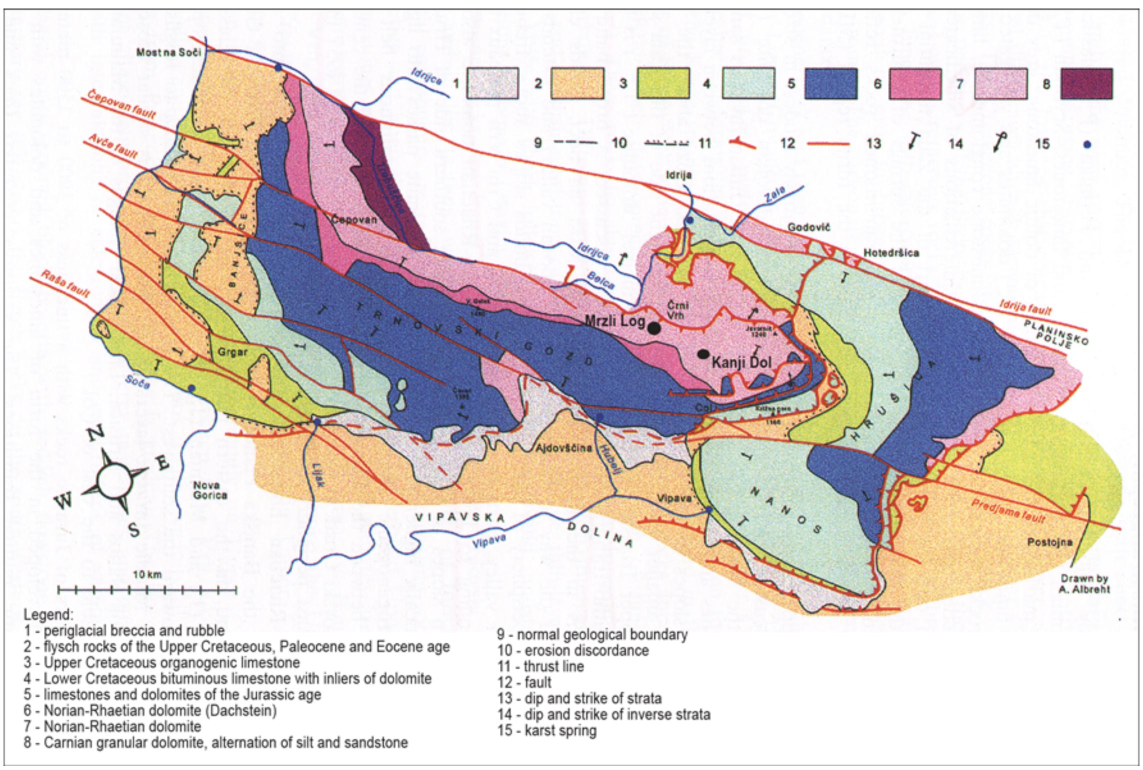

Fig. 5.7: Geological sketch of Banjšice, Trnovski Gozd, Nanos and Hrušica (Čar, 1997), with added positions of Mrzli Log and Kanji Dol

All these lithostratigraphical units are situated within a major overthrust structure, which is from north and south bounded by regional strike-slip faults – Idrija fault on the north and Predjama (Avče) fault on the south. Such a position caused the existence of numerous tectonically fractured zones in the study area.

Fig. 5.8: Uvala Mrzli Log, view from the north

Uvala **Mrzli Log (ID_2)** is situated to the SW from the settlement Črni Vrh. Its bottom lies at the altitude of 768 m a.s.l, while the highest peak at its northern rim reaches 1069 m (Špik). The highest closed contour is that of 840 m, encircling the planimetric area of 0.75 km^2. The uvala is of irregular shape; it is an asymmetrical heart-like shape, with larger western lobe covered with dolines, and smaller eastern lobe with more or less flat bottom covered with sediments and several alluvial dolines. Habič (1997b) mentions Mrzli Log as "a large ouvala, with partially filled up and partially doline-like bottom". Tracing experiment showed that Mrzli Log is situated in a recharge area of the karst spring Podroteja, close to Idrija (Zupan & Reichert, 1997), which is more than 400 m below the uvala bottom. The whole uvala is formed in the above-mentioned Norian-Rhaetian dolomites, in which stromatolites can be observed. Detailed structural-geological mapping has shown that two dominant orientations of fissures are present: 110/80 and 40/90. These orientations point to the structures striking in directions 20-200º and 310-130º, which exactly explain the morphology of this uvala. Two distinctive broken zones, with observable fragments of crushed zones, can be followed along the direction 310-130º, which is the direction of the larger lobe of the uvala.

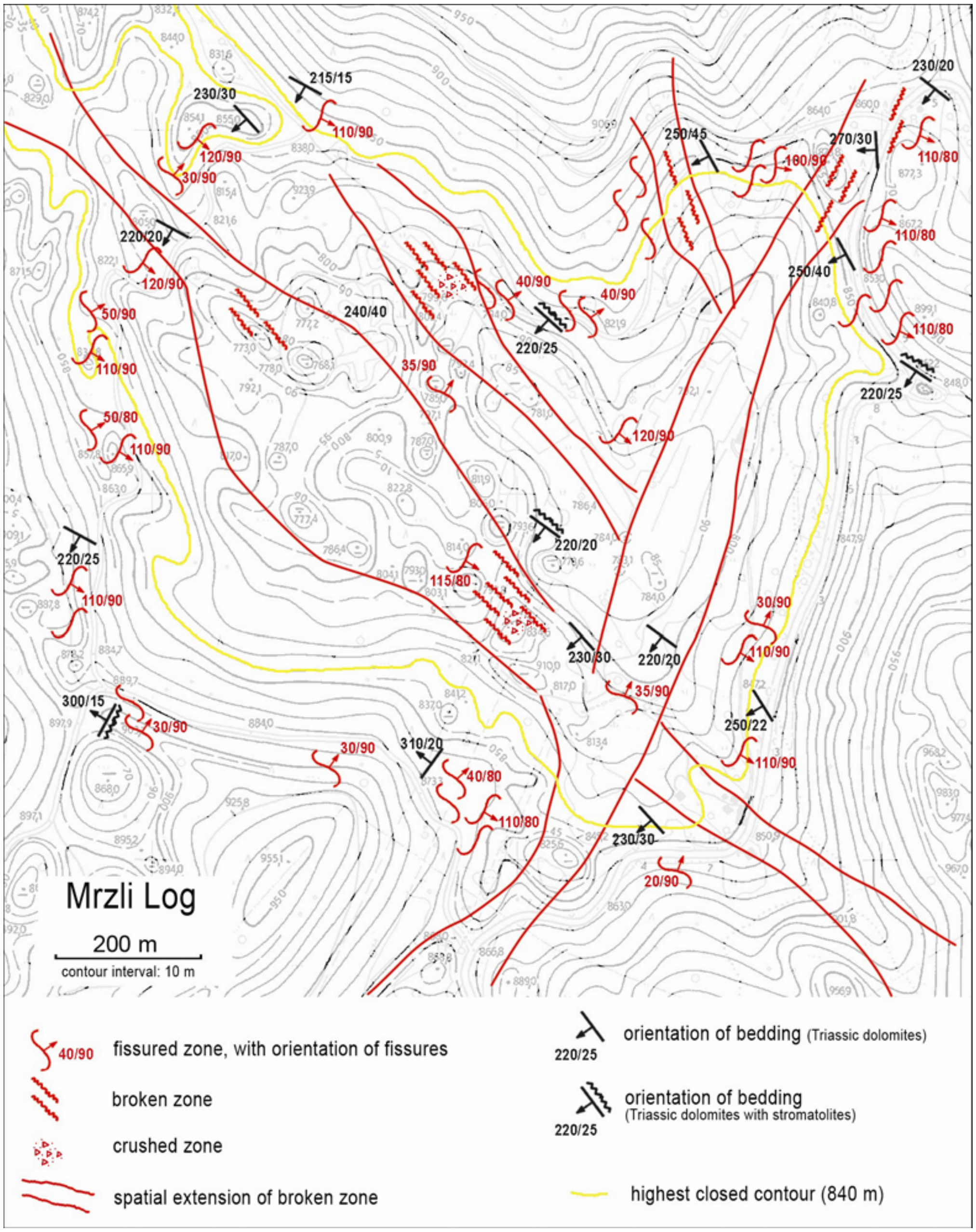

Fig. 5.9: Structural and lithological settings in the uvala Mrzli Log

Fig. 5.10: Outcrop of broken zone in north-western part of Mrzli Log

Genesis and development of Mrzli Log can be better explained if we take into account Kanji Dol – another uvala studied in this area. **Kanji Dol (ID_1)** is situated about 3 km to the south-east of Mrzli Log.

Fig. 5.11: Uvala Kanji Dol, view from the south-east

The lowest point of Kanji Dol lies at 880 m a.s.l, while the highest peaks in its closest vicinity exceed the altitude of 1100 m (Habatov Vrh 1176 m; Črtež 1119 m). The highest closed contour is at 930 m, below which the depression volume equals 8.93 millions of cubic meters.

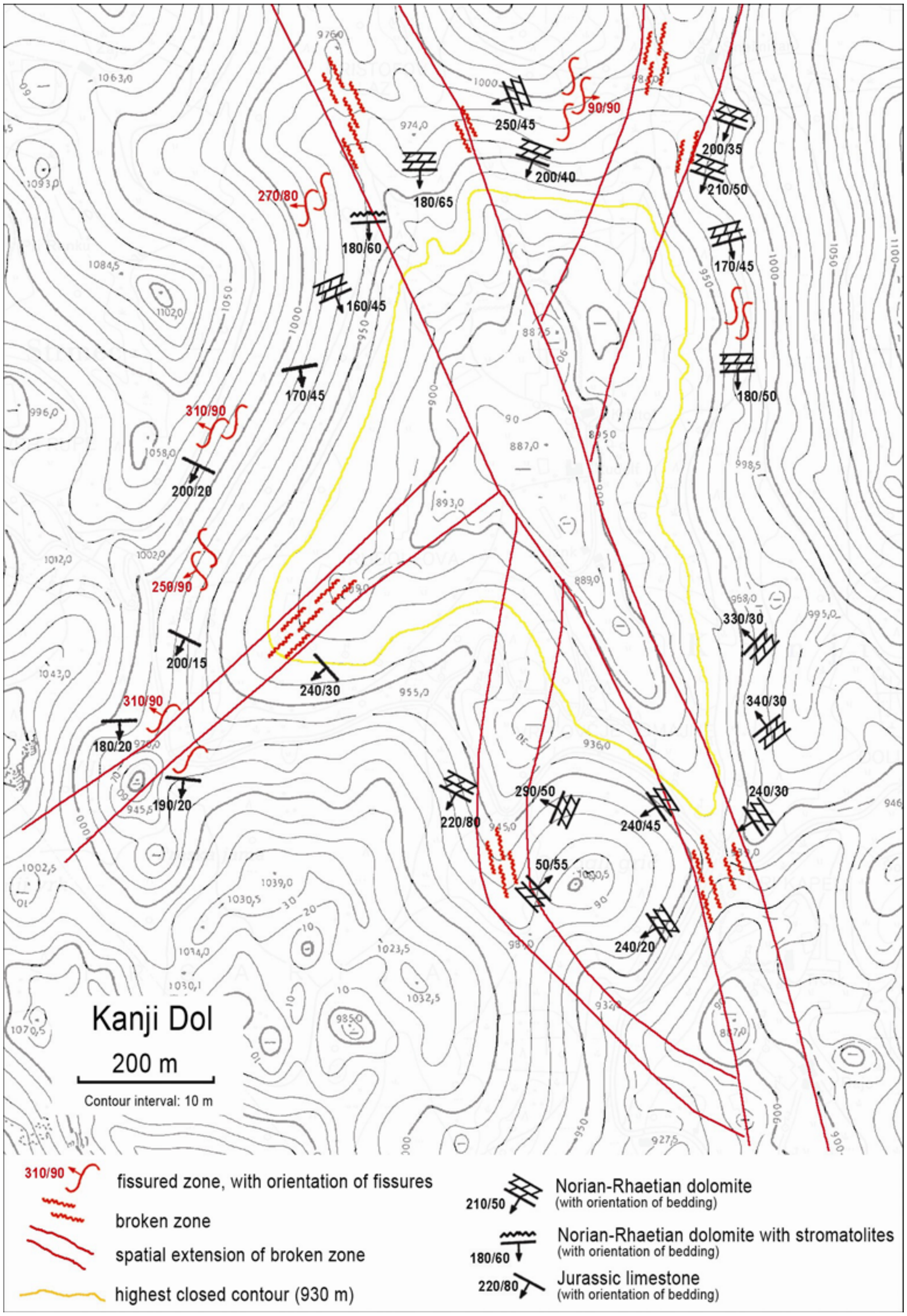

Fig. 5.12: Structural and lithological settings in the uvala Kanji Dol

South-western part of the uvala is developed in Jurassic limestones, while the other parts are in Norian-Rhaetian dolomites. Rocky ridges at places protrude through a layer of thin sediments at the bottom, but generally the surface is undulating, with scattered dolines.

Structural and lithological mapping revealed an interesting cluster of tectonically fractured zones which guided the development of the uvala. A broken zone reaches the uvala from the NNW, and continues through the most elongated lobe towards SSE. Another broken zone, from the direction of Snežnikar on the north, feeds into the previously mentioned zone, while the third branch is joining from the south-west.

If we analyze this area altogether, we can see that there is a prominent broken zone which starts from the polje of Zadlog (J. Čar, pers.comm.), extends through Mrzli Log uvala, across NE foothill of Črtež, to Kanji Dol uvala. Further on towards south-east, this zone continues through the dry valley Široka Dolina, and turns towards east to Vodice. Part of this zone is mentioned by Habič (1997b), as a *relief gap*: “there is a deep relief gap which starts at Vodice with a small margin karst polje, continues with elongated ouvala Široka Dolina and ends in the ouvala of Kanji Dol”. Now we can see that this zone extends further to Zadlog and that it played a major role in formation of deep closed depressions of the eastern part of Trnovski Gozd.

There still remains an open question of the deepest and most conspicuous depression in the area – Malo Polje, to the east of Kanji Dol. Habič (1997b) calls it “half open ouvala”, but we are not sure whether it is an appropriate definition. Obviously, this problem is waiting for some future research.

Considerably dissected relief with high peaks and deep depressions can be partially contributed to dolomite lithology and high extent of tectonic fracturing of the rock. This enhances denudation, and in combination with abundant precipitation (>2000 mm; Pristov 1997), attributes to the development of such morphology. Furthermore, as stated by Habič (1991), “in cooler Pleistocene periods the waters deepened karst depressions mostly”. While in higher ridges of Trnovski Gozd deep dolines are often filled with glacial scree, the lower portions host some subglacial nival forms (Habič, 1991).

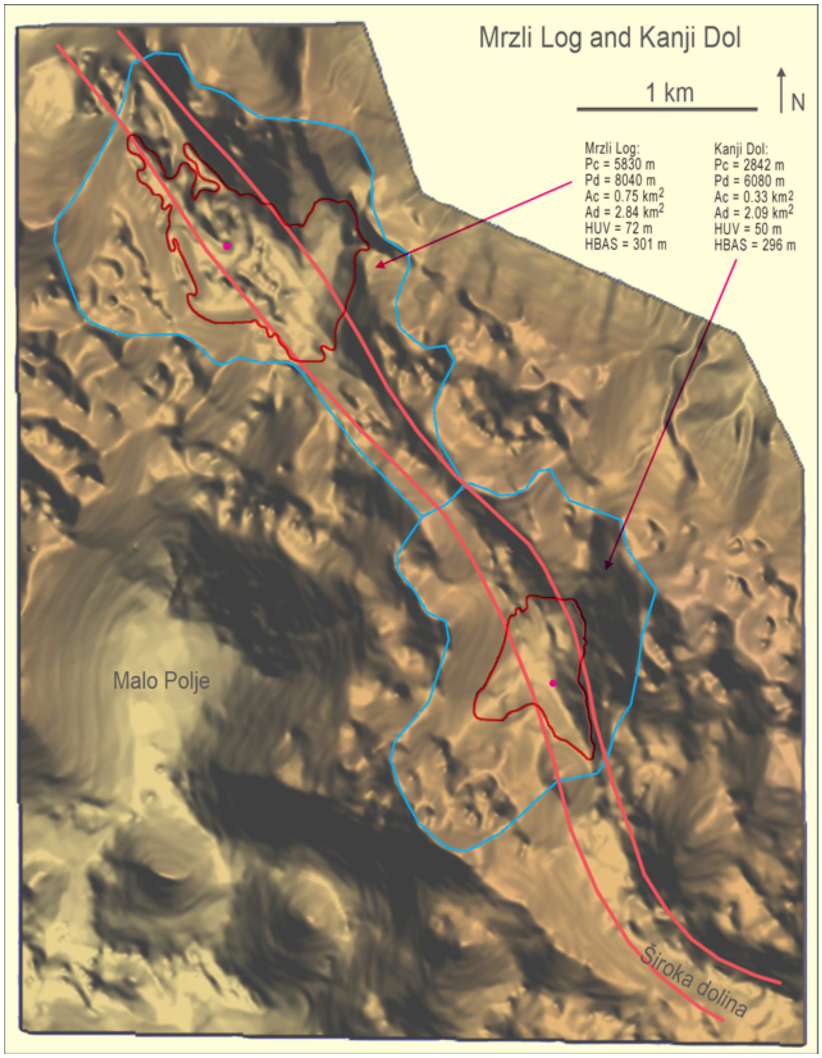

Fig. 5.13: Digital elevation model of the vicinity of Mrzli Log and Kanji Dol (thick red lines represent spatial extension of a regional broken zone)

5.1.2. Uvala Hrastov Dol, the region of Suha Krajina (Dolenjska)

The uvala **Hrastov Dol (ID_3)** is situated in the Slovenian region of Dolenjska, on a low karst plateau ranging in elevation between 300 and 500 m a.s.l. This plateau, between the Krka River on the south and Temenica River on the north, is also known as eastern Suha Krajina (Habič, 1988). The geological map by Buser (1965) shows that the uvala Hrastov Dol is formed in the Upper Jurassic limestones, and filled with Plio-Quaternary clays which were probably deposited when the water table was closer to the surface

(Knez et al., 2004). An extensive fault passing along the north-eastern rim of the uvala is called the Stična fault. Its direction is typically dinaric, and it is one of the principal faults around the "Sava compressive wedge" (Placer, 1999).

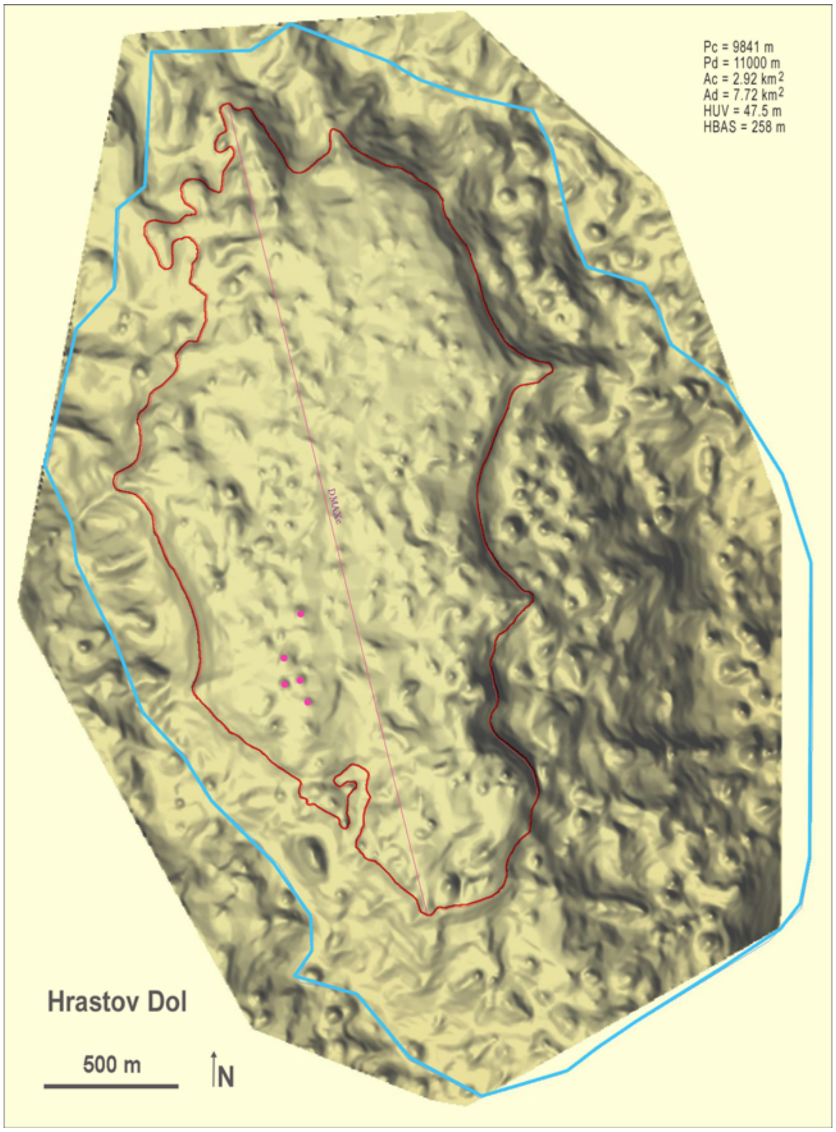

Fig. 5.14: Digital elevation model of the uvala Hrastov Dol (grid resolution 5 x 5 m)

According to Habič's (1991) geomorphological classification of Dinaric karst in Slovenia, the surroundings of Hrastov Dol are a part of karst margin plains and pediments of the Suha Krajina region, on the border of the Pannonian basin. Most karst ridges and interlying depressions are oriented in north-south direction. The bottoms of karst depressions lie in the zone of karst floodwaters, or just a little above it (Habič, 1991).

Hrastov Dol is, by elevation, the lowest among the uvalas included in this study. Five bottom points lie at 287.5 m a.s.l. The highest closed contour is at 335 m, while the highest point along the topographical divide is Trnovski Grič (545 m), at the eastern side of the depression. Hrastov Dol can be considered a rather large uvala, with the planimetric area of 2.92 km^2 within the 335 m contour. Slope inclinations are mild (Fig. 5.15), as well as the whole surrounding relief, so we can suppose that the development of slopes is in the steady-state condition.

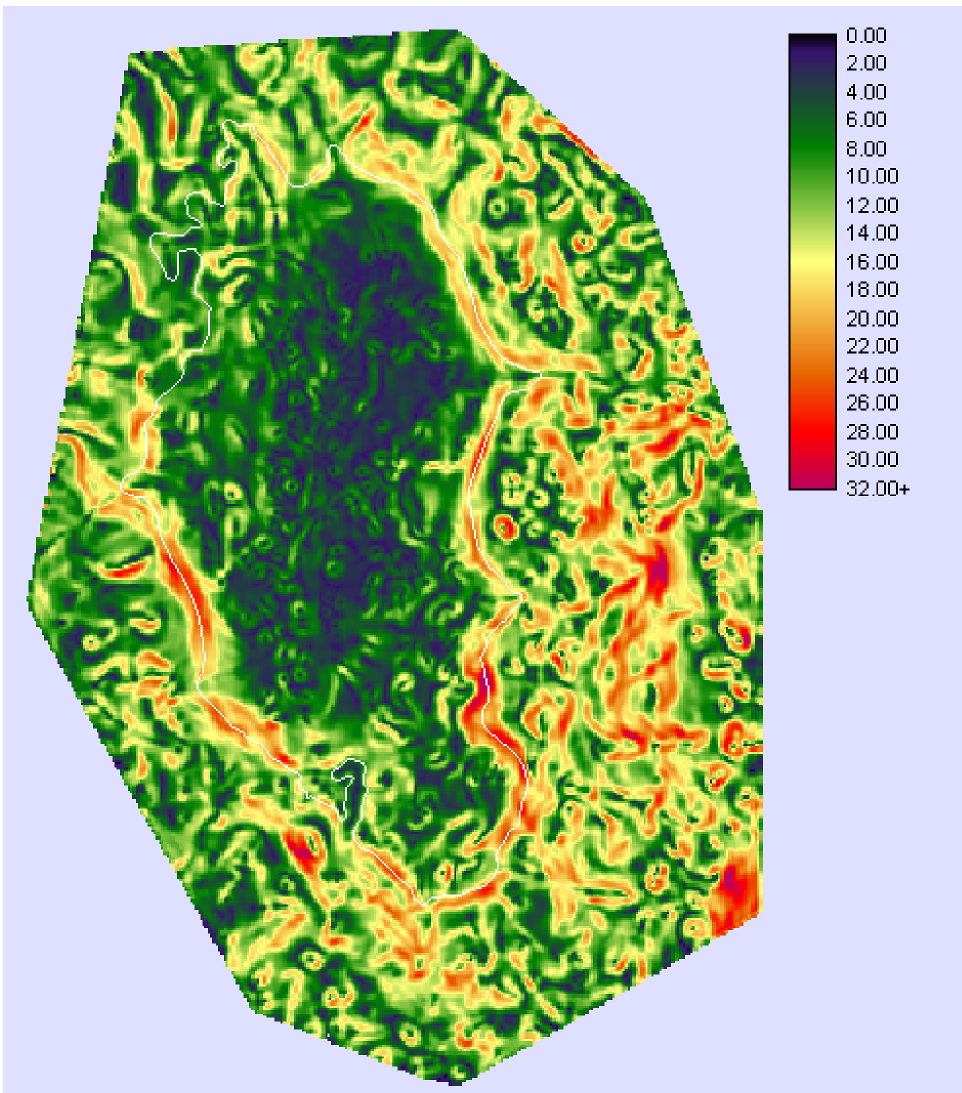

Fig. 5.15: Slope inclination map of Hrastov Dol (grid resolution 10 x 10 m)

The dominant landscape type in this part of Dolenjska lowland is a shallow fluviokarst with “normal” surface valleys which are usually dry, but occasionally active, during heavy rainfalls (Knez et al., 2004). Hrastov Dol is situated to the south from the Dob uvala (sometimes called the Dob polje, having some characteristics of both). Gams (1974) states that in the time of higher water table the streams were flowing towards the south and formed the valleys, which have, due to overall karst surface lowering, disintegrated into “dols” (uvalas). The same author (Gams, 2004) also claims that “due to reddish soils and undulating fields in the middle of green woods, as well as a small lake formed at the place of the previous muddy pond, Hrastov Dol is the most picturesque uvala in Slovenia”.

5.1.3. Uvala Ravan on the Bloke Plateau

A small uvala **Ravan (ID_4)** is situated at the south-eastern end of the Bloke Plateau. It is formed in the Lower Jurassic limestones (north-eastern part) and dolomites (south-western part), within the structural unit of Racna Gora brachisyncline (Buser, 1965). The area is not considerably tectonically fractured; the only significant fault stretches in the dinaric direction from Nova Vas towards Loški Potok. The Ravan uvala and Mt.Racna Gora are situated on the south-western block of that fault (Buser, 1974).

Fig. 5.16: Uvala Ravan

(view towards the south, from the low ridge between northern and southern lobe)

According to morphotectonic division defined by Habič (1982) for the Notranjska region, the area of Ravan belongs to the unit "high flat surface" (*"visoka polica"*) north of the Lož polje. Within the geomorphological classification of Dinaric karst in Slovenia, the area of Ravan Uvala is a part of karst margin plains and pediments between Cerknica polje and Velika Gora (Habič, 1991).

This uvala is a compound feature consisting of two connected basins (lobes). The southern part is larger and deeper, with a small dry streambed which channels the occasional flushes of excessive rainwater towards the ponor. As the bottom is covered with a layer of colluvial sediments of uneven depth (there are bedrock protrusions of limestone), we can suppose that a certain amount of water gathers on the sediments and flows through a short channel (about 150 m) to the lowest point (ponor), at an elevation of 740 m.

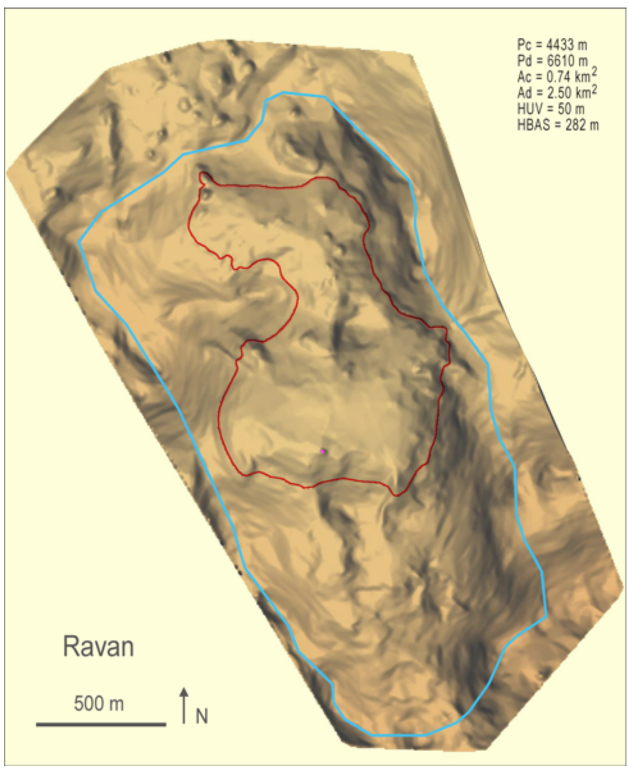

Fig. 5.17: Digital elevation model of the uvala Ravan

Hydrogeologically, Ravan most probably belongs to the drainage area of the karst aquifer between Bloke Plateau and Cerknica polje (the aquifer has been studied by Kogovšek et al. 2008). Dispersed infiltration of precipitation waters from the area of

Ravan might be directed toward the springs Izvir v Podložu (600 m a.s.l.) or Studenec v Ložu (588 m), or even toward Šteberščica spring (563 m); however, no precise data is available up to date.

5.1.4. Uvala Grda Draga on Mt.Snežnik

Grda Draga (ID_5) belongs to the group of uvalas at high elevations (considering the case examples within this study). It is situated on western slopes of Mt.Snežnik in Slovenia, at the elevation of 1120 m a.s.l. (bottom point). Along the western and, especially, north-north-eastern rim, it is possible to see the "real" border of the uvala, along the line of sudden inclination change, similar as those for delineation of dolines (see chapter 4.2.1.1). Unfortunately, this is a very rare case, and only a segment of the perimeter. At the eastern rim we can see an opposite case, where the slope inclination is almost constant up to the peak Mali Snežnik, and the only perimeter which would include this slope into the uvala is the topographical divide.

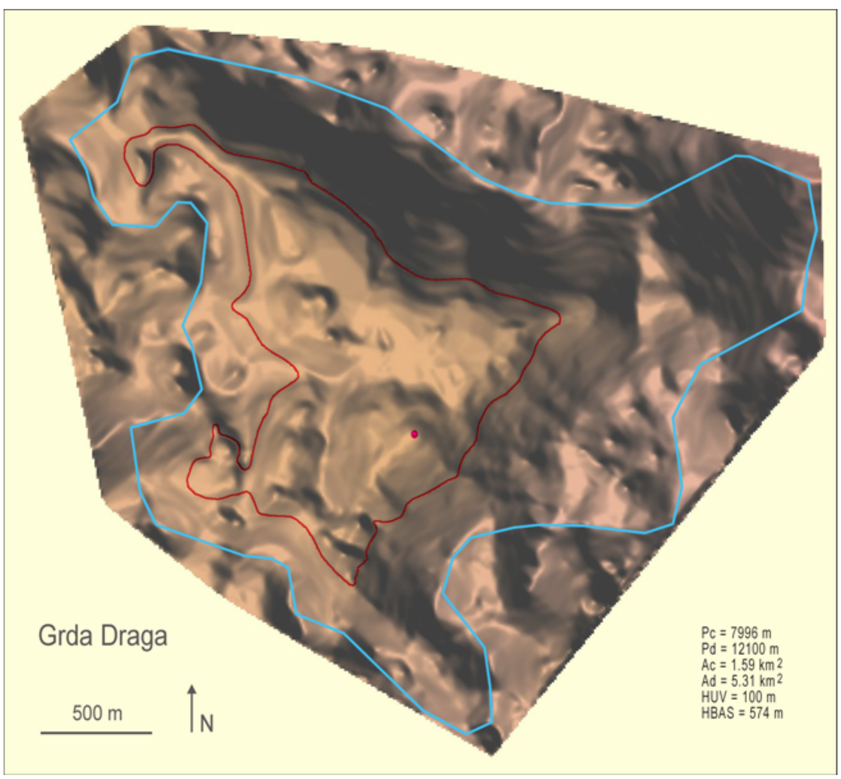

Fig. 5.18: Digital elevation model of Grda Draga

The whole area abounds in various closed karst depressions – dolines, kettles ("kotliči" – snow-dolines with sub-vertical slopes and long-lasting snow accumulations, characteristic for high-mountain karst), and uvalas. Gams (1974) states that "exceptionally deep and wide uvalas are situated on north and north-eastern side of Notranjski Snežnik. Thanks to the existence of roads, the best known are Leskova dolina, Mašun, and Grda Draga, but a number of greater ones on the north-eastern side of Snežnik do not even have the names". According to the geomorphological regionalization given by Habič (1991), Mt.Snežnik belongs to the unit of high conical karst. Lithology in the area of the uvala is rather complex. There are various formations of limestone and dolomite, ranging in age from the Middle Jurassic to the Lower Cretaceous.

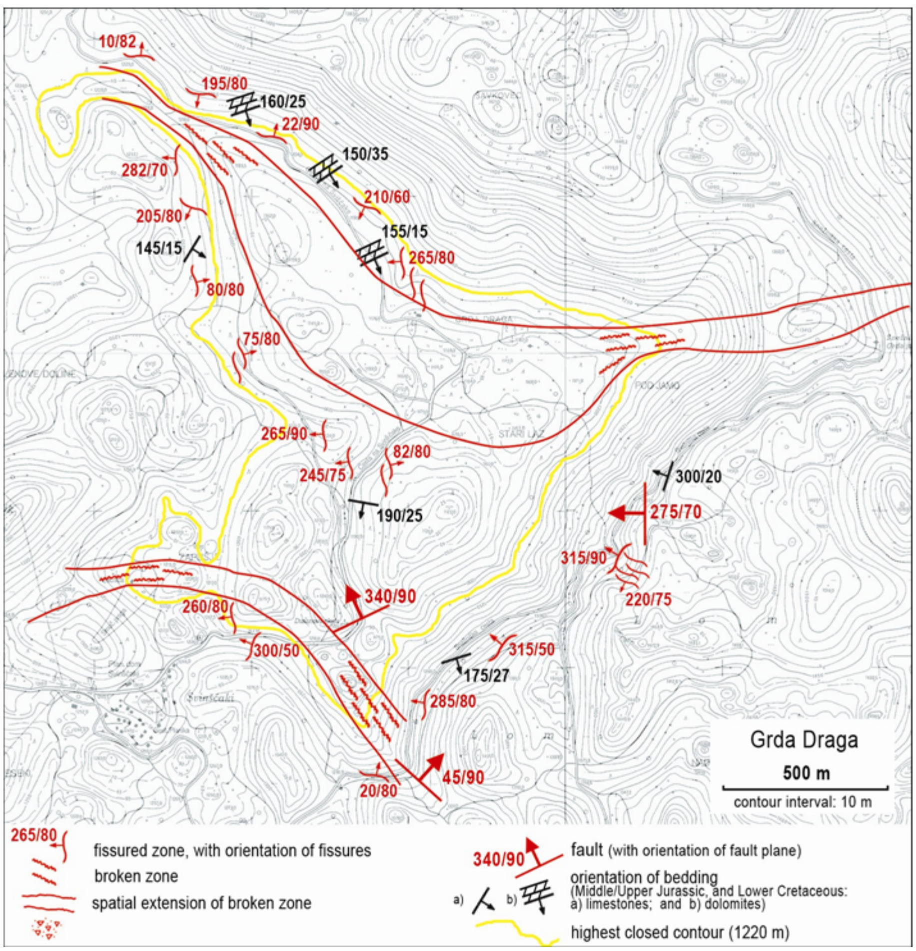

Fig. 5.19: Structural-geological map of the uvala Grda Draga

The area belongs to the structural unit called Jurassic-Cretaceous thrust of Snežnik – carbonate rocks thrusted over flysch (the NE limb of the Brkini syncline). The central part of Snežnik is a horst, whose Jurassic and Lower Cretaceous beds lie almost horizontally around the peak Veliki Snežnik (1796 m) (Šikić et al., 1967).

The results of structural-geological mapping showed that two broken zones are traversing the uvala along the north-eastern and south-western edge, causing its rather irregular planar shape. The dominant structures follow this pattern, and their orientation is on average 20/80. The fissure set of second order is striking approximately north-south (orientations 85/85, 270/90) – these fissures are more numerous, but of lesser importance (Fig. 5.21). There is, however, the registered case in which there were minor movements along these planes (the fault 275/70 at the eastern margin, Fig. 5.17).

Fig. 5.20: The fault plane 275/70, at the eastern part of the uvala

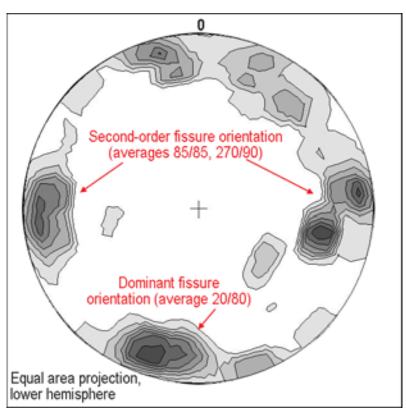

Fig. 5.21: Stereoplot of fissures in Grda Draga (poles of fissure planes)

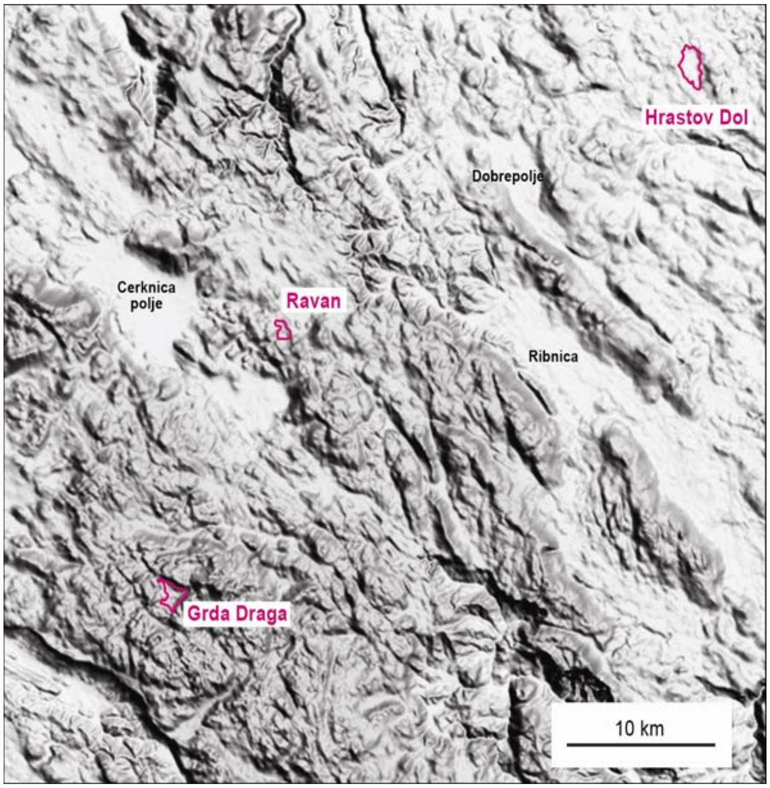

Fig. 5.22: Situation map of the uvalas Hrastov Dol, Ravan, and Grda Draga (mapped on the SRTM DEM)

Mt.Snežnik was glaciated during the Pleistocene. The most detailed study of the glacial traces was done by Šifrer (1959). He detected the directions of glacier movements and the positions of moraines. One of the glacial tongues was moving from the SW of Veliki Snežnik towards the Grda Draga, and deposited its terminal moraine there. The Pleistocene snowline was at the elevation of about 1250-1300 m.

Habič (1991) analyzed the number and dimensions of the closed depressions in the area of Planinca (south of the highest peak), and detected over a hundred forms of kotlič, about fifty dolines, and nearly eighty forms which he named "kotel", ranging in diameter from 50 to 400 m. "The karst depressions reflect long lasting karstification. The effects of glacial and periglacial transformation are expressed" (Habič, 1991).

Zupan Hajna (1997) has studied a particular type of steep-walled depressions very similar to kettles (but also with certain characteristics of shafts), several tens of meters deep and up to 100 m in diameter, which are locally called "ždrocle". They are situated south of the peak Veliki Snežnik, at the levelled surface at 1400 m a.s.l. Their development is a combination of favorable structural conditions in a N-S trending fissured zone (mapped by Zupan Hajna, 1997) and the fact that the snow accumulated at the bottom remains there permanently.

The morphostratigraphic sequence in Mt.Snežnik area encompasses pre-glacial karstification with development of closed depressions of various kinds, subsequent Pleistocene glaciation during which the glacial tongues were reaching a great number of uvalas in the elevation zone above 1000 m a.s.l, and post-glacial karstification accompanied by periglacial processes.

"Development of closed depressions is enhanced also by high precipitation (…) The station in the uvala Mašun, at 1027 m a.s.l, at the northern slopes, receives 2041 mm; 1961-1990" (Gams, 2004).

5.1.5. Uvalas of Mt.Velebit

Mt.Velebit is the longest and most prominent mountain range in Croatia, extending along the Adriatic coast. It has been extensively studied in all fields of geo-sciences for almost two centuries.

Orographically, Mt.Velebit can be divided into three major units: northern, central, and southern Velebit. These units are defined by conspicuous faults. The whole mountain is bordered on the SW by an overthrust Velebit fault, striking along the Velebit channel of the Adriatic Sea, to the Zrmanja River valley (Prelogović, 1995; cit. by Faivre, 2002).

Northern Velebit is defined on the north-east by the Senjsko Bilo fault, which is a dextral strike-slip, and on the south by the normal Bakovac fault. Central Velebit stretches from the Bakovac fault on the north to the Oštarije fault on the south, while its eastern border is the Lika fault, which is of normal type, but covered with Quaternary sediments and not particularly conspicuous in relief. Southern Velebit extends from the Oštarije fault on the north, to the valley of the Zrmanja river on the south-east, while its north-eastern boundary is the Lika fault (op.cit.). The regional tectonic stress, characteristic for the whole Dinarides and directed approximately SW-NE was dominant in formation of Mt.Velebit as well. However, during the Quaternary, change in motion of the Adriatic plate from the NE to the NW direction caused the rotation of structures and change of the faulting pattern, with the new maximum stress oriented in N-S direction (Prelogović, 1995; Prelogović et al., 1998). Geophysical and seismological findings have been confirmed by quantitative geomorphological analyses as well (Faivre & Reiffsteck, 1999; Faivre, 2007).

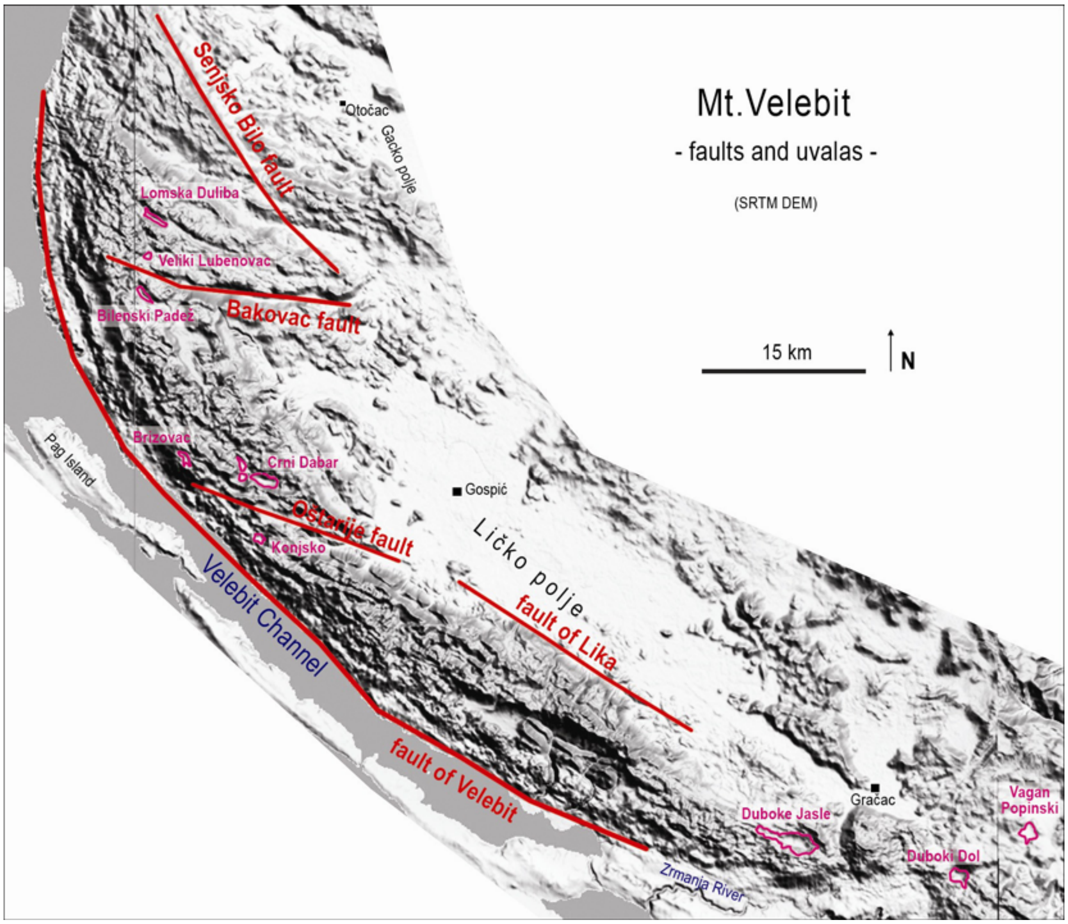

Fig. 5.23: Elements from the structural map of Velebit, by Prelogović (1995), with the positions of the studied uvalas (mapped on SRTM DEM)

The oldest members of the Velebit lithostratigraphic column are Carboniferous and Permian sandstones and schists (exposed only on NE slopes, at the margin of the Ličko polje), as well as Lower Triassic dolomites. Carbonate sedimentation started at the end of the Lower Triassic, and was more or less stable from the Middle Triassic to the Lower Cretaceous. Paleogene is present as the famous Jelar formation, consisting of highly permeable carbonate breccias (limestone fragments with calcite cement) (Sokač et al., 1976a, 1976b; Ivanović et al., 1976b).

The greatest part of the mountain is positioned between the large poljes (Ličko polje and Gacko polje) on eastern and north-eastern side, and the Adriatic Sea on western and south-western side. The total area of Ličko polje, with karstified rocky plains and undulating floor on Paleogene sediments included, is 474 km^2, while Gacko polje is smaller, with 86 km^2 at the average elevation of 450 m a.s.l. (Gams, 1978). The ponors of the Gacka River are situated in Švica region (southern branch of the river) and the region of Brlog and Vlaško polje (northern branch). The Lika River sinks in the Lipovo polje, which is a segment of the Ličko polje (presently, waters from the Lika River are artificially re-directed towards the Gacka River, through a tunnel; Bonacci & Andrić, 2008). The waters from both rivers emerge through a series of submarine springs in the Velebit channel of the Adriatic sea, from Novljanska Žrnovnica on the north to Karlobag on the south (Biondić, 1981).

Thanks to thick carbonate succession and tectonic fragmentation, Mt.Velebit is extensively and deeply karstified. Favorable conditions enabled the formation of the deepest caves of the whole Dinarides, the deepest of which is the system Lukina Jama – Trojama (-1392 m). The deepest explored parts lie only 83 m above the sea level. Entrances to majority of deep caves are situated in the Jelar formation of carbonate breccias, highly susceptible to karstification (Kuhta & Bakšić, 2001).

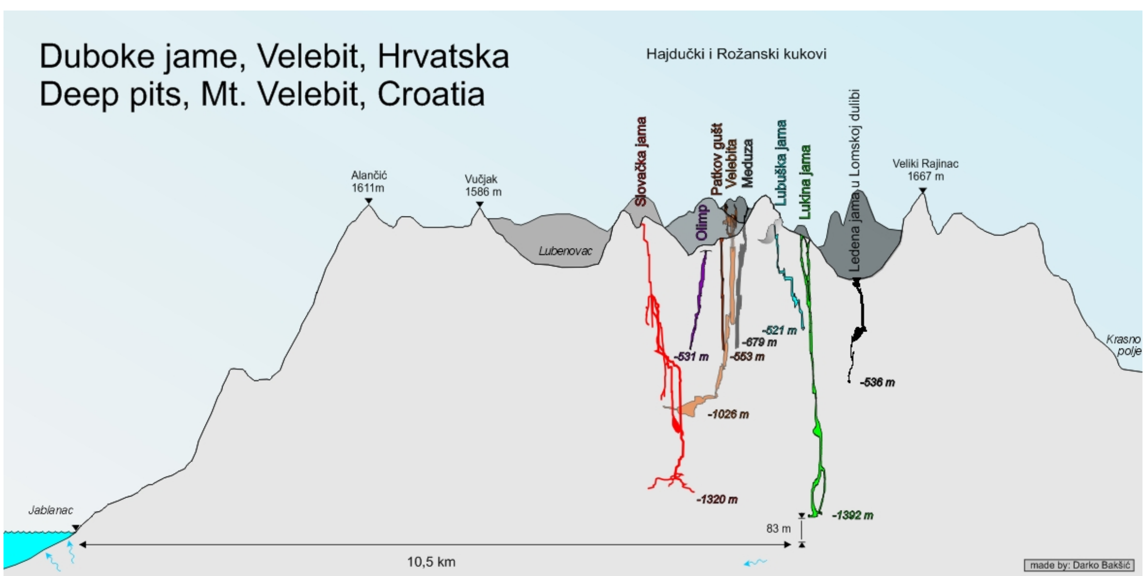

Fig. 5.24: Cross-section through Mt.Velebit, with positions of deep caves (Bakšić, 2008)

Surface karst forms are remarkably developed on Velebit as well. From small-scale features like karren, thoroughly studied by Perica (1998), to dolines and uvalas. Distribution of dolines and their relation to the main structural elements was studied in detail by Faivre (1992; Faivre & Reiffsteck, 1999). Positions of about 40.000 dolines were mapped within the analyses. Their density is higher in northern and central part, where up to 121 dolines per square kilometer can be found (op.cit.). Uvalas were most thoroughly analyzed by Poljak (1951), who claimed that "rare areas are so rich in karstic uvalas as it is Mt.Velebit". Poljak found that most Velebit uvalas are found in the elevation range between 900 and 1250 m, and that their longer axes are conspicuously parallel with the main tectonic directions. High plateau on southern Velebit, thickly pitted with dolines, served as an argument against the Cvijić's cyclic model doline-uvala-polje: "they should coalesce to form uvalas, but uvalas are missing in that part of Velebit" (Poljak, 1951).

Upper parts of the whole Velebit range were glaciated during the Pleistocene. Northern Velebit hosted glaciers of cirque-, valley-, and plateau-type. One of the most significant glaciers was Lomski glacier, passing through the uvala Lomska Duliba. The snowline was at the approximate elevation of 1300 m a.s.l. (Bognar et al., 1991). Deep dolines on the plateau of central Velebit have played the role of cirques, and they accumulated sufficient quantities of ice. In combination with the plateau morphology, there were favorable conditions for formation of several large plateau glaciers. Development of large dolines beneath a plateau glacier on central Velebit was discussed by Sauro (1995) ("they are developed in limestone breccia which shows a very low sensitivity to cryoclastic weathering"). Similarly as on northern Velebit, the Pleistocene snowline of central Velebit is estimated at 1300 m a.s.l. (Bognar & Faivre, 2006). Pleistocene glaciation of southern Velebit was studied by Belij (1985). Most cirques were situated between the peaks Kozjak and Vaganski Vrh, and the snowline was at the approximate elevation of 1200 m a.s.l.

Lomska Duliba (ID_6) is situated on northern Velebit, and belongs to its morpho-structural unit called Lomska Duliba – Ledena Draga – Konjska Draga (Faivre, 1996).

Fig. 5.25: View from the slopes of Veliki Rajinac towards the SE part of Lomska Duliba

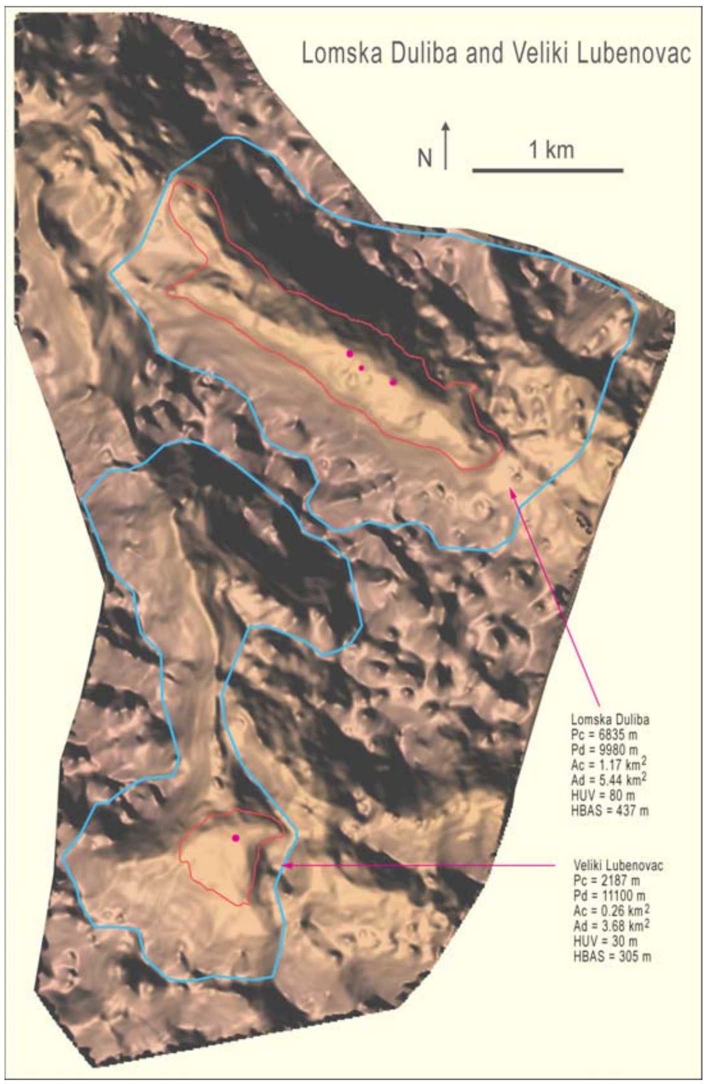

Fig. 5.26: Digital elevation model of Lomska Duliba and Veliki Lubenovac

The deep karstic (and partially glacial) incision of Lomska Duliba between the ridges of Hajdučki Kukovi and Veliki Rajinac can be explained by its lithological settings – position in the formation of highly permeable Jelar breccia. During the Pleistocene, Lomska Duliba was a glacial valley of a glacier that originated close to Zavižan and moved towards the south-east. At the location of Ledena Draga, at the SE margin of the uvala, the glacier deposited its frontal moraine. The bottom of the uvala hosts a rather deep cave Ledena Jama u Lomskoj Dulibi (-536 m; Fig. 5.24), which is the only such example among the studied uvalas.

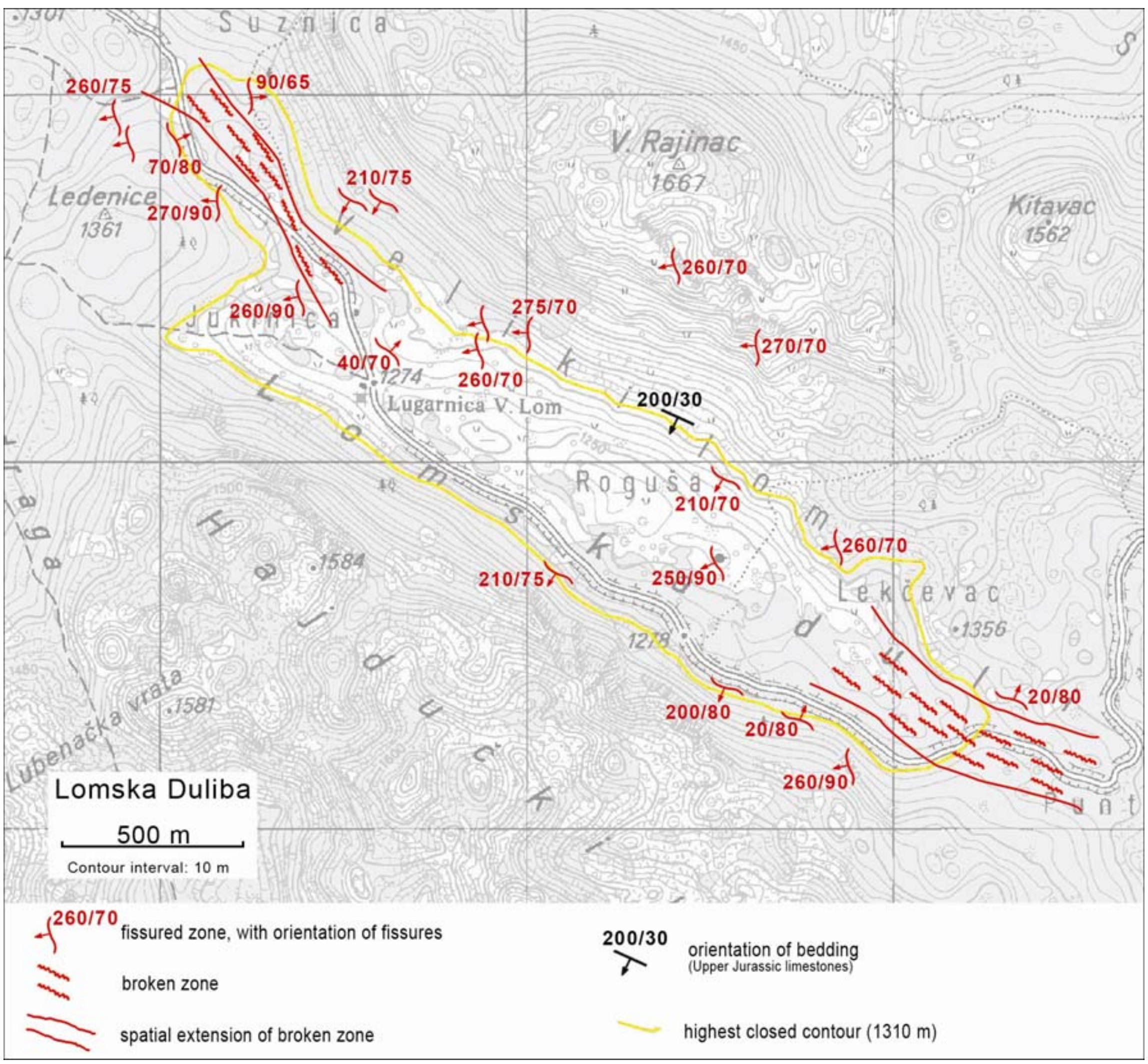

Fig. 5.27: Structural-geological sketch of Lomska Duliba

Structural-geological mapping of both Lomska Duliba and Veliki Lubenovac revealed the existence of significant tectonically broken zones along which the development of the depressions took place. In Lomska Duliba, existence of a fault stretching along its major axis is supposed, although the fault plane has not been observed in the field. However, most interesting finding is the enormous presence of fissures striking in N-S direction. They are dominating the whole tectonic pattern, crossing the large relief units. These fissures can be explained as the consequences of neotectonic change of dominant stress in the area from NE-SW to approximately N-S (Prelogović, 1995); they represent the tensional fissures striking parallel to the direction of maximum stress. This is completely in accordance with the results of quantitative geomorphological analyses (Faivre & Reiffsteck, 1999; Faivre, 2007).

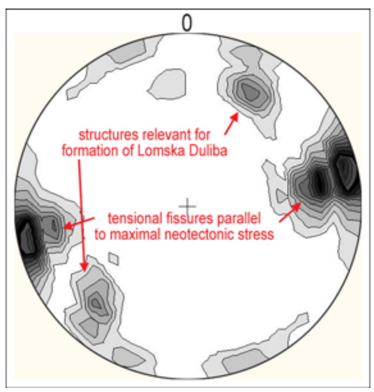

Fig. 5.28: Stereoplot of fissures in Lomska Duliba (poles of fissure planes); the situation in Veliki Lubenovac is almost the same.

Veliki Lubenovac (ID_7) is one of the smallest uvalas within the study, if the perimeter Pc is taken into account. However, the area which is topographically oriented towards the uvala contributes to the impression of a prominent landform. Dissected relief of Mt.Velebit made a Pd perimeter (topographic divide) of Veliki Lubenovac one of the most irregular among the studied examples. It was very difficult to delineate the perimeter, because the adjoining uvalas Mali Lubenovac and Jurekovac have a common closed contour (1300 m a.s.l.) with Veliki Lubenovac, and they can conditionally be considered a single compound depression (see .kmz files in the Appendix 1).

Fig. 5.29: Veliki Lubenovac; view from the peak Mali Kuk towards the east

The floor of Veliki Lubenovac is covered with colluvial sediments; it is mildly undulating, with indications of small, shallow dolines. Relatively close to the uvala, there is the entrance to the cave Slovačka Jama, the second deepest cave on Mt.Velebit (-1320 m). The entrance lies at 1520 m a.s.l, close to the peak Mali Kuk. According to Lacković et al. (1999), one of the phreatic channels in the cave, at the depth of 350 m (1170 m a.s.l.), could be genetically linked to the period of formation of the uvala Veliki Lubenovac ("The channel may be a part of an underground waterway which drained the uvala."). Although there are no known cave entrances at the bottom of Veliki Lubenovac, which would perhaps add new insight into this hypothesis, Lacković et al. (1999) consider that the mentioned phreatic passage possibly indicates the water table level at the time of uvala formation. Stalactites from this passage were dated by ^{14}C isotope analysis, and their age exceeds 37.000 years (op.cit.).

During the Pleistocene, the area of Veliki Lubenovac was covered by a plateau glacier from which the glacial tongues spread in four directions (Bognar et al., 1991).

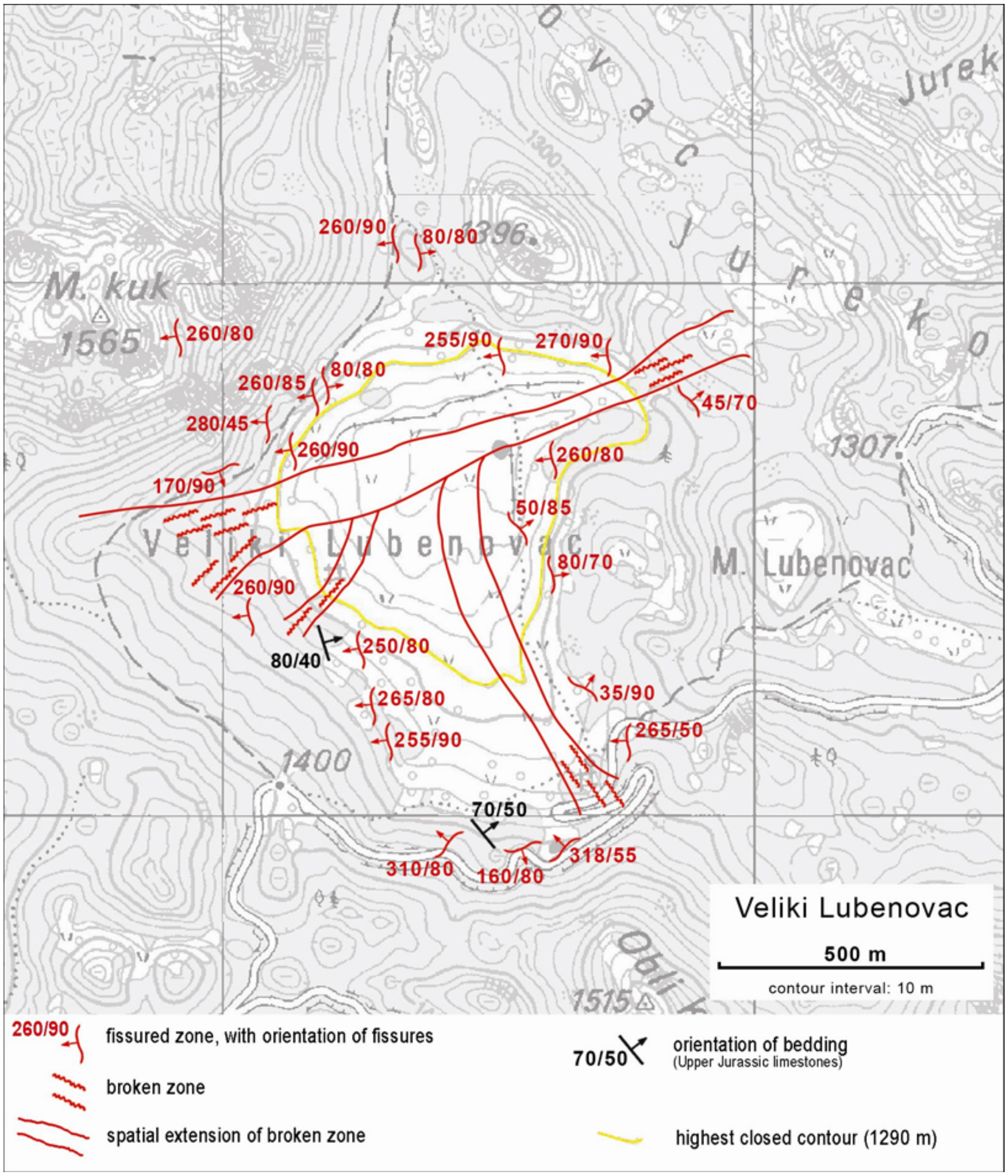

Fig. 5.30: Structural-geological sketch of Veliki Lubenovac

The position of **Bilenski Padež (ID_8)** is south from the Bakovac fault, thus it belongs to the structural unit of central Velebit. The shape of Bilenski Padež is very elongated, and its bottom is dissected by very deep dolines. With its bottom at 1215 m, the uvala was below the snowline during the Pleistocene. According to Bognar & Faivre (2006), it was a lacustrine basin filled by glacier meltwaters, although the exact traces of lacustrine sedimentation have not been found yet.

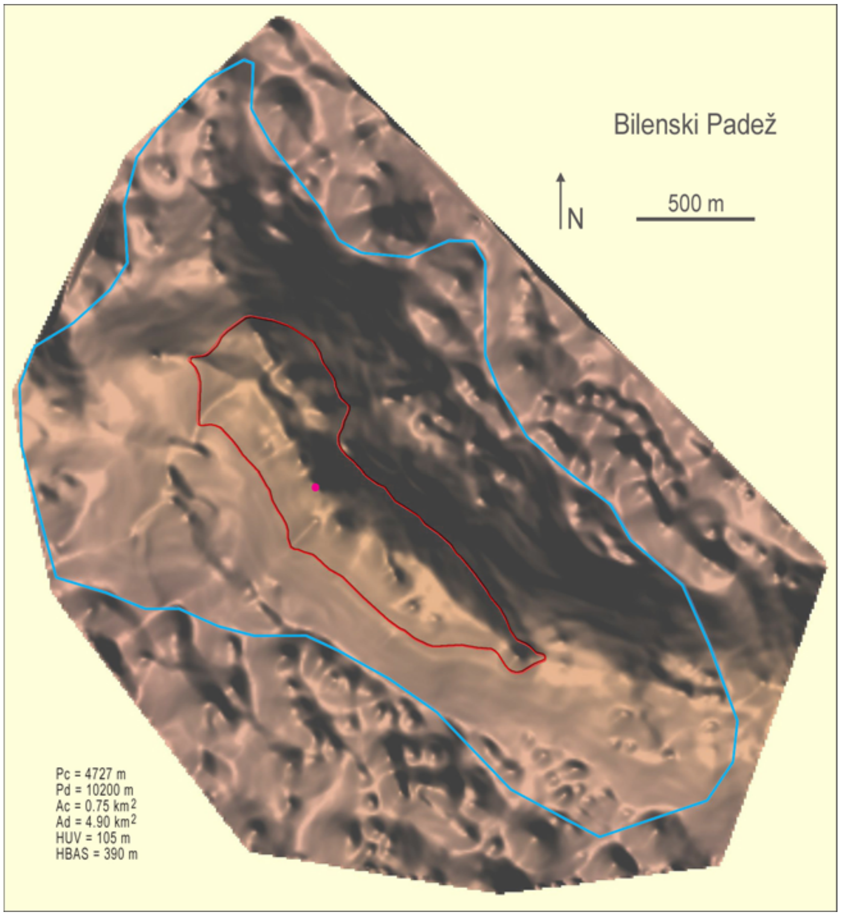

Fig. 5.31: Digital elevation model of the uvala Bilenski Padež

A small uvala **Brizovac (ID_9)** is situated on the western slopes of Mt.Velebit, facing the Adriatic Sea. The littoral slope, although steep, is not continuous. There are two levelled surfaces, one between 100 and 300 m, and another between 700 and 900 m a.s.l. (Faivre, 2006). The upper surface is composed of a series of karstic uvalas, one of which is Brizovac, with its bottom point on 820 m. The morphology of the uvala is relatively simple, its slopes are rather uniform and smooth.

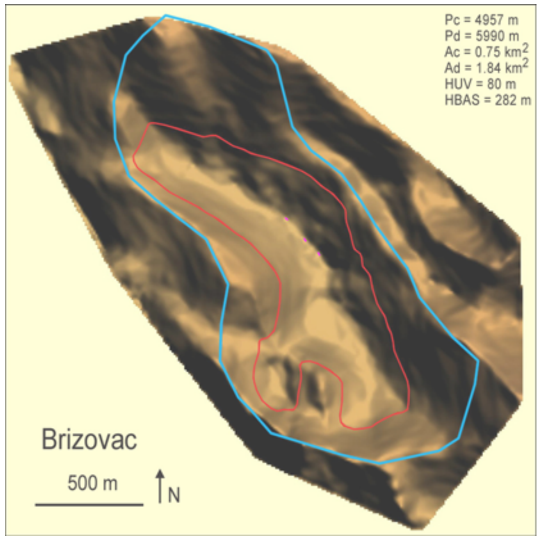

Fig. 5.32: Digital elevation model of the uvala Brizovac

Three uvalas of central Velebit are situated next to each other, in the area of Dabarski Kukovi: **Crni Dabar (ID_10)**, **Ravni Dabar (ID_11)**, and **Došen Dabar (ID_12)**. The uvalas are mentioned in already cited paper by Poljak (1951), although not extensively. According to Poljak, Ravni Dabar is a large doline; "it could be considered a small polje thanks to its flat, wide floor, and geological structure indicates that it is not an erosional form… ". However, later in the same text it is called a flat-floored uvala, the same as Crni Dabar. The central part of this "triple-uvala", which also has the common contour of 870 m a.s.l.) is formed in Paleogene carbonate breccia, but most of the area is generally composed of Jurassic limestones (Sokač et al., 1967).

Fig. 5.33: Photos of Crni Dabar from 1951 (by J.Poljak), and 2008; taken from approximately the same place

Crni Dabar is the largest among the three, and it has a vast flat floor consisting of colluvial sediments washed down from the slopes. It was populated until the 1970s, when the last inhabitants moved away.

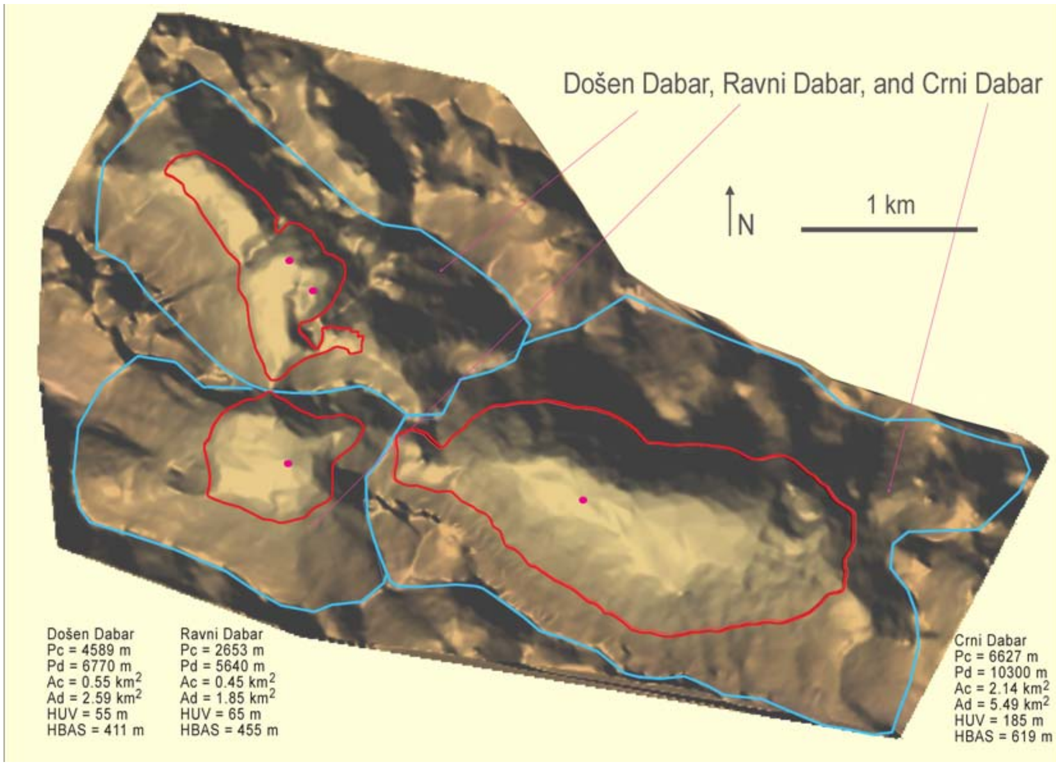

Fig. 5.34: Digital elevation model of Crni Dabar, Ravni Dabar, and Došen Dabar

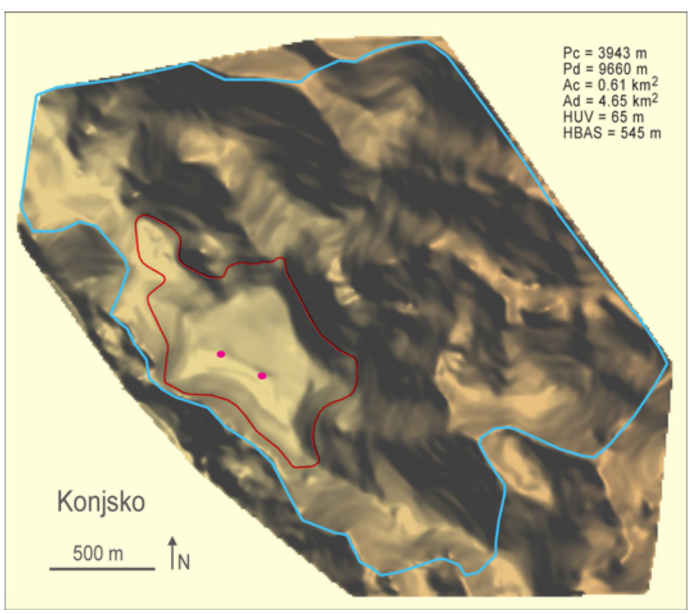

Fig. 5.35: Digital elevation model of the uvala Konjsko

Konjsko (ID_13) is a small uvala situated on littoral slopes of southern Velebit, close to the Oštarijsko polje and the Oštarije fault. It is not mentioned in any published literature, but geomorphology of the close surroundings (Oštarijsko polje and Crno Vrilo creek valley) was studied by Perica & Buzjak (2001) and Perica et al. (2002).

The area to the east from the Mali Alan pass is sometimes treated as south-eastern Velebit. Sinking rivers Otuća and Ričica in Gračačko polje and Štikadsko polje are draining through this part of Southern Velebit towards the springs on the right (northern) bank of the Zrmanja River (Biondić, 1981). In this area, one of the most stunning Dinaric uvalas is situated – **Duboke Jasle (ID_14)**. It will be shown further in the text that, together with some very large uvalas from the western Bosnia, this one is completely outstanding by its size. We can suppose that its development is helped by great quantities of groundwater that drain from the mentioned poljes towards the springs that feed into the Zrmanja River. The uvala have probably started its development in the formation of Jelar breccias, which are now eroded from its strict area, but are present on the ridge which closes it from the south.

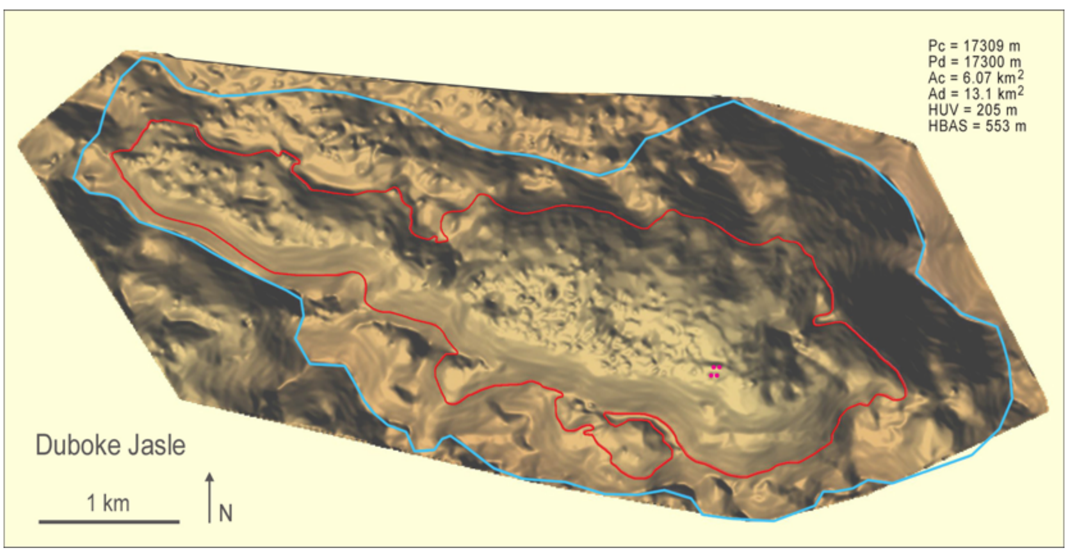

Fig. 5.36: Digital elevation model of Duboke Jasle

Fig. 5.37: The uvala Duboke Jasle, view from the eastern margin (the slopes of the peak Ćelavac)

Duboki Dol (ID_15) is situated to the south from the conical peak Tremzina. The uvala has a flat, but inclined bottom, at the elevation of 520 m a.s.l. Although no faults in the area of the uvala are shown on the basic geological map (Ivanović et al., 1967b), it is obvious from the relief that Duboki Dol is situated on the crossing of structures coming striking NNW-SSE and WSW-ENE.

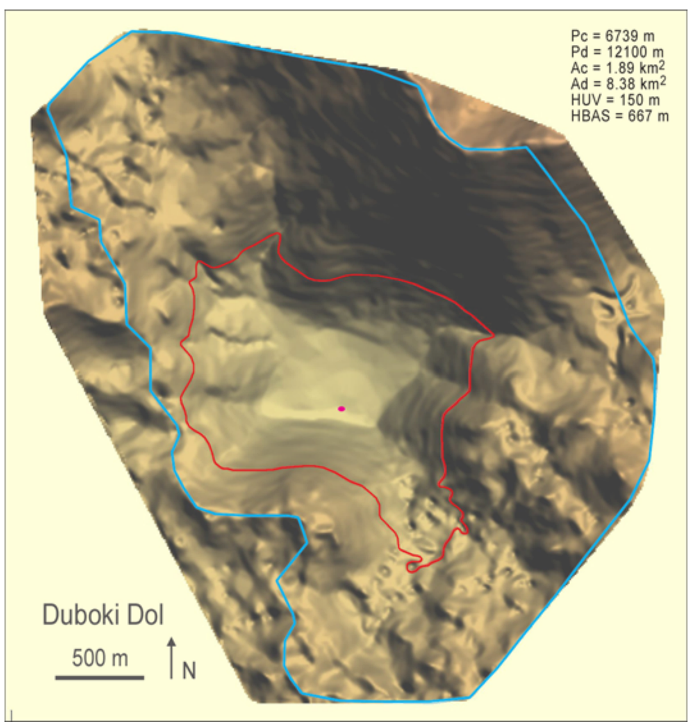

Fig. 5.38: Digital elevation model of the uvala Duboki Dol

Fig. 5.39: The uvala Duboki Dol, view from the west (Photo: P. Ćalić)

Vagan Popinski (ID_22) is situated in the tectonic unit Popina-Kom-Radučić, which belongs to the south-eastern end of Mt.Velebit (Grimani et al., 1975). The area is composed of Lower Malmian formations – layered, partly bituminous limestones, with layers of brown-gray coarse grained dolomites (op.cit.).

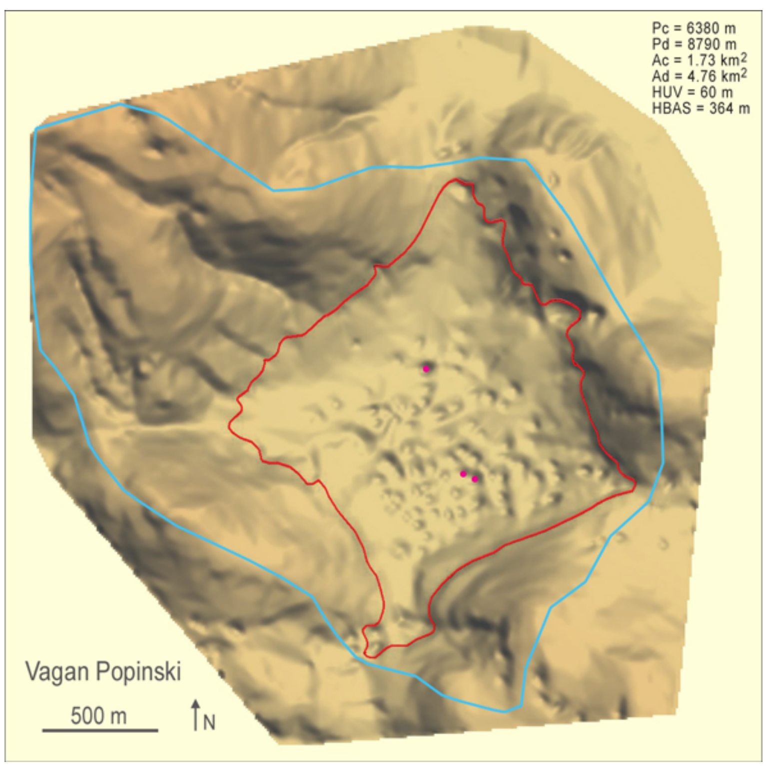

Fig. 5.40: Digital elevation model of the Vagan Popinski

Vagan lies next to the polje of Velika Popina, at a slightly higher elevation. The polje is never flooded, although it hosts some weak seasonal streams, while Vagan is completely without water. Poljes of Velika Popina and Mala Popina have more characteristics of karst plateaus than typical poljes. They are situated in the area of the Adriatic / Black Sea watershed, but particularly the polje of Velika Popina (Velikopopinsko polje) drains towards the spring of the Una River (Black Sea basin) (Biondić, 1981).

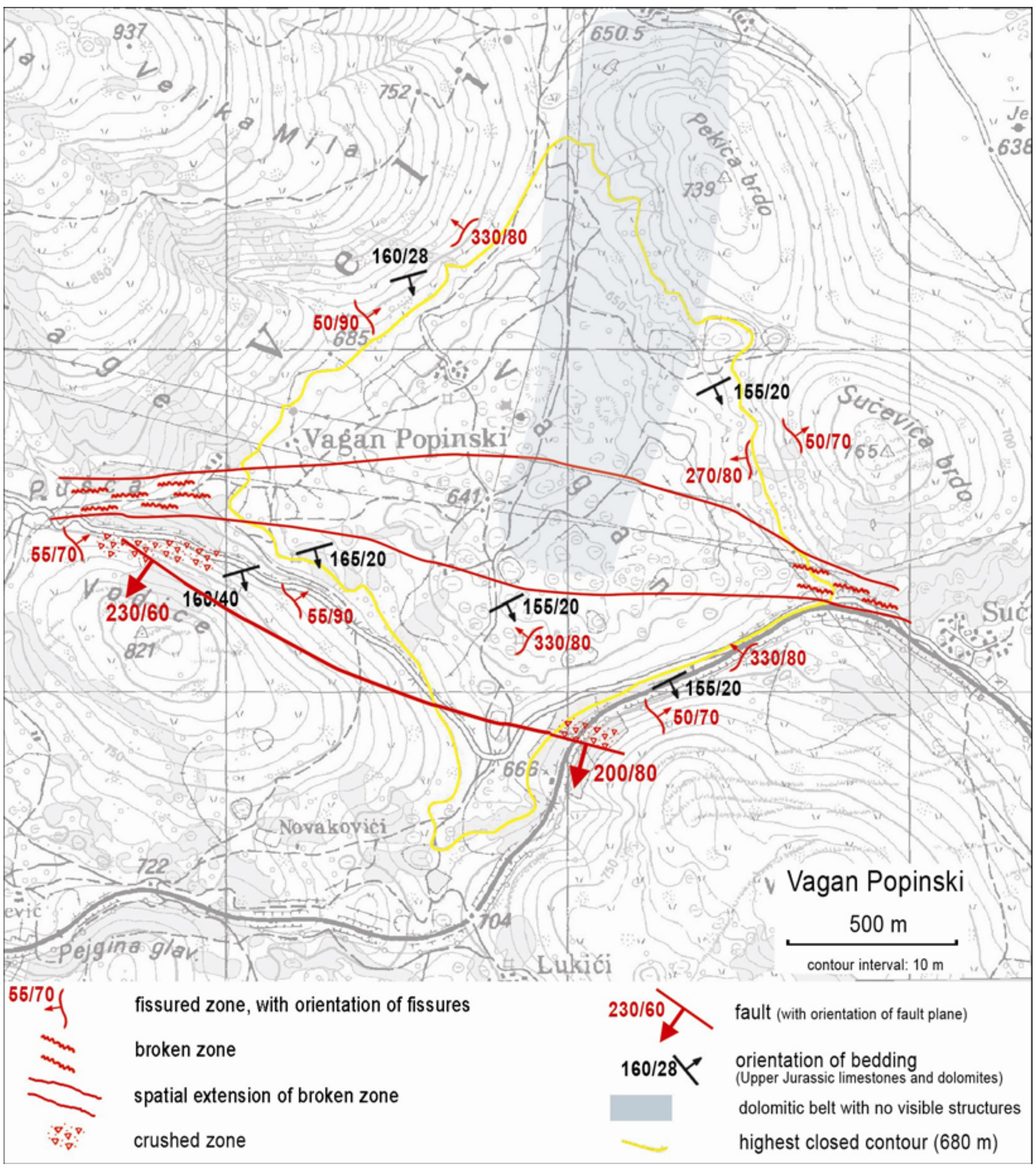

Fig. 5.41: Structural-geological sketch of the Vagan Popinski

A very interesting rhomboidal shape of Vagan is a result of its particular structural position, which was rather difficult to be determined in the field. The south-western side of the uvala is composed of rocks which are so much tectonically altered that they are difficult to recognize. It is also interesting lithologically, because of interbedded pure and detritic limestones. The dolomites in the north-eastern part of the uvala are weathered to the state of the rubble, so no structural or lithological elements could have been observed. The area is close to a regional thrust from the eastern side, but its possible impact is yet to be determined by experts.

Fig. 5.42: Vagan Popinski, view from the south

5.1.6. Uvalas of the tectonic unit Mala Kapela

Within the tectonic unit of Mala Kapela (some authors also call this unit Mala Kapela – Plješevica), it is possible to distinguish the area of the mountain Mala Kapela (*s.stricto*), and the area in its south-eastern continuation, which belongs to the same tectonic unit, but is marked by other toponymes.

Mt.Mala Kapela was not so extensively studied as some more prominent mountains of the area, like Velebit, Velika Kapela, etc. Perhaps the most famous and most investigated part of Mt.Mala Kapela are the Plitvice Lakes, on the far south-east of the mountain. Other parts have been studied predominantly by hydrogeologists (Herak, 1956; Herak et al., 1969; Bahun, 1989). In the article about geological bases of karst groundwater protection, Bahun (1989) takes the aquifers in the south-western part of Mt.Mala Kapela as case examples (Fig. 5.43)

Stratigraphical issues were studied by Polšak (1964). There are geological articles that deal with the surrounding areas, like the Ogulin-Plaški karst depression (Bahun, 1970), which contain brief remarks on Mala Kapela ("On the south-west of the investigated terrain, limestone rocks are the main constituent in the massif of Mala Kapela. It abounds in karst forms: karren, dolines, shafts, ponors, caves and plateaus. Many tectonic fractures have enabled the intense subterranean action of waters, thus surface streams are missing (…); Bahun, 1970). The fault Brlog – Gacko polje – Ramljani differentiates the tectonic unit Mala Kapela from the tectonic unit of Ličko Sredogorje on the south-west (Fig. 5.44). In fact, these two units are limbs of a large syncline, whose NE limb has been subsequently uplifted along the series of faults on Mt.Mala Kapela (Sokač et al., 1976b).

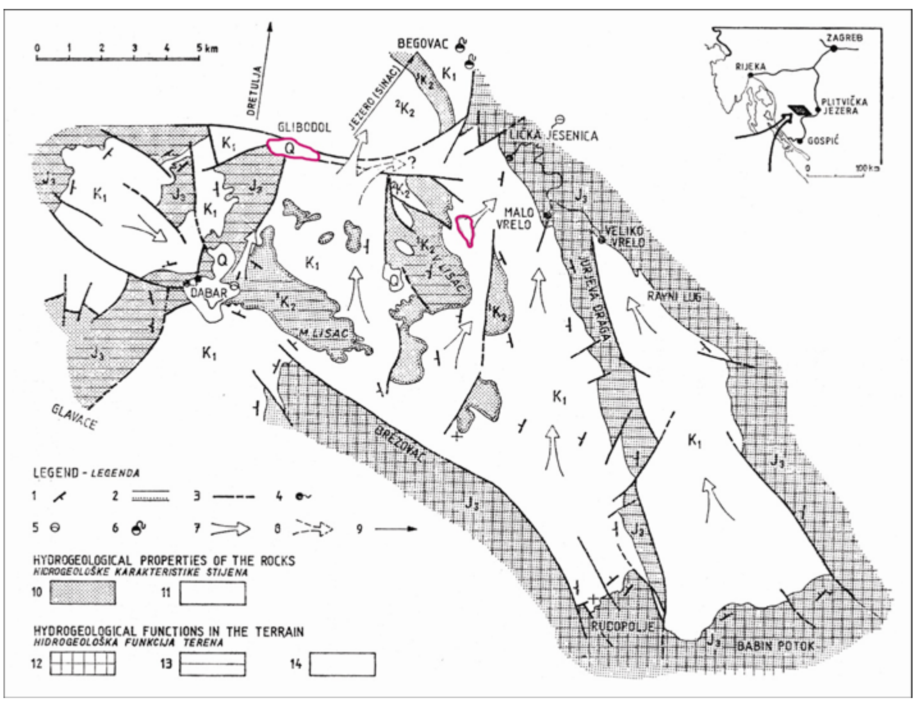

Fig. 5.43: Hydrogeological map of Lička Jesenica region, Mt.M.Kapela (Bahun, 1989)

(red outlines of the uvalas Glibodol and Mala Kapela, by J.Ćalić)

Uvalas of Mt.Mala Kapela were not in the glaciation zone during the Pleistocene, but they were, without doubt, subject to intensive periglacial processes that had particular impact on their development ("Climate changes during the Pleistocene caused the increased denudation, so the material thus created has been transported, gravitationally and by water, to lower areas – poljes, uvalas, valleys"; Sokač et al., 1976b).

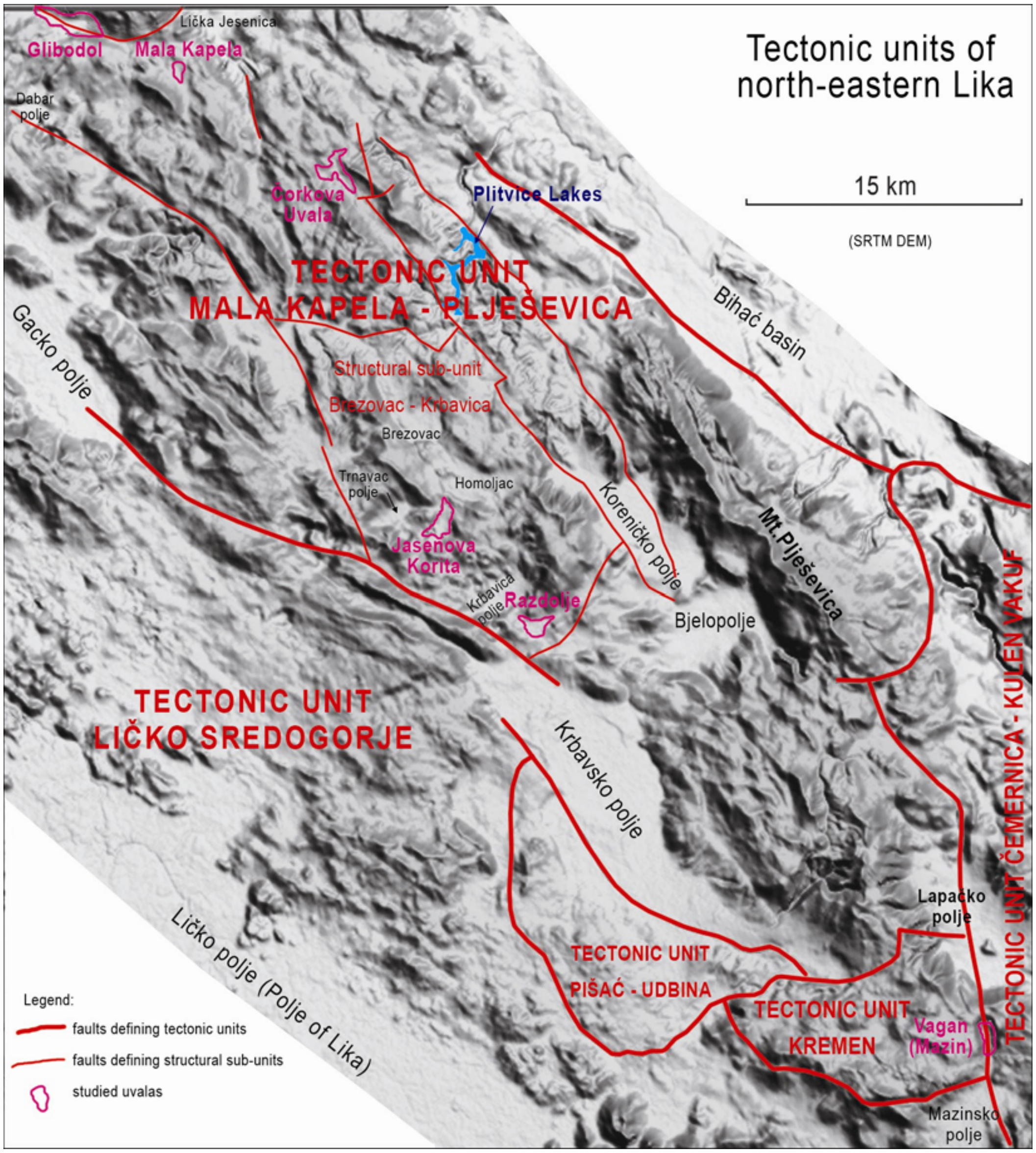

Fig. 5.44: Tectonic units of the north-eastern part of Lika, with the positions of the studied uvalas (locations of faults according to Sokač et al. (1976b), Polšak et al. (1967), Šušnjar et al. (1965); mapped on the SRTM DEM)

Uvala **Glibodol (ID_16)** is situated to the north from the Dabar polje, at the elevation of 515 m a.s.l. (bottom points). According to Velić et al. (1970) and Sokač et al. (1976b), it lies along the fault Glibodol – Lička Jesenica. Although the relatively flat floor of the uvala may remind of a polje, it is completely without surface waters, and the slopes transform rather gently into the flat bottom consisting of Quaternary colluvial material (Fig. 5.45).

Fig. 5.45: The uvala Glibodol

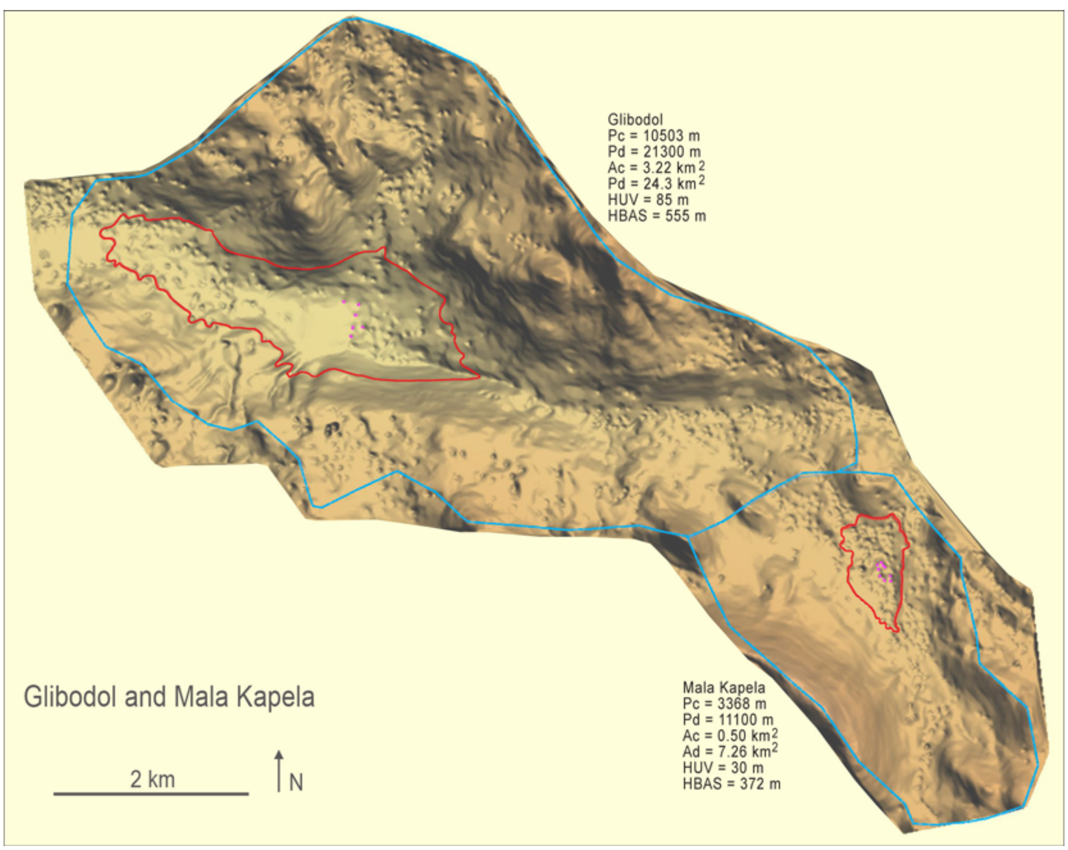

Fig. 5.46: Digital elevation model of the uvalas Glibodol and Mala Kapela

Waters that sink in the Dabar polje drain towards the north, below Glibodol, to the springs Jezero (Sinac) and Dretulja (in the polje of Plaški), thanks to the fact that limestones between the Dabar polje and Mt.Veliki Lisac lie on the dolomitic base inclined towards the north (Bahun, 1989). Morphology of the uvala is conspicuously influenced by the fault Glibodol – Lička Jesenica, whose eastern part has caused the development of a form which resembles a huge dry valley pitted with dolines.

Uvala **Mala Kapela (ID_17)** lies next to Glibodol, towards the south-east. Although the whole depression is a prominent form in the surrounding relief, the depth from the lowest points (at 770 m a.s.l.) to the highest closed contour (800 m) is relatively small, because of the low saddles on the south and the north-west. The area within the topographical divide (Ad = 7.26 km^2) is more than 14 times larger than the area within the highest closed contour (Ac = 0.5 km^2), which is the second largest dfference between these parameters, considering the whole study sample. The bottom is pitted with dolines and the whole uvala is overgrown by forest. Surface waters are completely missing, while underground karstic drainage is directed towards the Malo Vrelo spring, in the valley of Lička Jesenica (Bahun, 1989).

According to geomorphological regionalization of Croatia, suggested by Bognar (1999), the area of the uvalas Glibodol and Mala Kapela belongs to the geomorphological sub-region “Series of ridges in the south-western part of Mt.Mala Kapela”.

Čorkova Uvala (ID_18) is much more famous for the diversity of its flora, than its geo(morpho)logical characteristics. It hosts a unique beech-fir virgin forest, studied both for its botanical (Anić & Mikac, 2008) and pedological characteristics (Bakšić et al., 2007).

Fig. 5.47: View from the central part of Čorkova Uvala towards the virgin forest on the north-west

Hydrological and hydrogeological studies of the Plitvice lakes, situated in the close vicinity, have not considerably discussed the karst depressions in the surroundings. Čorkova Uvala has a very high sinuosity index of the highest closed contour (ISINc = 2.44), indicating a very intense process of karst doline formation, as well as stressing its lobate shape. Depth of the vadose zone below the uvala is about 200 m – the bottom points are situated at 810 m a.s.l, while the spring of the Plitvica Potok (left tributary of the Korana River, in the region of the Plitvice lakes) has an elevation of 610 m.

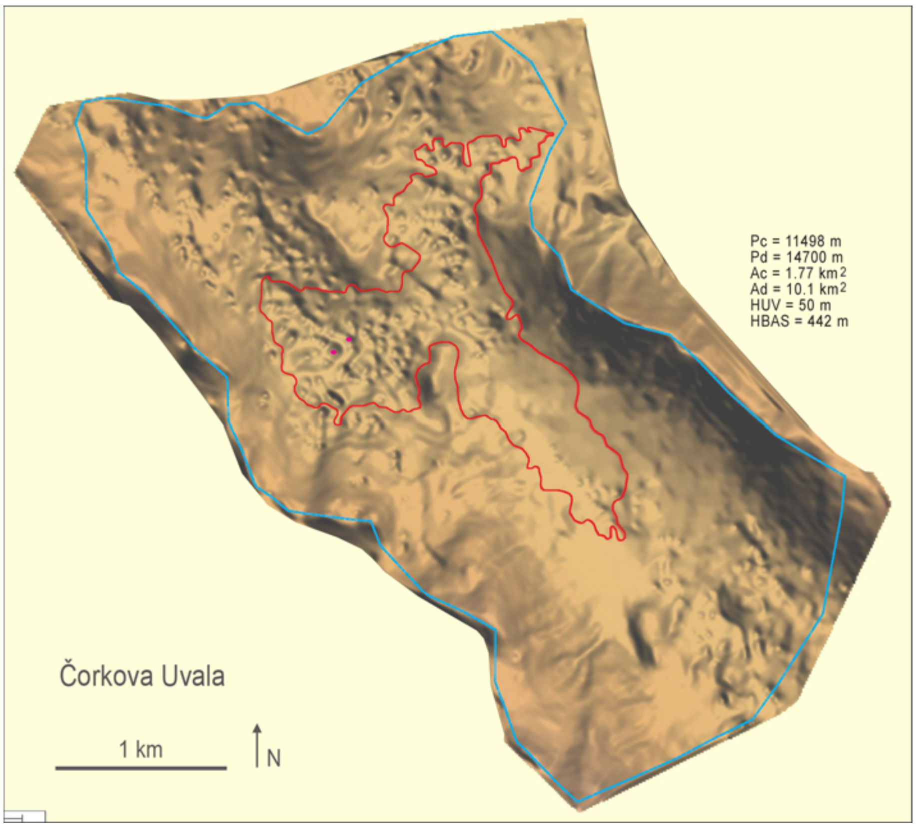

Fig. 5.48: Digital elevation model of Čorkova Uvala

Uvalas which toponymically do not belong to Mt.Mala Kapela, but are situated within the tectonic unit Mala Kapela (more precisely, structural sub-unit Brezovac – Krbavica) are Jasenova Korita and Razdolje. The unit Brezovac – Krbavica is a "relict of anticlinal structure of great dimensions, re-modeled by a series of faults" (Polšak et al., 1967; 1978). The fault which marks the western border of this tectonic unit is a segment of the Adriatic / Black Sea watershed in Lika region (Biondić, 1981).

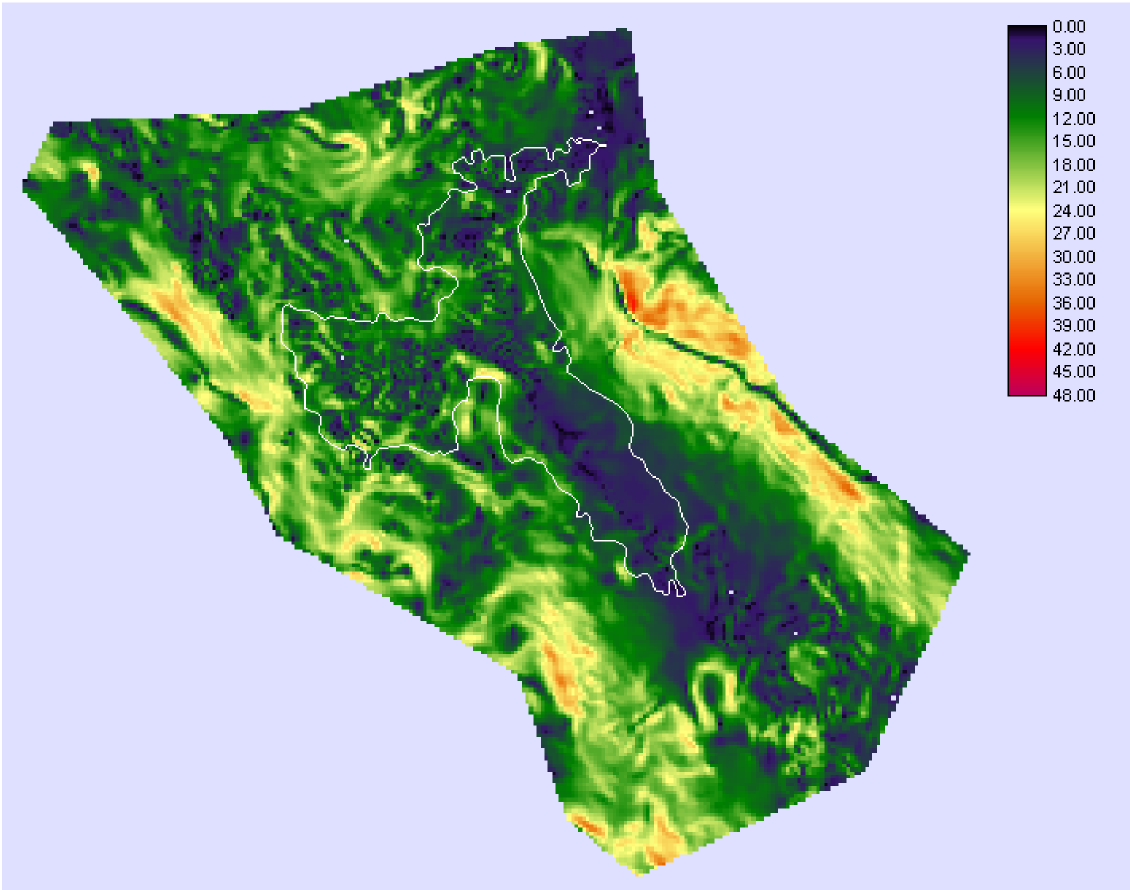

Fig. 5.49: Slope inclinations in the region of Čorkova Uvala (grid resolution 20 x 20 m)

The uvala **Jasenova Korita (ID_19)** lies between the small poljes of Trnavac on the NW and Krbavica on the SE (see profile on Fig. 5.x). The depression of Homoljac, situated north of Jasenova Korita, has a combination of characteristics of a dry polje and an uvala. Its elevation is even a bit higher (755 m a.s.l.) than the elevation of Jasenova Korita (735 m on the bottom points, in a compound doline called Bliznice – "The Twins"). Homoljac is discussed more in detail in the chapter 8.6.

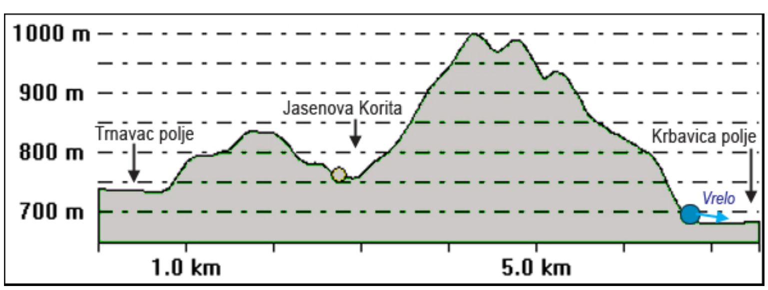

Fig. 5.50: Surface profile from the Trnavac polje to the Krbavica polje

Fig. 5.51: The uvala Jasenova Korita, view towards the south

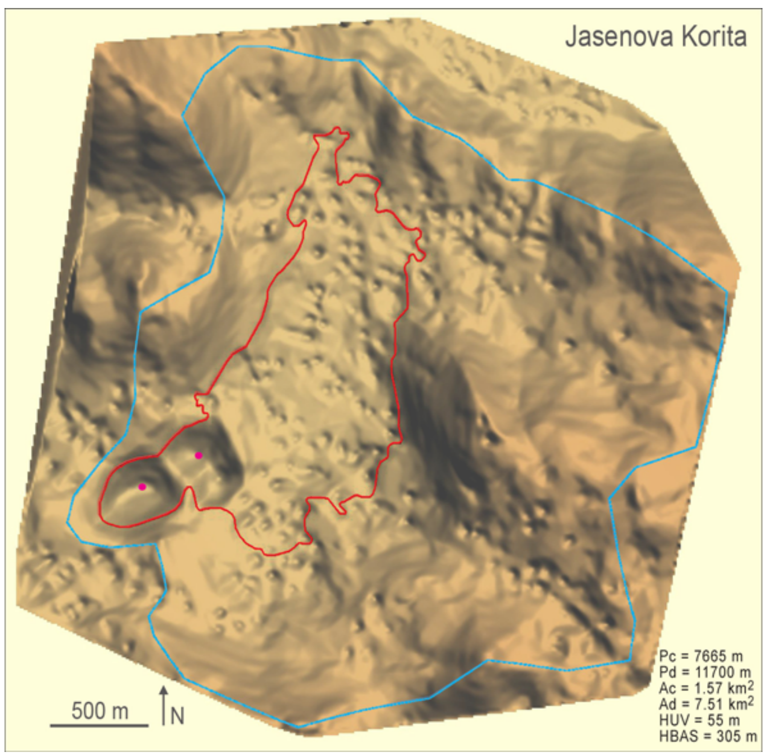

Fig. 5.52: Digital elevation model of the uvala Jasenova Korita

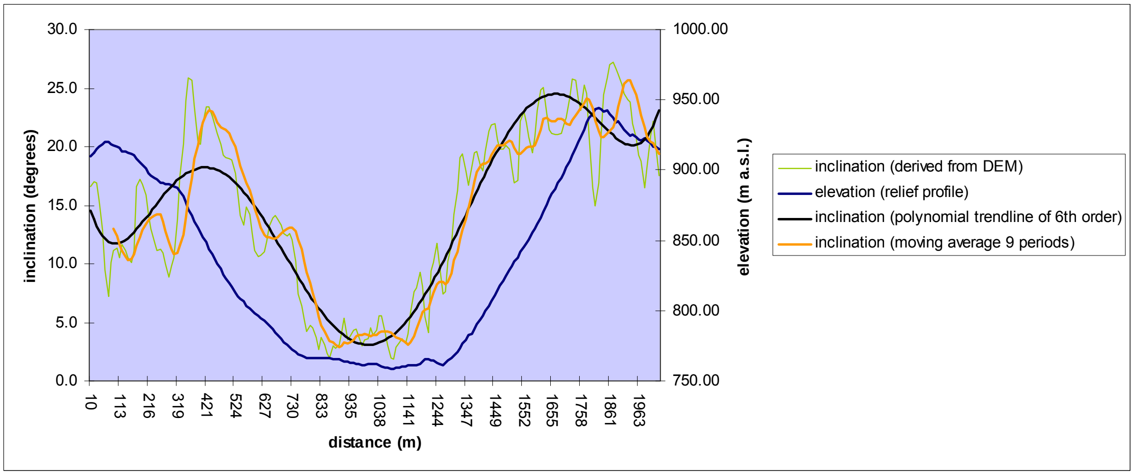

Fig. 5.53: Cross section through Jasenova Korita, in the W-E direction

Lithological composition of the uvala is stratigraphically rather complex – four different formations consisting of limestones and dolomites vary in a span from the Lower Jurassic to the Lower Cretaceous. Depth of Jasenova Korita to the highest closed contour at 790 m a.s.l. is 55 m. It is interesting to say that it is actually a part of a much more complex, extremely lobate depression, because the 800 m contour encompasses Trnavac polje, Ambar uvala, and Jasenova Korita. This complex form could not be categorized in terminology of karst depressions, because it consists of quite different parts. Trnavac is a true polje (relatively small, but flat-bottomed and seasonally flooded), Ambar is at the "boundary" between a doline and an uvala (relatively regular circular shape; size of a large doline or a small uvala), while Jasenova Korita could even be declared as one of the typical examples of uvalas.

Depth of the vadose zone below Jasenova Korita is approximately 50 m, because the permanent spring Vrelo in the polje of Krbavica lies at 685 m a.s.l. Trnavac polje and Krbavica polje are the upstream parts of the drainage area of Krbavsko polje (Biondić, 1981).

Uvala **Razdolje (ID_20)** is situated on the northern margin of the Krbavsko polje (92 km^2; Gams, 1978). It is a shallow uvala formed in Cretaceous limestones and dolomites, on a small plateau between the Krbavica polje on the north-west and Krbavsko polje on the south. There are some studies treating geology of the area (Čubrilović, 1940;

Ivanović et al., 1967a), but geomorphological references are generally missing. Digital elevation model of the uvala Razdolje is shown on Fig. 4.3.

Krbavsko polje is, together with Krbavica polje and Trnavac polje, which are situated in its drainage area, a part of the Black Sea basin. Water tracing has proven the underground hydrological connection between the ponors in the Krbavsko polje and the spring Klokot close to Bihać (Una River valley) (Biondić, 1981). Part of the water from Krbavica polje probably drains directly to the Una basin, because the springs in Krbavica are permanently active, while those in Krbavsko polje are seasonal.

5.1.7. Uvala Vagan, between Mazinsko polje and Lapačko polje

Lapačko polje lies in the contact area of three tectonic units: Mala Kapela-Plješevica, Kremen and Čemernica-Kulen Vakuf. Waters from the polje drain towards the springs Dobrenica in Kulen Vakuf, and Ostrovica in Bihać (Biondić, 1981). The springs in the polje are not permanent, but in the wet season are very rich in water, thus flooding the polje due to poor capacity of ponors.

Mazinsko polje is never flooded. The streams which come from the Lower Triassic impermeable clastic rocks of Mt.Čemernica sink at the north-eastern margin of the polje, and drain towards the springs in Kulen Vakuf and the Una River valley. Tracing experiment showed that the water from the ponor M-47 in Mazinsko polje (at 817 m a.s.l.) appeared in Ostrovica spring in the Una valley (Biondić, 1981).

Uvala **Vagan (ID_21)** is referenced elsewhere in this text as "Vagan Mazin" in order to be distinguished from another studied uvala with similar name, Vagan Popinski (ID_22). It is situated next to the thrust of Kremen Šuma (Triassic over Jurassic; tectonic unit Kremen), between the Mazinsko polje on the south and the Lapačko polje on the north. Its greatest particularity is its hydrological position. Being situated lower than the adjoining Mazinsko polje, Vagan is permanently hydrologically active, being the only studied uvala with such hydrological status. Its geomorphological form reminds of a typical uvala, but the sinking stream is making it very specific.

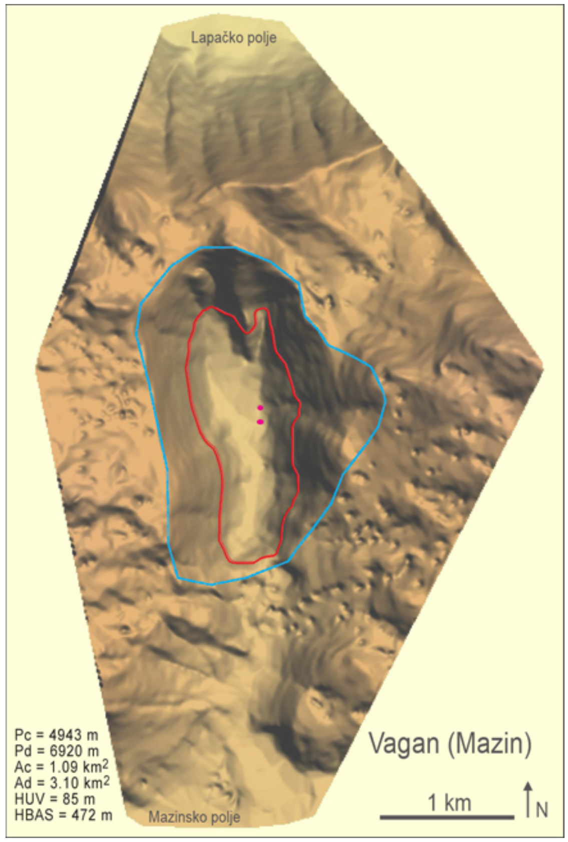

Fig. 5.54: Digital elevation model of the uvala Vagan, close to Mazin

Fig. 5.55: Vagan (Mazin), view from the south-east

5.1.8. Uvala Poljica, in the area of the Imotsko polje

The area of Imotsko polje was most comprehensively studied by Roglić (1938), who offers the complex geomorphological approach, including not only the polje bottom, but the broader area in the study ("Neighboring areas make a natural unit with the polje bottom, and understanding of tectonic relations, geomorphologic characteristics, as well as climatic and hydrographic features, would be impossible without understanding of the surrounding areas"). Roglić elaborates the complete sequence of geomorphological evolution, starting from the final stages of marine sedimentation in the Upper Cretaceous and Paleogene (Middle Eocene), and folding after the emersion (from the Middle Eocene on). In the neighboring areas, there are Miocene freshwater sediments (e.g. in Posušje depression), but not in the Imotsko polje, which means that it did not exist as a depression at that time. Folding after the Oligo-Miocene had a great impact on enhancing the surface erosion in the region of the present polje. Paleogene sandstones and marls were almost completely fluvially eroded, then the marly limestones as well, and the erosion reached the Cretaceous limestones, even their dolomitic base at some places. Roglić (op.cit.) considers that the area had a long-lasting period of fluvial erosion during the whole Neogene. Fluvial process was possible thanks to (1) non-carbonate cover (at the beginning), (2) shallow water table, (3) dolomitic rocks, where present. Evolution of the polje depression took place by tectonic lowering, during the stages marked by formation of a sequence of fluvial levels (six in total). The most important is the fluvial level of Gornji Proložac (600-700 m a.s.l.), now preserved on the NW margin of the polje. According to Roglić, this level is the "geomorphological basis in which the polje depression was formed".

Tectonic activity which formed the polje depression took place most probably at the end of the Pliocene or in early Pleistocene. It changed the former direction of surficial drainage (which was to the NW), towards the south-east, i.e. towards the Neretva River. The most important tectonic line is the fault (flexure at some places) along the NE polje margin, best expressed between Gorica and Sovići. Another tectonic line along which the polje was lowered follows the NE foothill of Osoje hillslope, along the uvala Poljica (at SW margin of Imotsko polje).

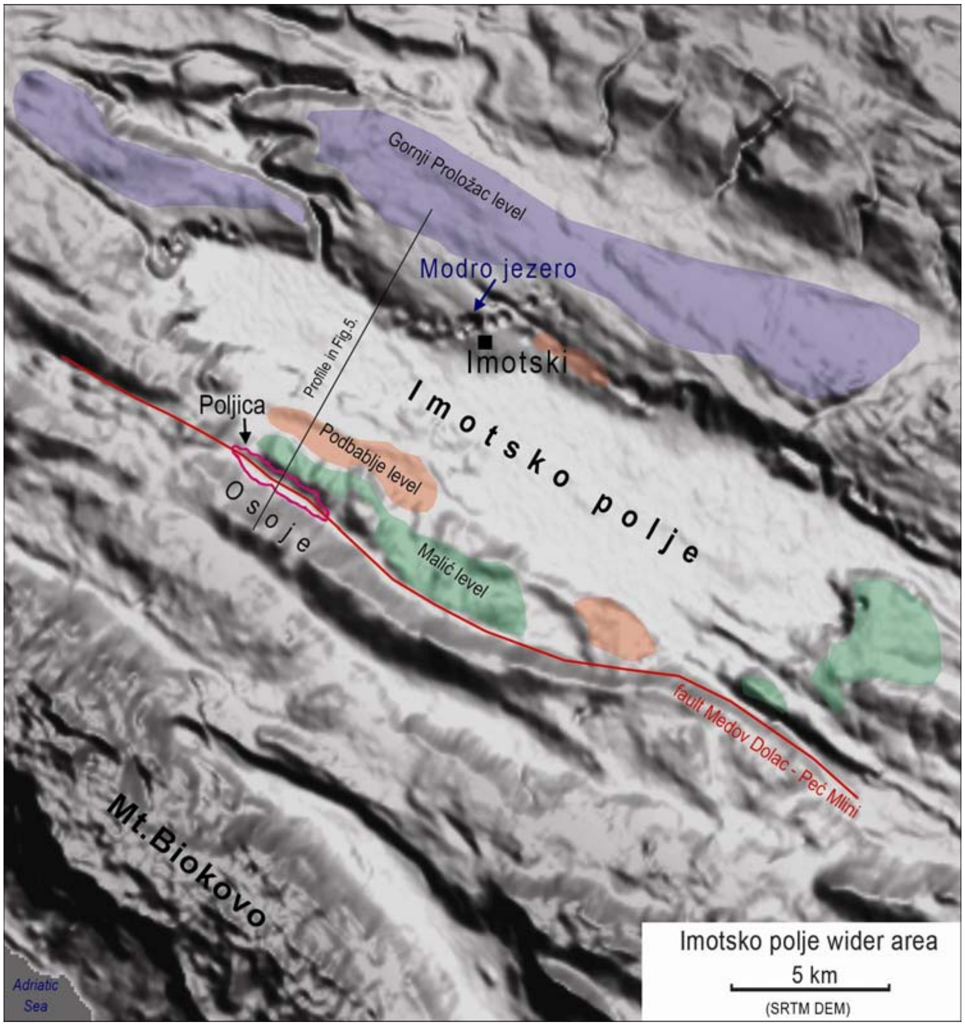

Fig. 5.56: Situation map of the wider area of Imotsko polje,
with selected geomorphological and structural elements
(fluvial levels according to Roglić (1938); mapped on the SRTM DEM)

Successive phases of fluvial levelling were decreasing in strength and duration, due to karstification of uplifted parts. Therefore the youngest levels occupy the smallest surfaces. Before the start of cold phases of the Pleistocene (which meant the periglacial environment in this area), the whole depression of the Imotsko polje was already formed by tectonic and erosional activities (Roglić, 1938).

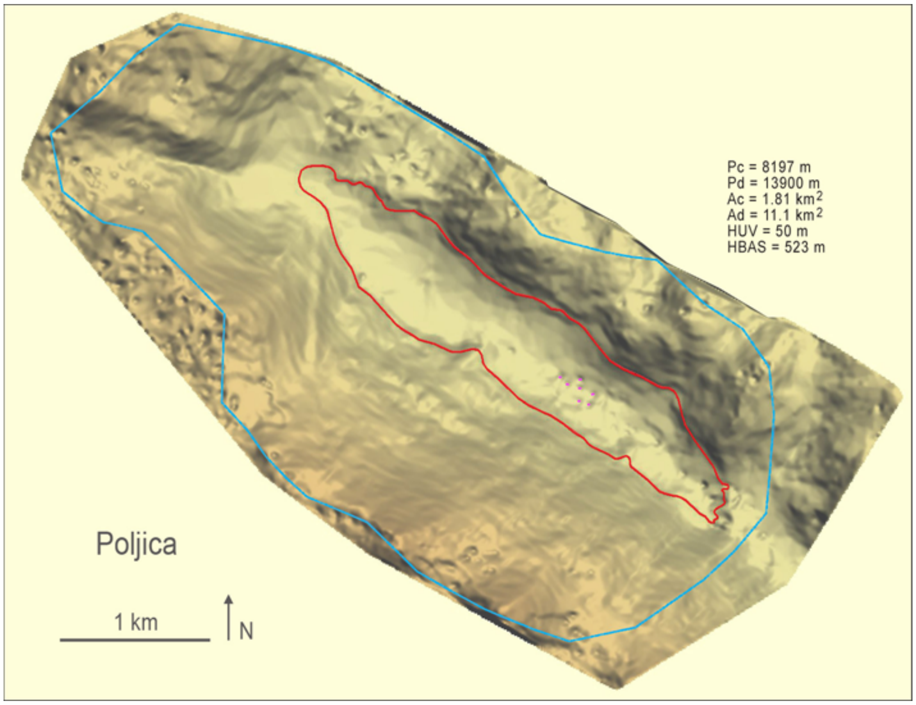

Fig. 5.57: Digital elevation model of the uvala Poljica

The uvala **Poljica (ID_23)** is, as mentioned above, located along the SW margin of the Imotsko polje, at the foothill of Osoje hillslope. It stretches in the Dinaric direction along the fault which is also marked on the basic geological map under the name "Medov Dolac – Peć Mlini fault", within the structural unit Biokovo – Zagora (Raić et al, 1968; Raić & Papeš, 1978). Poljica is the most elongated among the studied uvalas (ELONGc = 5.58). The lowest points of the uvala are situated at the elevation of 345 m a.s.l, which is about 80 m higher than the bottom of the Imotsko polje.

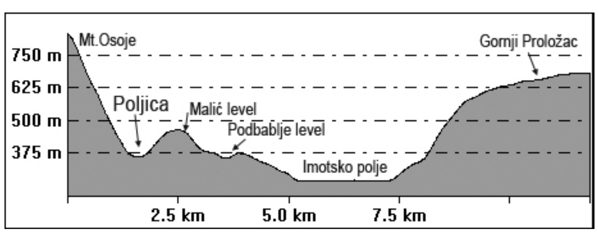

Fig. 5.58: Surface profile from Osoje to Gornji Proložac (generated from SRTM DEM)

The NE margin of the uvala is the ridge Gradina – Baba, which corresponds to the Roglić's (1938) fluvial level of Malić (420-480 m a.s.l.). This is the first level that followed the level of Gornji Proložac, after the start of tectonic activity that formed the

Imotsko polje depression. In morphostratigraphical sequence, this puts the start of the uvala formation to the time of formation of the third fluvial level (Podbalje level, closer to the polje bottom). Roglić considers that the uvala Poljica is “the most important karst form of the wider margin of the Imotsko polje” (op.cit.), taking also the south-eastern continuation as the component of the compound form (in our study, it is only the NW part; see Fig. 5.56). According to Roglić, the uvala Poljica is extremely longitudinally developed thanks to favorable petrographic and tectonic settings – less resistant thin-bedded limestones are exposed in between the areas of massive, resistant limestones of Osoje (SW) and Gradina-Baba ridge (NE). Osoje limestones are dipping towards the uvala, directing the water seepage towards the thin-bedded limestones, which favors their dissolution. Roglić states that “the former karst researchers have already detected such locations as the most favorable for formation of big karst depressions”.

In one of the more recent studies of the area, covering the issues of geoecological valorization, Zdilar (2001) mostly cites the results of Roglić (1938) when referring to Poljice. In the text, Zdilar uses the term uvala, while in the caption for the Photo 22, he changed it for the term “sub-mountainous depression” (*“submontana udolina”*).

Fig. 5.59: The uvala Poljica, close to Imotski

5.1.9. Uvala Rupa on Mt.Grmeč

Within geomorphological regionalization of Bosnia and Herzegovina, Mt. Grmeč belongs to the macro-unit of high Dinaric karst (Lepirica, 2009). Structurally, central part of Grmeč is a horst-syncline morphostructure (Mojićević et al., 1979). South-eastern part of Grmeč is a ridge between the karstic Lušci polje on the NE, and the basin of Bosanski Petrovac, with fluvial relief developed on Cretaceous flysch.

The uvala **Rupa (ID_24)** is situated on south-eastern flanks of Grmeč, at the elevation of 935 m (bottom points). Within the Grmeč structural-facial unit, Rupa is located in the block Majkići – Lastva, between the fault Krnjeuša and the dislocation Koprivna – Sanica. The syncline of Lastva is conspicuously folded in a number of smaller normal synclines and anticlines (Mojićević et al., 1979). Longer axis of Rupa overlaps with a prominent counter-Dinaric fault, while its shorter axis stretches along an anticline in Lower Jurassic limestones (Mojićević et al., 1971).

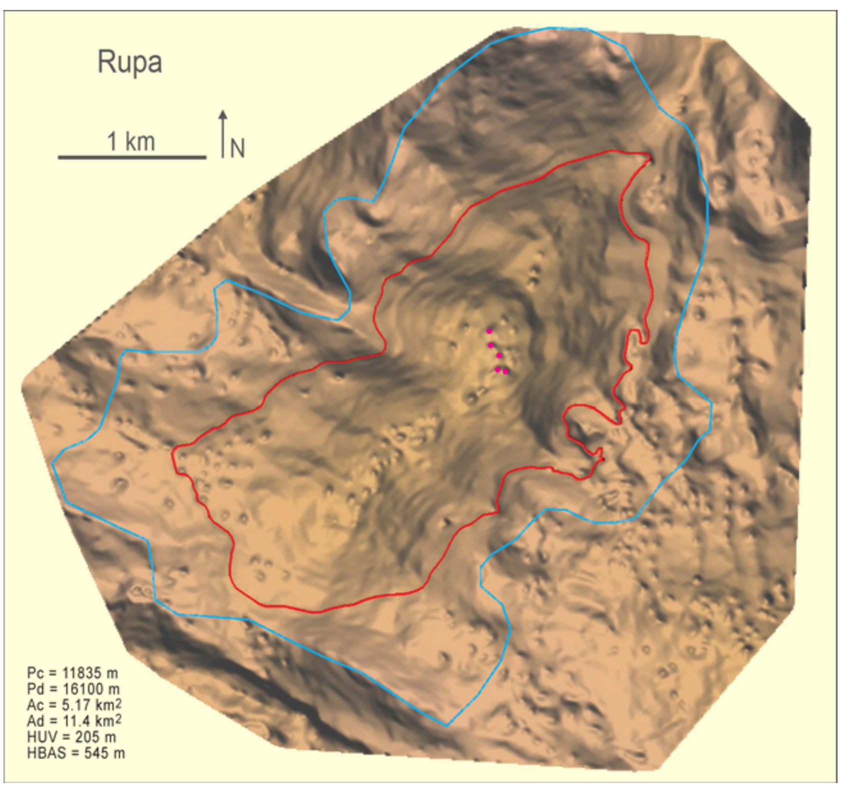

Fig. 5.60: Digital elevation model of the uvala Rupa

This crossing of structures surely contributed to the impressive dimensions of the uvala (depth 205 m, volume 407 millions of cubic meters). It can be inferred that open, tensional fissures which are characteristic for anticline crests, enabled more efficient vertical percolation of rainwaters, and more intensive corrosion.

5.1.10. Uvalas in the area of Mt.Lunjevača and Mt.Klekovača

Katzer (1909) mentioned this area in his discussion on the term uvala, stating that this is where the term originated ("the name uvala is used by people in western Bosnia, but not uniformly. It is mostly the name for the depressions between the high ridges of Grmeč and Srnetica, Klekovača and Lunjevača, Tisova and Javorova Kosa, etc.").

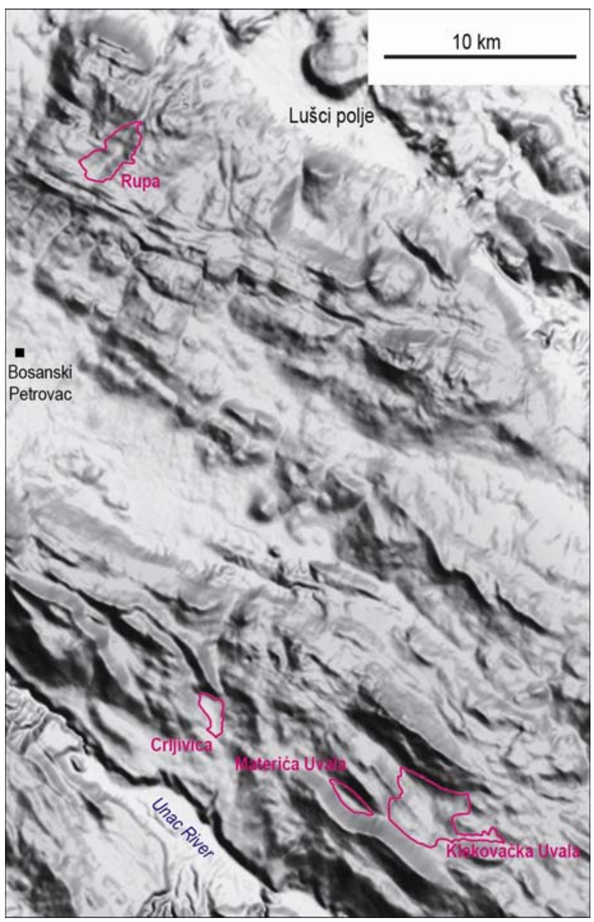

Fig. 5.61: Situation map of the uvalas of Grmeč, Lunjevača, and Klekovača (mapped on the SRTM DEM)

Lepirica (2009) also indicates that uvalas are one of the main morphological marks of the area ("in the subcutaneous karst of Grmeč, Srnetica, Šiša, Klekovača, and Crna Gora, deep uvalas are formed; their areas are several square kilometers, and they are densely pitted with dolines (on average 50-100 dolines/km²).

In the area between the mountains Osječenica and Lunjevača, the uvala **Crljivica (ID_26)** is located.

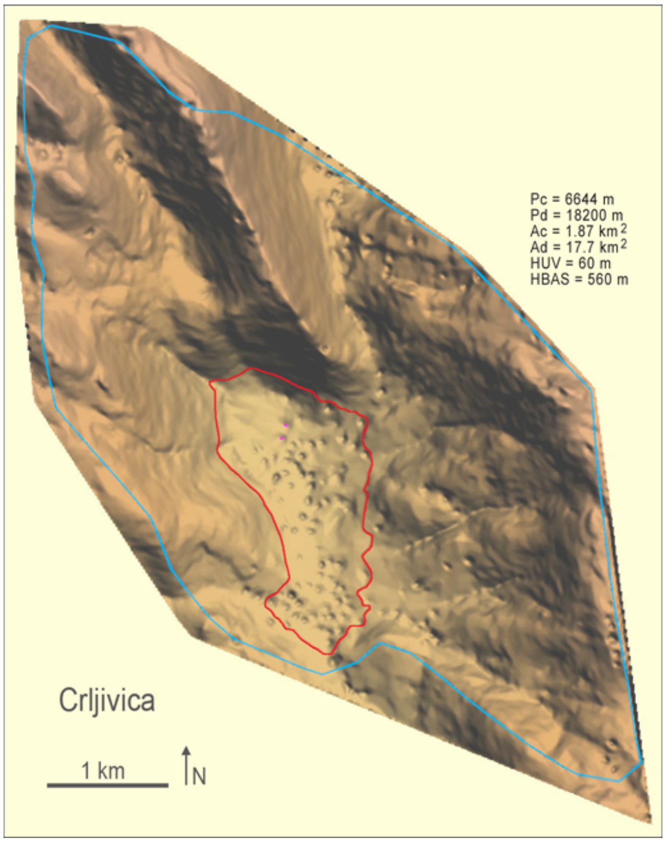

Fig. 5.62: Digital elevation model of the uvala Crljivica

Fig. 5.63: Crljivica, view from the south-east

The area within its highest closed contour is mildly undulating, with scattered dolines. However, the area within its topographical divide includes steep and uniform mountain slopes, so the relief in general is very dissected. The uvala is completely dry. Two small caves within Crljivica have been described by Dukić (1966).

On the north-eastern foothill of Mt. Lunjevača, there is the **Materića Uvala (ID_25)**, completely covered by forest vegetation. Its uniform elongated plan area is a result of its development along a single fault. The exact elements of the fault have been detected during the structural-geological field mapping. The fault stretches along the north-eastern slope of the uvala, where its crushed zone is formed. The lowest parts of the uvala, together with the saddles on its perimeter, are situated within the tectonically broken zone of the same fault. Several broken zones which stretch in perpendicular direction have been detected, but they (still?) do not have any impact on the uvala morphology.

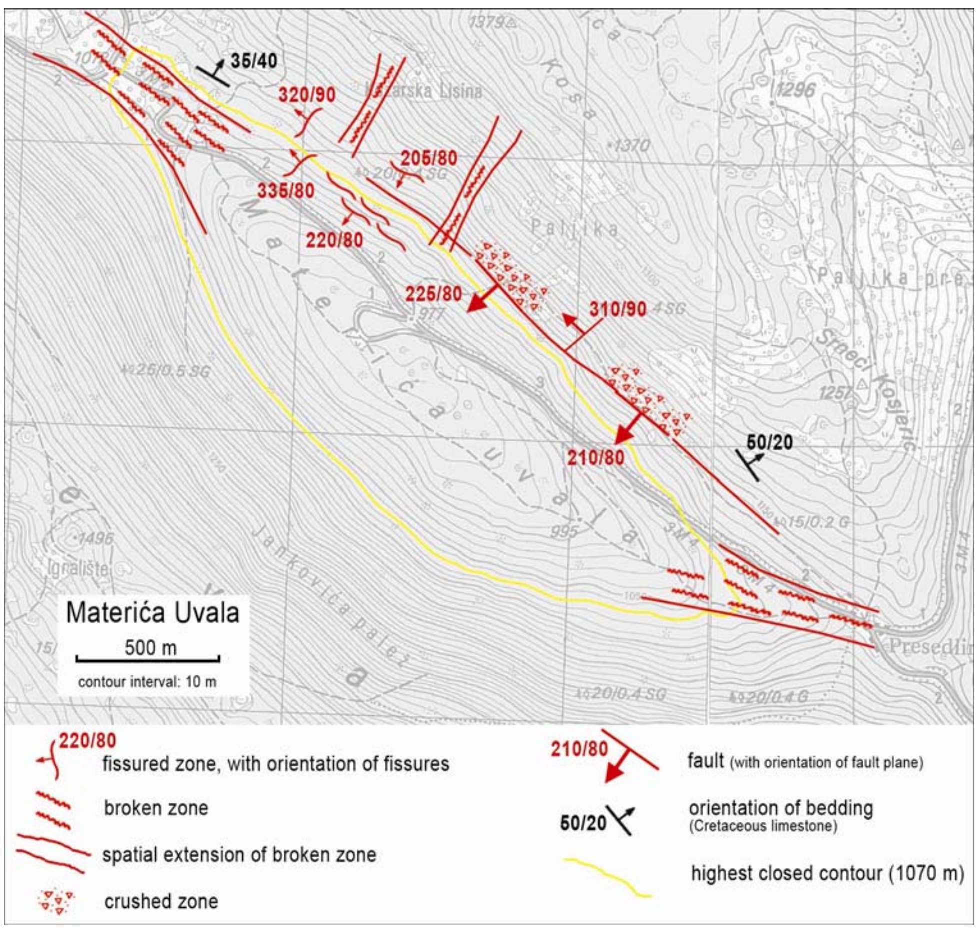

Fig. 5.64: Structural-geological sketch of Materića Uvala

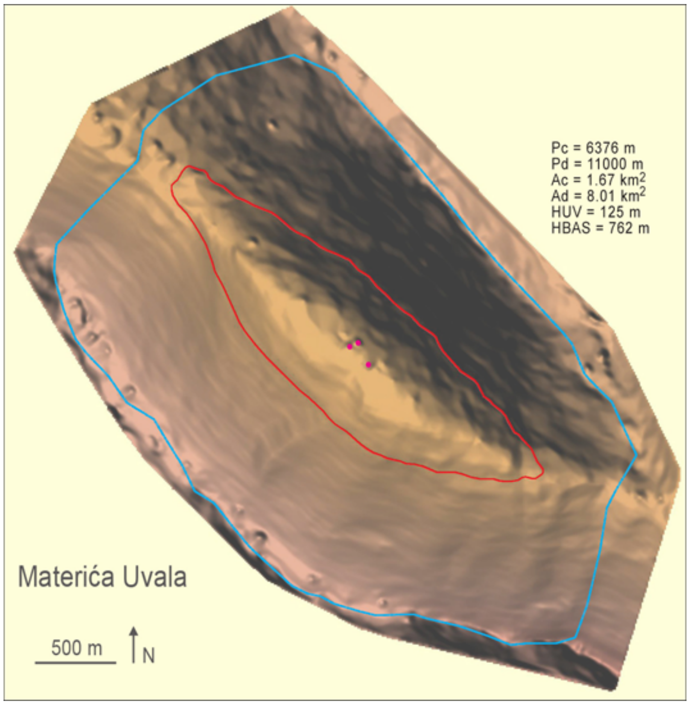

Fig. 5.65: Digital elevation model of the Materića Uvala

Klekovačka Uvala (ID_27) is situated between the mountains Klekovača and Lunjevača, within the structural unit Grmeč - Šiša. Cretaceous limestones dominate in the lithological composition. It is interesting to mention that the adjoining mountains have the synclinal structure, while the uvala is situated within an anticline (Vrhovčić et al. 1976). The vast bottom of the uvala and mild segments of its slopes are densely populated with dolines. By the majority of morphometrical parameters, this uvala is the absolute leader within the studied sample. Its depth up to the highest closed contour is 215 m, while the basin depth (HBAS) exceeds 1000 m. This extraordinary feature deserves the place among the most stunning phenomena of the Dinaric karst.

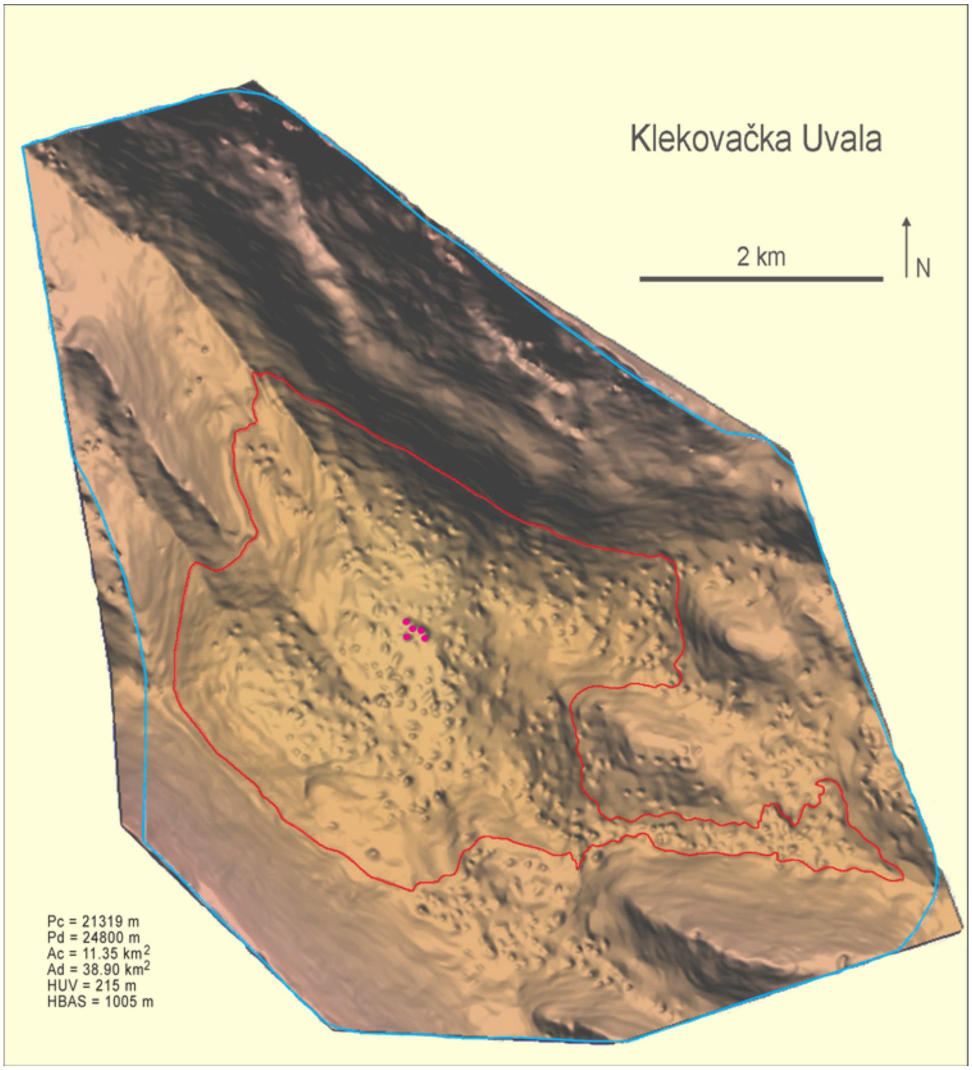

Fig. 5.66: Digital elevation model of the Klekovačka Uvala

5.1.11. Uvalas of the areas around Livanjsko, Glamočko and Kupreško polje

These great poljes in western Bosnia have been, due to their prominence in the relief and importance in history of karstology, the focusing points in karstological and geomorphological research of the whole area. On the other hand, the vast karstic areas of higher terrains around the poljes are totally scientifically neglected. This region is a part of so-called Bosnian-Herzegovinian High Karst.

Roglić (1954) considered the Livanjsko polje a "tectonically formed depression in which Tertiary marine and lacustrine sediments are situated". It is stretching in dinaric NW-SE direction, and the extreme NW and SE (Buško Blato) parts are the lowest in elevation and longest flooded. Gams (1978) classified it as an overflow polje, at the mean elevation of 700 m and with the flat floor surface of 385 km^2. Čečura & Bognar (1989) stress the dominant role of mass movement processes in shaping the relief of the basin, and its contact with the flat polje bottom. A series of pediments, "glacis" and "glacis terraces", as well as proluvial fans and deluvial cones, have been detected in the field.

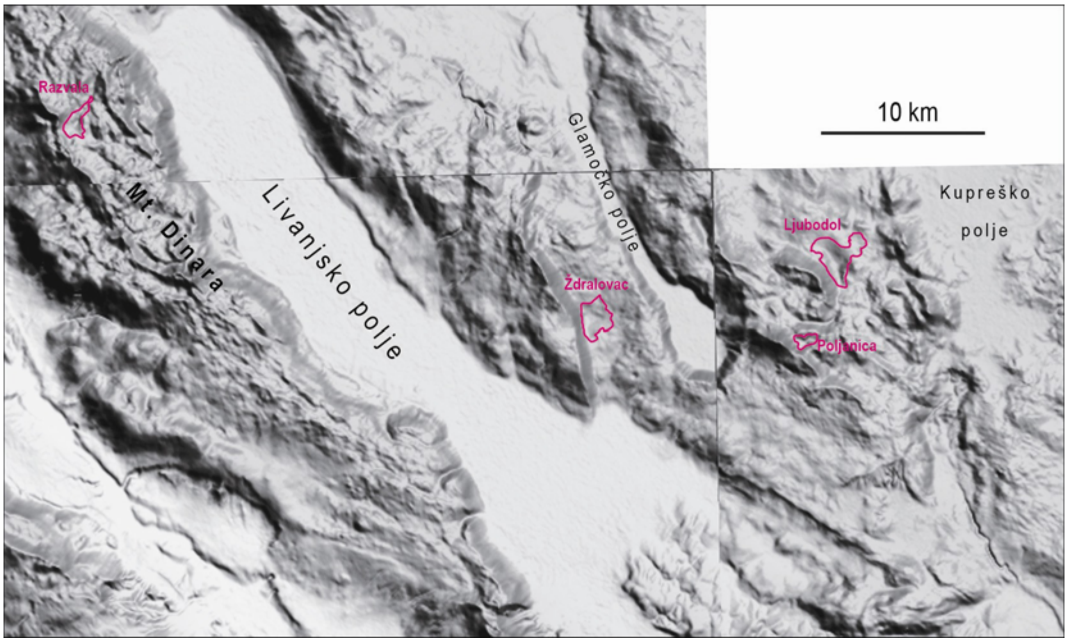

Fig. 5.67: Situation map of the uvalas in the area of great poljes of western Bosnia (mapped on the SRTM DEM)

Fig. 5.68: Sediments at the bottom of the Livanjsko polje (Mt.Dinara in the background)

The polje is filled with Upper Miocene and Lower Pliocene loose sediments, whose depth is close to 2000 m, which means that their rocky bottoms are deep cryptodepressions (Gams, 2005).

Glamočko polje is morphologically specific, having a very narrow middle part, and a very steep south-eastern margin. It is a border peripheral polje at the elevation of 890 m, with the flat surface area of 129 km^2 (Gams, 1978). This polje is also filled with Neogene sediments, about 500 m thick. Tectonic sinking of both Livanjsko and Glamočko polje started in the Lower Miocene, and is probably still active, trapping the sediments inside the basins (Gams, 2005). Hydrogeologically, Glamočko polje is a regional watershed between the Adriatic and the Black Sea drainage areas. The ponors along the NE margin of the polje are linked with the resurgences in the valleys of the rivers Pliva and Sana (Danube catchment), while the ponors along the SW margin direct the waters towards the Livanjsko polje and, subsequently, Cetina River, which feeds into the Adriatic (Papeš & Srdić, 1969).

Kupreško polje is of irregular shape and its bottom is not flat as those of other karst poljes in the region. The western margin is a tectonic line along which the eastern block of Cretaceous limestones has been subsided. The main ponors are lined along this structure. The north-eastern side of the polje is higher and composed of crystalline schists rich in water (Roglić, 1954). According to Gams (1978), the surface of the polje is 94 km^2, the average elevation 1130 m, and it has the characteristics of a peripheral polje type.

The uvala **Razvala (ID_28)** is situated on the north-eastern slopes of Mt.Dinara, at the elevation of 1460 m (bottom point, in a seasonal pond called Riduša). Its longer axis extends in a counter-Dinaric direction. Traces of glaciation on Mt.Dinara were detected by Grund (1902; cit. by Milojević, 1922). He estimated that the snowline was at about 1400 m, which would include Razvala among the ice accumulation depressions. Although only close vicinity of the peak Veliki Troglav is mentioned in the overview (Milojević, 1922), we can assume that the spread of cirques was wider than that.

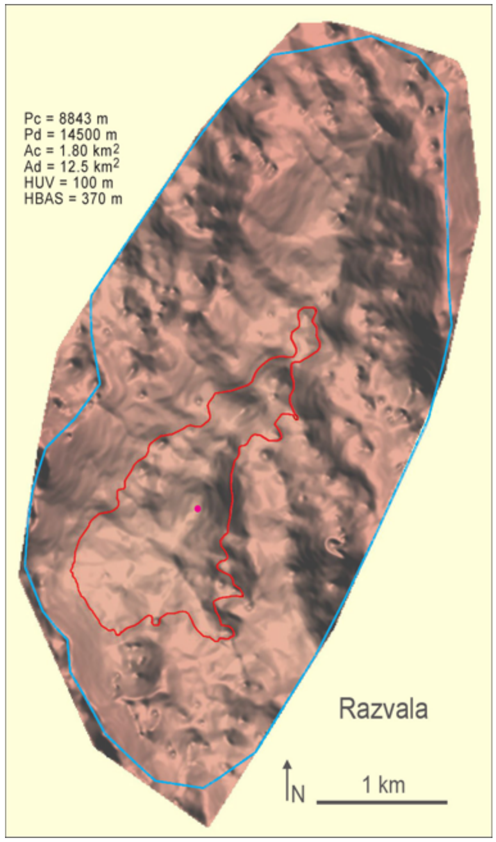

Fig. 5.69: Digital elevation model of the uvala Razvala on Mt.Dinara

The uvala **Ždralovac (ID_29)** is situated on a ridge between the Glamočko polje and Livanjsko polje. The area of closed depression in a strict sense is relatively small in comparison to the topographical area, which is dominated by the steep slopes of Mt.Velika Golija towards the Glamočko polje.

Fig. 5.70: Ždralovac, view from the south (Photo: I. Dolić)

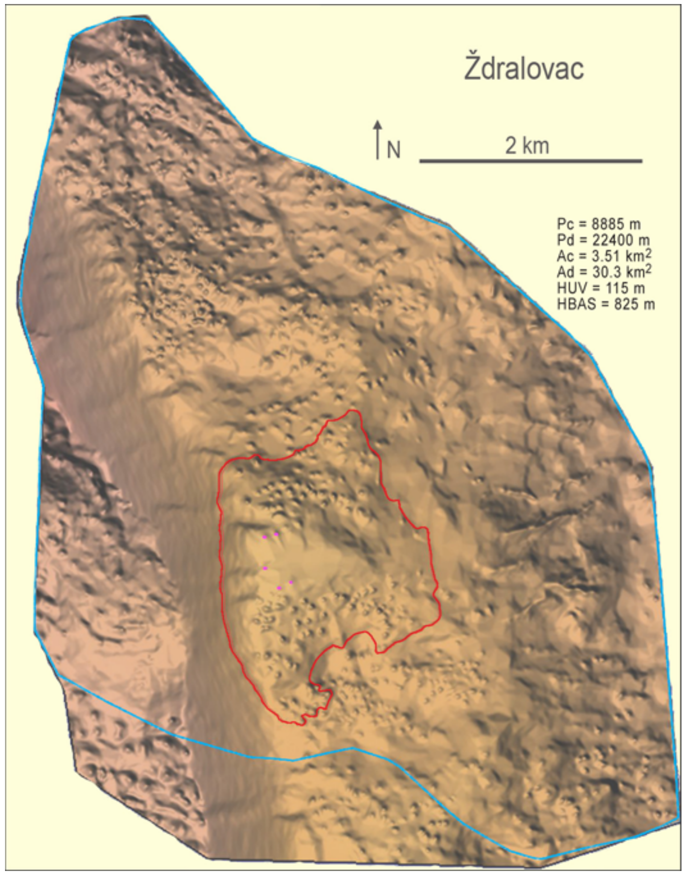

Fig. 5.71: Digital elevation model of the uvala Ždralovac

The uvala **Poljanica (ID_30)** is the highest among the studied case examples. Its bottom is situated at the elevation of 1510 m, while the highest closed contour is that of 1600 m. It is situated close to the peak Cincar (2002 m a.s.l), the highest peak in the region of great poljes of western Bosnia. Milojević (1922) mentions the uvala Poljanica ("Poljana") within the interpretation of glacial traces on Mt.Cincar. He states that a steep-sided doline (20 m wide and 20 m deep) SW from the Poljanica, had a function of a small cirque. At the phase of maximum glaciation, the ice was moving across the escarpment and collapsed into the uvala ("Poljana is an uvala pitted with dolines, with glacial pebble on its bottom").

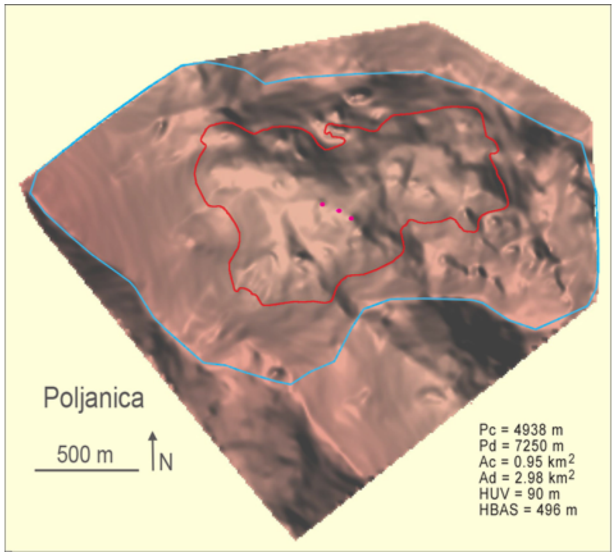

Fig. 5.72: Digital elevation model of the uvala Poljanica

The area between the Glamočko and Kuprěško polje abounds in large uvalas. One of them is **Ljubodol (ID_31)**, a compound uvala consisting of western, deep lobe of elongated plan area, and of eastern "satellite" sub-depression, which is more shallow, but encompassed within the same contour of 1260 m. Both lobes are densely pitted with dolines. Ljubodol is one of the largest uvala within the studied sample, and stands out in morphometrical overviews, together with Klekovačka Uvala, Rupa, and Duboke Jasle.

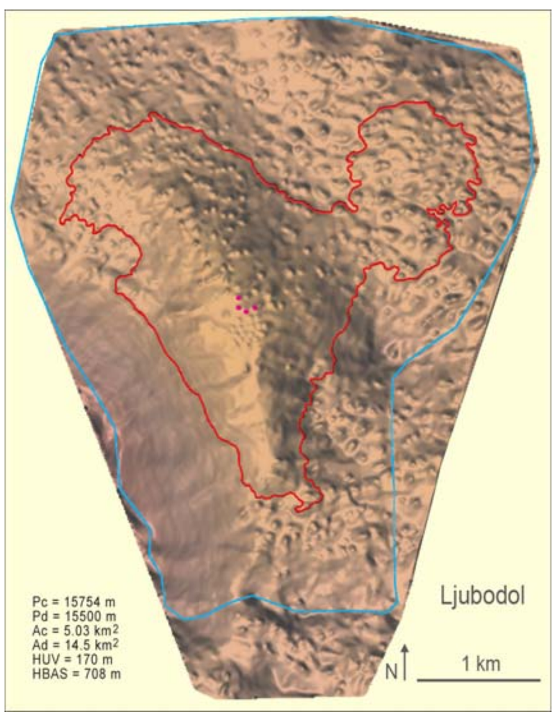

Fig. 5.73: Digital elevation model of the uvala Ljubodol

5.1.12. Uvalas in the regions Oputne Rudine and Banjani (western Montenegro)

In geotectonic division of Montenegro given by Radulović & Radulović (1997), the areas Oputne Rudine and Banjani belong to the unit High Karst Zone, and more precisely, to the anticlinorium Stara Crna Gora. The region has a long history of (paleo)karstification, considering the fact that complex conditions of bauxite genesis were reported in the area of Velimlje in Banjani (Grubić, 1964, cit. by Milovanović, 1965). Presently, this is a karstic plateau at the approximate elevation of 1000-1200 m a.s.l., situated between the artificial accumulation Bileća on the west, and Nikšićko polje on the south-east. Nikšićko polje is, according to Gams (1978), of overflow and border type, with the flat floor area of 48 km^2, while Nicod (2003b) considers it "the most complex among the Dinaric poljes".

The uvala **Vuči Do (ID_32)** is situated on the western rim of the plateau, close to the slope facing down to Bileća accumulation.

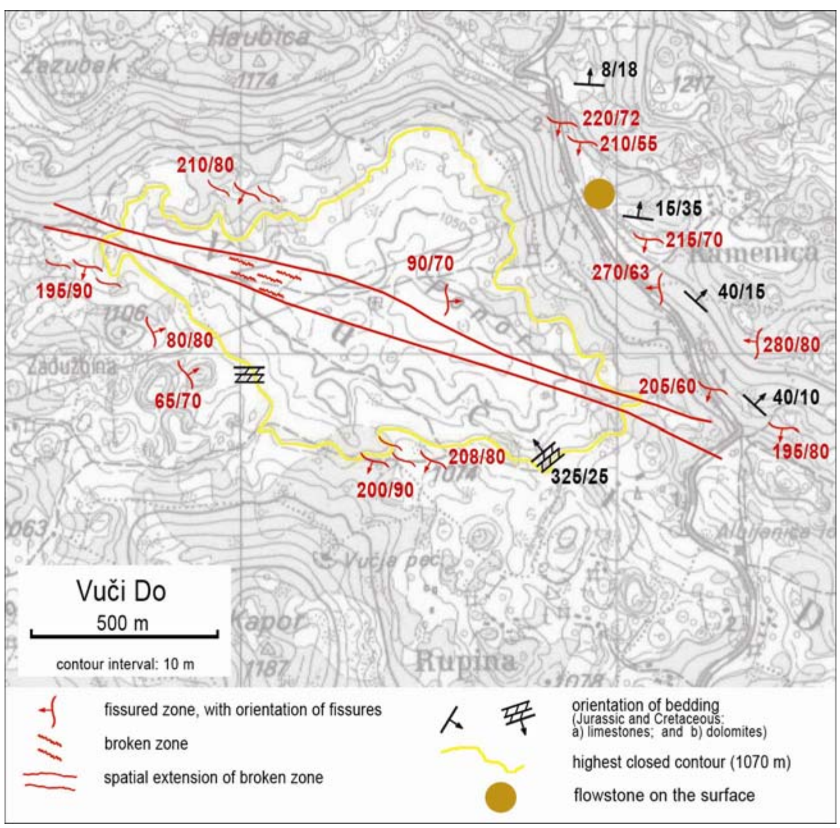

Fig. 5.74: Structural-geological sketch of the uvala Vuči Do

This is a relatively flat uvala, in large part built of dolomites weathered in a rubble. The dolomites enabled the existence of a small seasonal flow, sinking to the ponor in the central part of the depression. Structural-geological mapping was very difficult, because the rocky outcrops are very rare, and if found, they are often useless because no structural elements are visible.

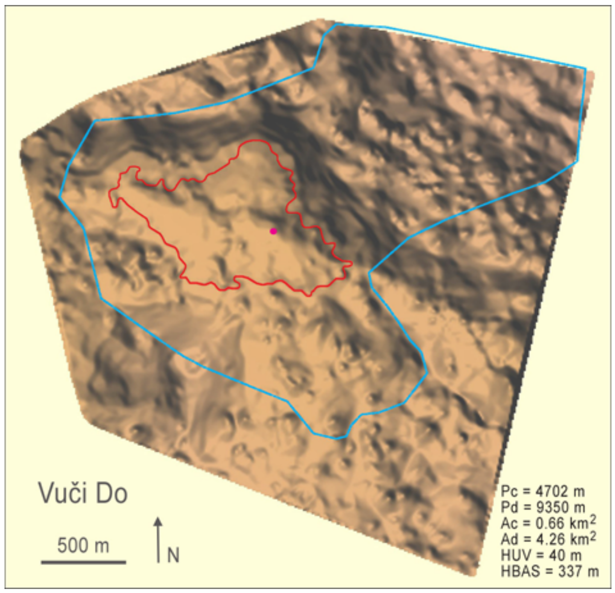

Fig. 5.75: Digital elevation model of the uvala Vuči Do

Fig. 5.76: Vuči Do, view from the south

Several kilometers towards the north-east, an uvala **Baljački Do (ID_33)** is situated. The uvala is very distinctive in relief, with the depth of 115 m. Two parallel anticlines within the Ac area have been mapped by Vujisić (1967), and the bedding is very well visible. Baljački Do is situated within relatively flat area with dolines (on some segments of its perimeter), so the delineation of the topographical divide is only approximate.

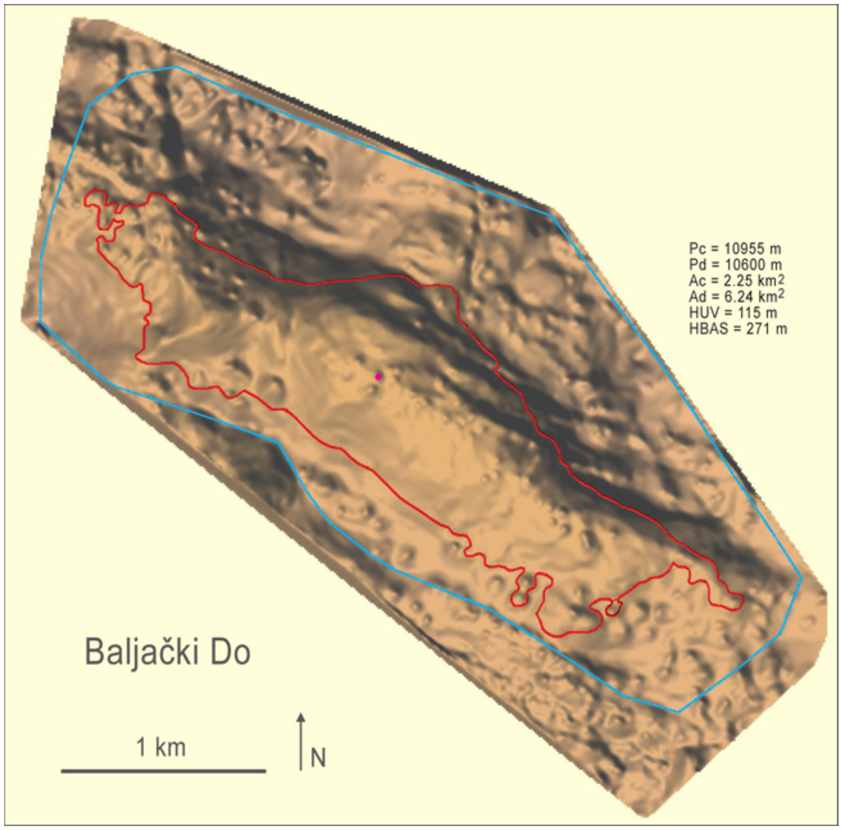

Fig. 5.77: Digital elevation model of the uvala Baljački Do

Fig. 5.78: Baljački Do, view from the north-west

An interesting uvala **Štrpca (ID_34)** is situated close to the large uvala Velimlje, in the region of Banjani. It owns its specific lobate plan area shape to the fact that it is situated on the crossing of two faults. They are not mapped on the basic geological map, but are clearly visible on the digital elevation model. The complete area of the uvala (even Ad area) is densely pitted with dolines.

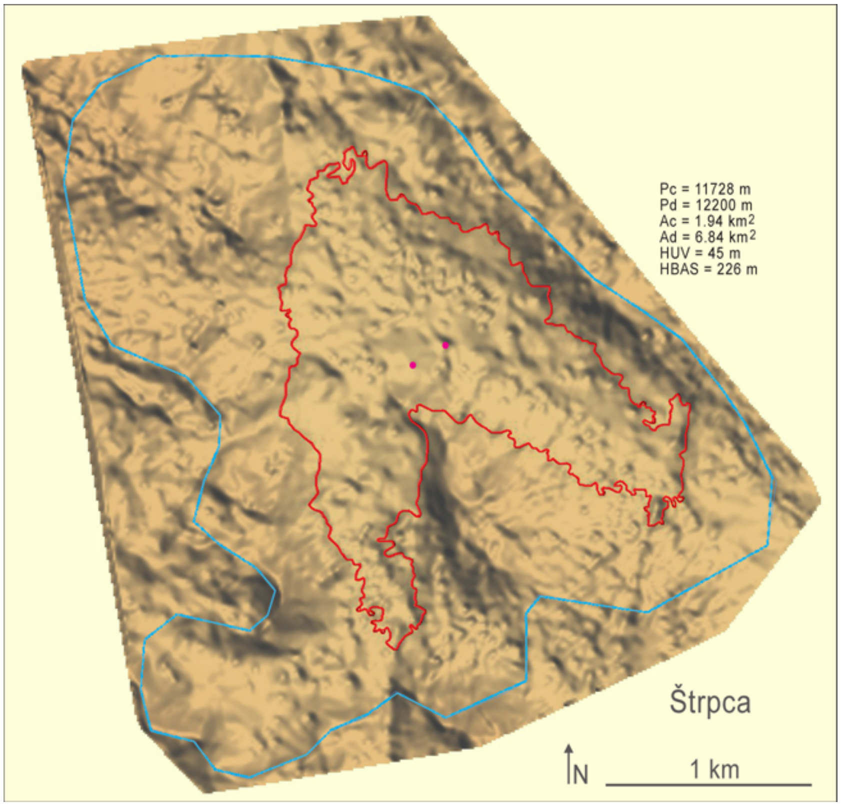

Fig. 5.79: Digital elevation model of the uvala Štrpca

5.1.13. Uvalas of the region Katunska Nahija

The historical region of Katunska Nahija (also known as Katunski Kras) is situated in south-western part of Montenegro. The region was one of the administrative units of Montenegro in the 19th century. Presently, this area belongs to municipalities of Nikšić (northern part) and Cetinje (southern part), and is not a formal unit any more. However, it is morphologically distinctive and can be rather clearly spatially defined. Due to extensive and prominent karstic relief, Katunska Nahija is sometimes called Katunski Kras.

The region stretches from karstic plateau south of Nikšićko polje to Mt.Lovćen. The western border is marked by Grahovsko and Dragaljsko polje, and the eastern approximately by the Zeta River valley and Cetinjsko polje.

The region of Katunska Nahija belongs to the anticlinorium Stara Crna Gora, within the structural unit High Karst Zone (Radulović & Radulović, 1997). In the lithological composition, there are predominantly limestones and partially dolomites, all ranging in age from Middle Triassic to Upper Cretaceous (Antonijević et al. 1969; Vujisić 1967). The region is extensively and deeply karstified. The surface is completely dry, without permanent springs. Problems with water supply (Mijatović, 2002) have caused severe depopulation of the area.

Karstic resurgences are situated in two zones: south-western (Gurdić, Škurda and Ljuta in Boka Kotorska Bay, at the sea level), and north-eastern (in the Zeta River valley – Oboštičko Oko at 55 m a.s.l.). Springs in the Boka Kotorska Bay are characterized by enormous oscillations of discharge, depending on the season (e.g. the discharge of the Ljuta spring is ranging from less than 1 m^3 to more than 350 m^3; Radulović & Radulović 1997).

Surface karst relief consists of a large number of closed depressions of various sizes, with conical hills and linear (structurally defined) ridges in between. Two depressions have certain characteristics of poljes: Njeguško polje and Cetinjsko polje (which is completely urbanized, hosting the town of Cetinje). Plateaus are pitted with dolines, while areas between the ridges host uvalas of various sizes. Their bottoms and slopes in most cases host secondary dolines. Some of the uvalas are of enormous dimensions; they are not included into the study, but their positions are indicated in the Fig. 5.80.

One of the most extensive uvalas in the area is Podbukovica – Gornja Zaljut, stretching along the longer axis (Dinaric NW-SE direction) for more than 10 km. It even does not have a single name (toponyme); we are using the names of villages situated on its opposite sides. Structural guidance is very prominent in this case.

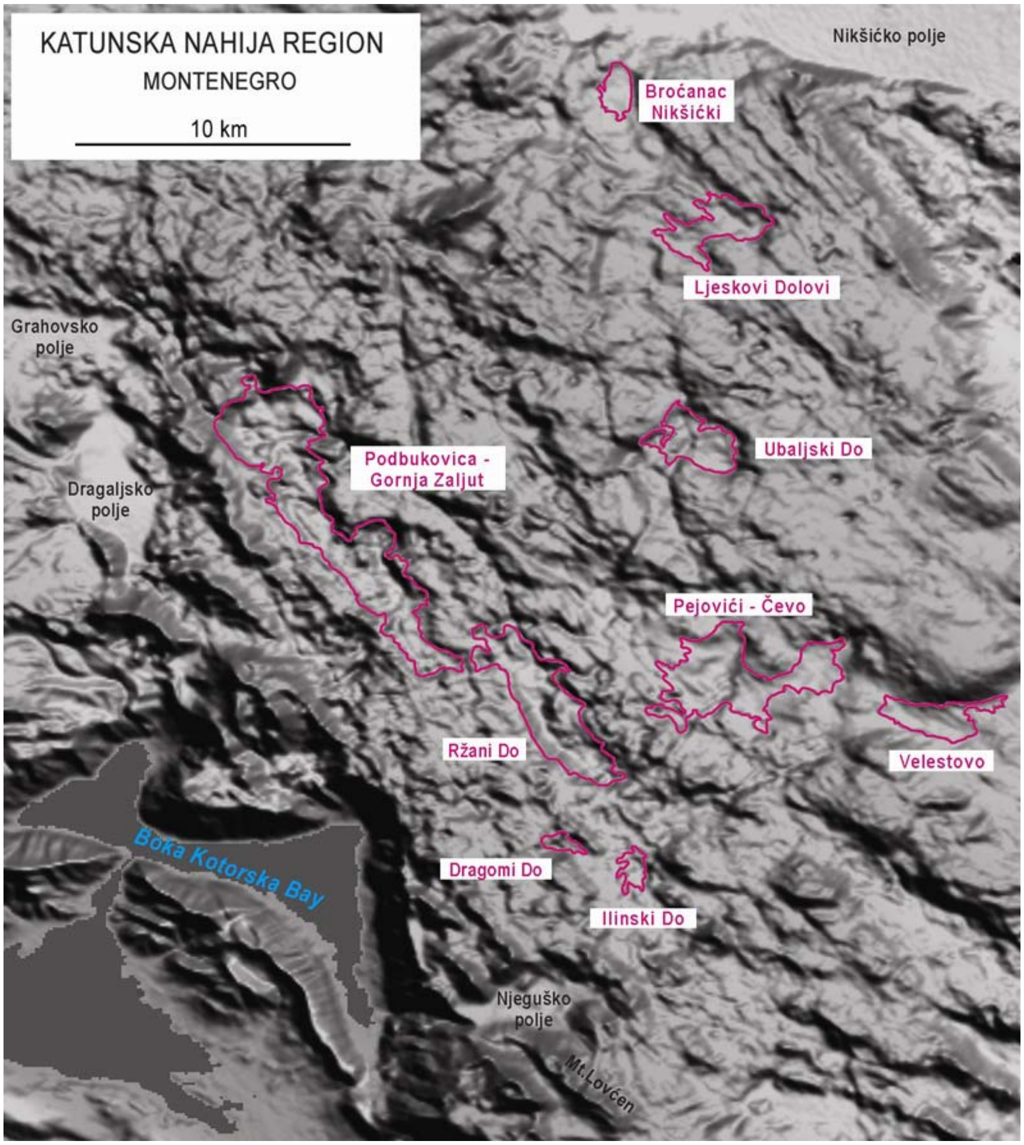

Fig. 5.80: Positions of some uvalas in the region Katunska Nahija (mapped on the SRTM DEM)

The ridge along the SW rim of the depression is formed of Lower Cretaceous cherts and marls and has an anticline form. The actual depression is in fact a block of Middle Cretaceous limestones and dolomites which has been lowered along a fault. The uplifted block is the mentioned chert-marly ridge. At the SE end of depression, a syncline form has been mapped by Antonijević et al. (1969).

The uvala **Broćanac Nikšićki (ID_35)**, situated close to the south-western margin of the Nikšićko polje, is formed along a N-S striking fault at its eastern rim. Lithologically, it consists of Lower Jurassic limestones and dolomites. One of the conspicuous characteristics of Broćanac Nikšićki is that the surface encompassed by hypothetical topographic divide considerably exceeds the surface encompassed by the highest closed contour.

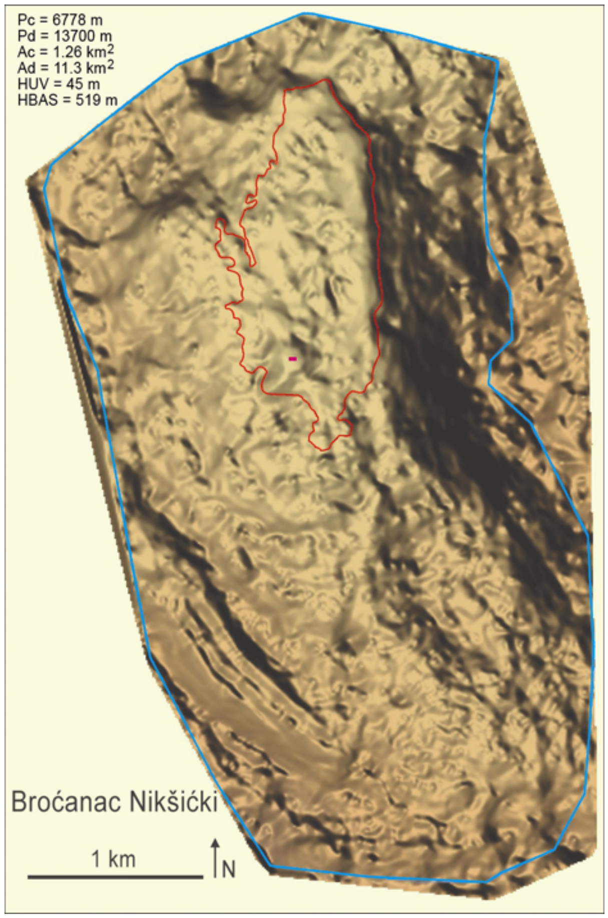

Fig. 5.81: Digital elevation model of the uvala Broćanac Nikšićki

Fig. 5.82: Broćanac Nikšićki, view from the north-east

Ljeskovi Dolovi (ID_36) is a compound uvala consisting of two large hollows. It is lithologically rather complex, consisting of various sub-types of limestones and dolomites ranging from Lower Jurassic to Upper Cretaceous. An interesting structural detail is that the north-eastern of the two sub-depressions is in fact formed in an anticlinal overturned fold (Vujisić, 1967). Thus its development can be interpreted (at least partially) by the existence of tension-type open fissures which enabled the enhanced infiltration of atmospheric waters and, consequently, enhanced erosion.

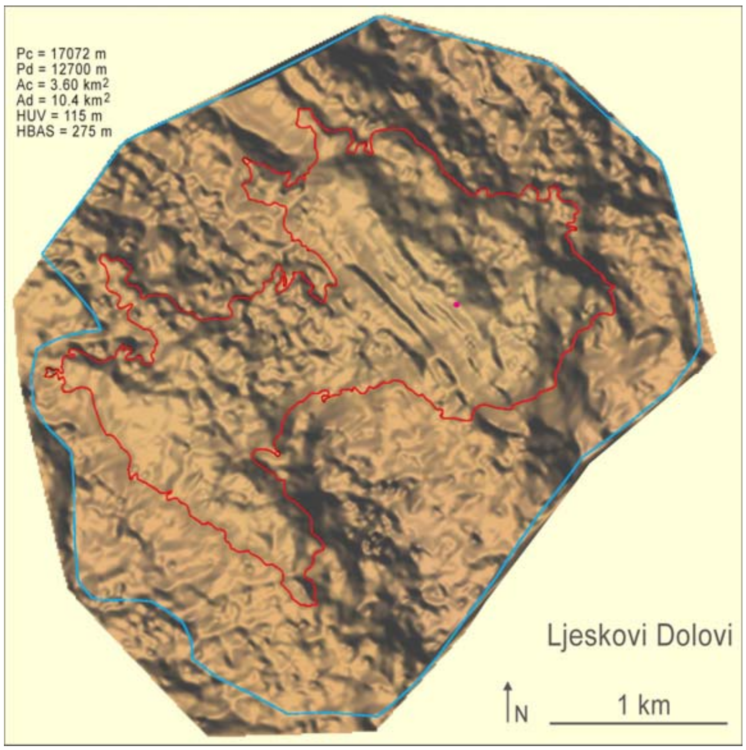

Fig. 5.83: Digital elevation model of the uvala Ljeskovi Dolovi

Fig. 5.84: Ljeskovi Dolovi, view from the north-east

Ubaljski Do (ID_37) is another compound uvala, consisting actually of three units – Bijelo Polje on south-east, Stažer on the west, and Ubaljski Do on the northern rim. Between northern and southern sub-depression, there is an abandoned bauxite quarry. Western part of Ubaljski Do is formed in Lower Jurassic limestones, while the eastern part consists of Middle Cretaceous limestones with dolomites (Antonijević et al., 1969).

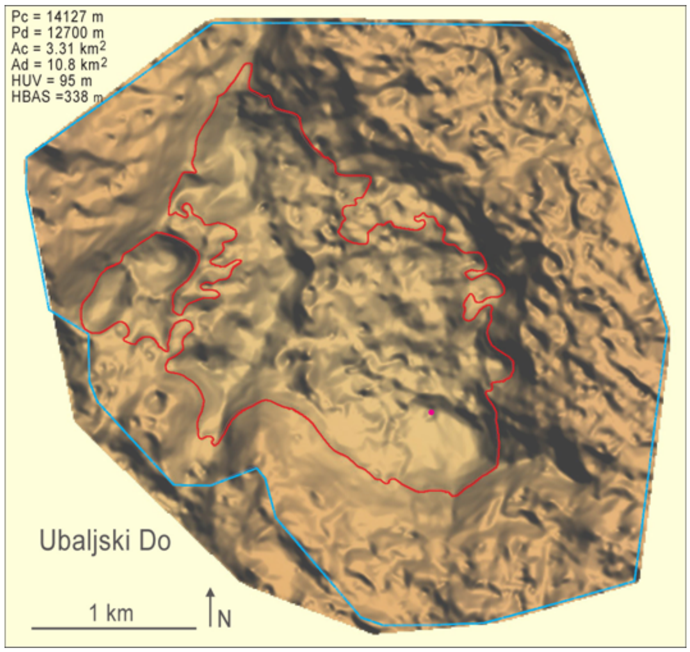

Fig. 5.85: Digital elevation model of the uvala Ubaljski Do

Fig. 5.86: Ubaljski Do, view from the north-east

The place of **Dragomi Do (ID_38)** in the classification of karst closed depressions could be discussed more in detail, due to the fact that it has several characteristics of a large doline – it fits both by dimensions and basic morphology, being a rather circular form whose shape can be approached by a cone. For the reason of consistency with other presented examples, the highest closed contour (890 m) is marked on its digital elevation model. However, it is possible to mark the actual rim of the depression where the slope inclinations abruptly change. Lithological composition is very simple – the whole area of Dragomi Do and its surroundings is formed of Middle and Upper Jurassic limestones (J_{2+3}) (Antonijević et al., 1969).

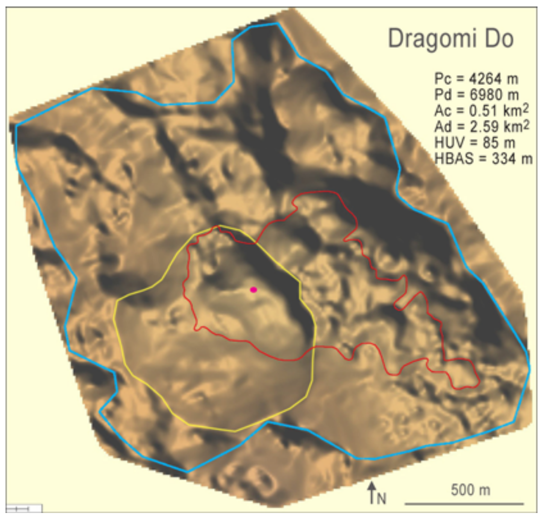

Fig. 5.87: Digital elevation model of the uvala Dragomi Do (yellow line represents the line of sudden inclination change)

Fig. 5.88: Dragomi Do, view from the south

Ilinski Do (ID_39) is situated close to the Dragomi Do, but its structural and lithological settings are much more complex. During the structural-geological mapping, a conspicuous tectonically crushed zone was detected in the south-eastern part. To the north-east of this structure, there is another heavily crushed zone, which also lies within the broader area of the depression. Ilinski Do is lithologically quite complex as well. The south-western part is formed of Triassic dolomites and dolomitic limestones, and the afore mentioned fault (with the crushed zone) divides the Triassic dolomites from Jurassic limestones, dipping towards west. Lower Cretaceous limestones without visible bedding are present on the north (Antonijević et al., 1969). The central part of the depression hosts a small flat area with a suffosion swallet in the sediments. The lowest point in the depression lies at 715 m, while the highest closed contour is that of 800 m.

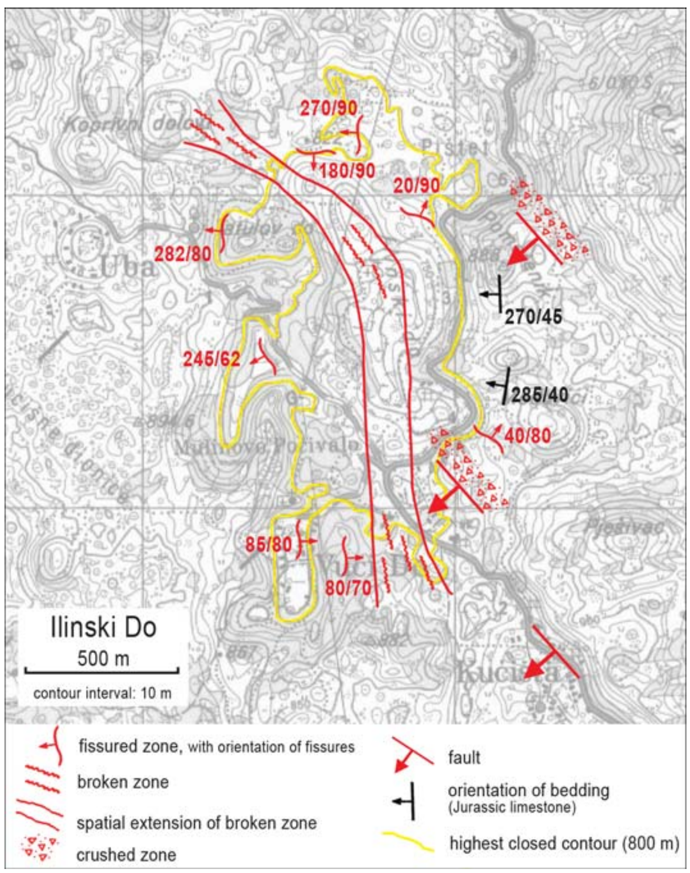

Fig. 5.89: Structural-geological sketch of the uvala Ilinski Do

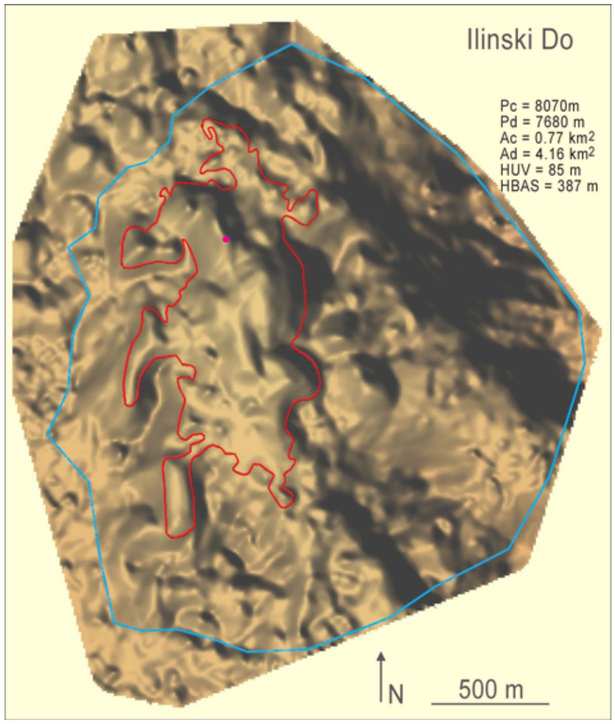

Fig. 5.90: Digital elevation model of the uvala Ilinski Do

Fig. 5.91: Ilinski Do, view from the south

5.1.14. Uvala Dolovi on Mt.Lovćen

Mt.Lovćen marks the southern edge of the region Katunska Nahija, and it is the highest and most conspicuous mountain in this area, rising in steep littoral slopes over the Boka Kotorska Bay. The highest peak is Štirovnik (1749 m a.s.l). Studying the Pleistocene glaciation of Mt.Lovćen, Cvijić (1903) noticed the existence of broad uvalas between the highest peaks: “They are dissecting this mountain instead of normal valleys. They are so deep that they are not constituents of the main ridge, but a particular form (…) their bottoms are in a form of mesh – they contain small limestone ridges and other protrusions, among which there are small dolines”. Although it is not specifically mentioned in the text, one of such uvalas is the uvala **Dolovi (ID_40)**. It is situated on the very front of the High Karst thrust over the Pindus-Cukali, or Budva zone. Considering the great depth of the vadose zone (1200 m), the uvala is not particularly large nor deep, but there is another characteristic which distinguishes it among other studied examples. During structural-geological mapping, it was detected that the uvala formed in a mild syncline, as opposed to majority of others, which are formed mainly along tectonically broken zones. A small broken zone was mapped on the southern margin of Dolovi, but it does not have particular impact on the relief. The syncline in the area of Dolovi is not mapped on the basic geological map (Antonijević et al. 1969), but it is mapped in the same direction further to the north, close to the peak Štirovnik. Another small syncline is mapped in the adjoining uvala Ivanova Korita.

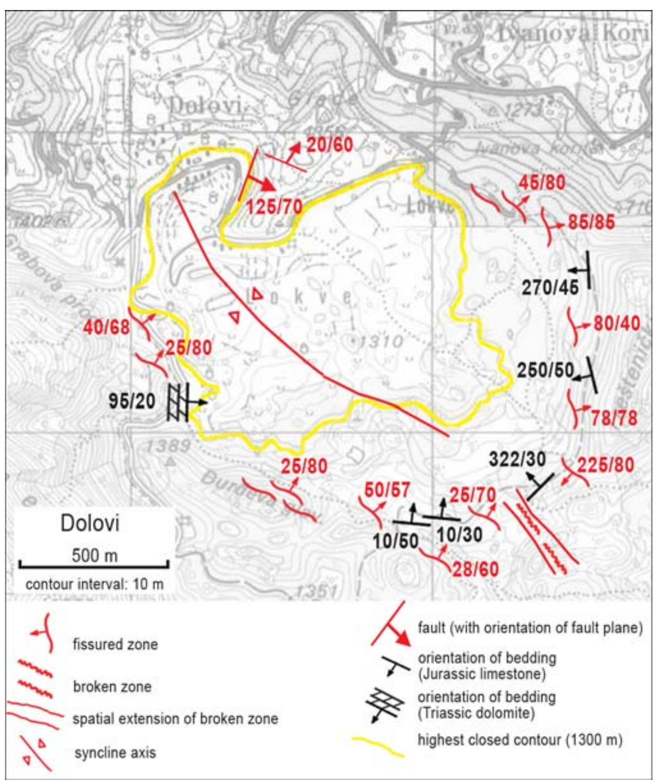

Fig. 5.92: Structural-geological sketch of the uvala Dolovi

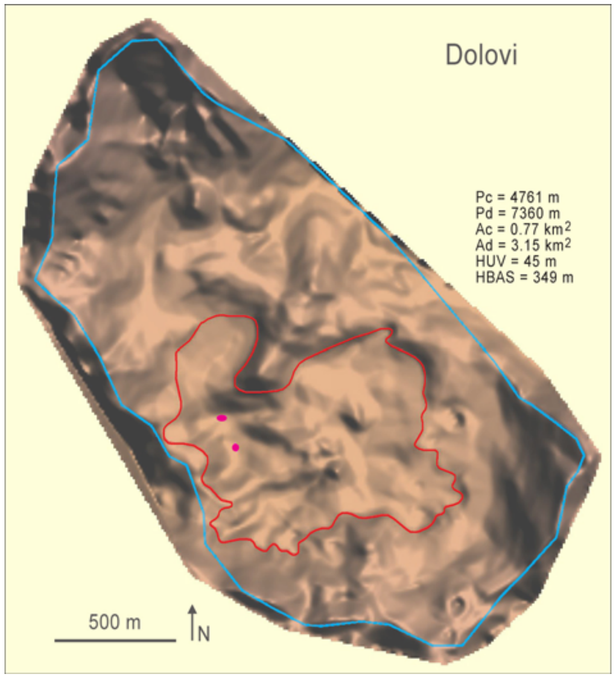

Fig. 5.93: Digital elevation model of the uvala Dolovi

Fig. 5.94: Dolovi, view from the south

5.2. Carpatho-Balkan Mountains

Carpathian mountain belt extends through great part of Central and Eastern Europe, from Czech Republic, Slovakia and Poland on the north, where the belt has a W-E direction, through Ukraine, where it rotates to the south-east, and Romania, where it abruptly changes the direction from NW-SE to E-W, and subsequently towards the south. Southern Carpathians extend across the Danube Gorge (Iron Gates), between Romania and Serbia. Mt.Balkan stretches from the Serbian-Bulgarian border towards the east across the whole Bulgaria. Carpathian and Balkan mountain chains are orographically a single belt. The segment where the Carpathians bend from N-S direction to the east towards Mt.Balkan, is called the Carpatho-Balkan Mountains, or Carpatho-Balkanides (see Fig. 5.1).

Carpatho-Balkanides have a very complex geological composition. Formations of all ages are present, from the Precambrian to the Quaternary. Precambrian and Palaeozoic formations are mostly metamorphic; Triassic and Lower Jurassic are represented to smaller extent, with terrigeneous formations, while significant transgression took place in the Middle Jurassic. Sedimentation took place till the end of Lower Cretaceous, and the Upper Cretaceous was characterized by volcanic activity and deposition of thick volcanic-sedimentary complexes. Tertiary sedimentations took place in isolated lacustrine basins, formed by tectonic activity (Stevanović, 1991). In most of those basins, Neogene sediments are still present.

The main Carpatho-Balkan structures (regional faults) stretch in the north-south direction, rotating towards north-east on the north, and towards south-east on the south. The majority of regional dislocations stretching from the southern Carpathians are dextral transcurrent, while the direction of thrusting is from the west to the east, caused by the stress from the direction of Serbo-Macedonian unit (Grubić, 1974). According to Kräutner & Krstić (2003), several tectonic units take part in the structural pattern of the Carpatho-Balkanides (Fig. 5.95).

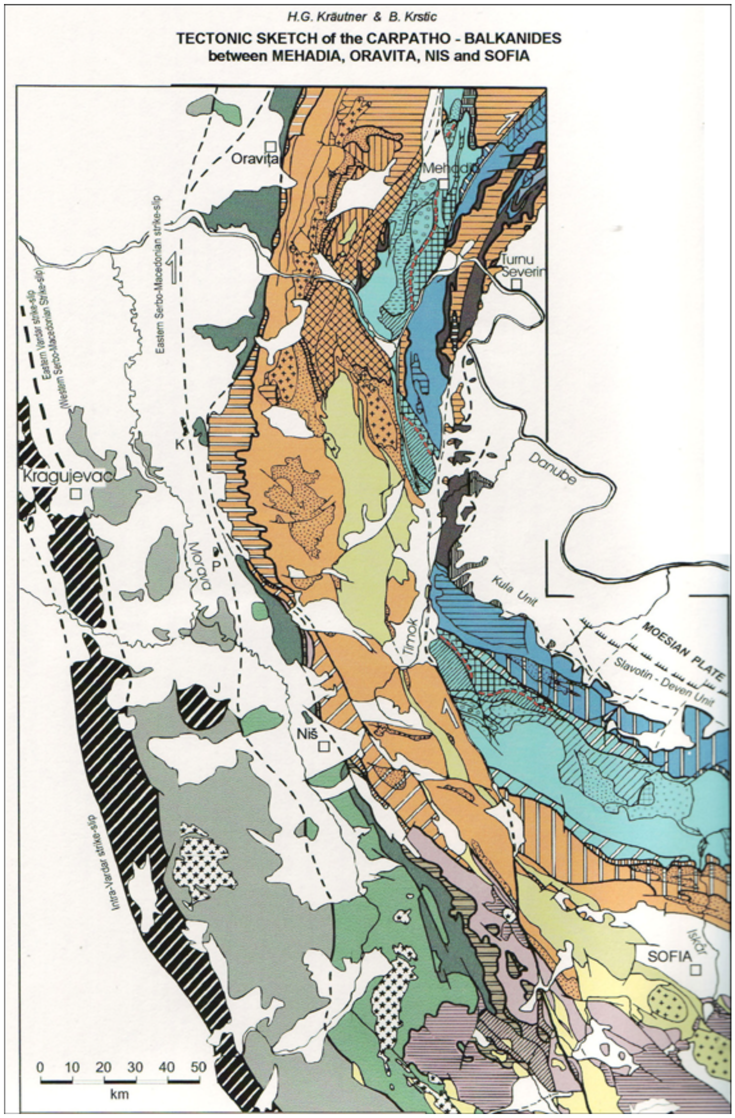

Fig. 5.95: Tectonic sketch of the Carpatho-Balkanides (Kräutner & Krstić, 2003)

Distribution of limestones and karst differs greatly in the Carpatho-Balkanides, in comparison to the Dinarides. Due to complicated tectonics, and greater lithological variations, limestone portions of the Carpatho-Balkanides are segmented and isolated, surrounded by impermeable rocks. Karst forms are smaller in extent and in size, while the occurrences of contact karst and fluviokarst features are more common. Total potential for vertical development of karst is from 300 to 700 m. It was difficult to find true uvalas for the study, because most locations which are in literature treated as uvalas are in fact blind valleys. Veliko Igrište was selected for historical reasons and for the purposes of comparison, while the uvalas Baševica and Ovča can be regarded as true representatives of the kind.

5.2.1. Veliko Igrište on Mt.Kučaj

Mt.Kučaj is one of the most significant karst areas within the Carpatho-Balkan Mountains in Eastern Serbia. It consists mainly of Lower Cretaceous limestones, but in the western part of the mountain the limestones are covered with a huge regional nappe of red Permian sandstones (Veselinović, 1964).

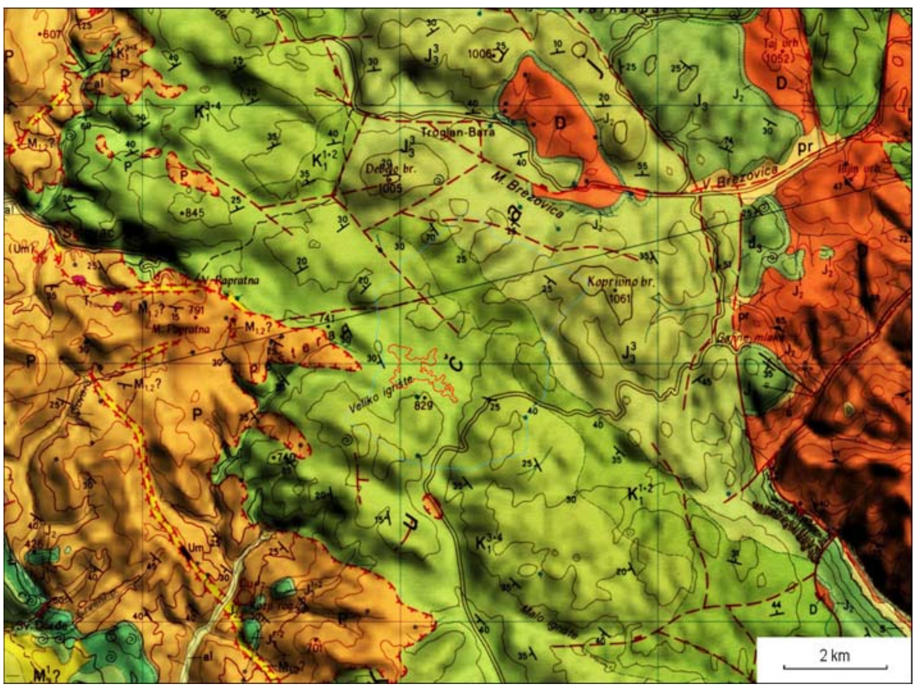

Fig. 5.96: Geological map of a part of the western Kučaj (Veselinović, 1964)

(P – Permian sandstones; J, K – Jurassic and Cretaceous limestone; D – Devonian schists)

Mt.Kučaj was one of the first karst areas that had been studied by Jovan Cvijić (1889). He noticed the large depressions on the mountain, but – contrary to some common opinions, he did not call these depressions uvalas at first. He was rather using the term *udoljine* (low lands), and in the 1889 paper he even called Igrište, Torovište (in Cvijić papers it is wrongly named Trgovište), Brezovica, and Valkaluca – the huge dolines.

Veliko Igrište (ID_41) is usually considered one of the typical uvalas of east Serbian karst (Petrović, 1994). Its bottom is covered with numerous dolines. However, Igrište does not really have an uvala-like morphology, because it is open on many sides (NW, W, SW, SE) towards the surrounding lower relief. We have selected it for the study more because of historical than of morphological reasons. The lowest altitude, within one of the dolines, is 755 m, while the highest closed contour is at 770 m, and has an extremely irregular shape which is almost "zig-zagging" through the dolined bottom. The elevations of the surrounding hills are up to 900 m. Due to the lack of typical uvala morphology, this example has often been an extreme outlier within the performed statistical analyses in the present study.

Fig. 5.97: Veliko Igrište, view from the north

The whole area of Veliko Igrište is situated within the lithostratigraphical unit of Lower Cretaceous limestones. Due to its position in western part of Mt.Kučaj, 0.5 to 2 km from the front of the red sandstones nappe, it can be expected that the process of intense overthrusting from the west had a certain impact on its development.

During the structural-geological mapping of Veliko Igrište, a number of small quarries for road-making was observed. These excavations enabled us to see a high degree of rock damage, as a consequence of tectonics, particularly thrust contacts (J. Čar, pers.comm.). The quarries are lined up in approximate west-east direction, with one branch which joined this main direction from the north-west. It is interesting that this zone extends across positive forms of relief (small hills and ridges without dolines). This points to the fact that the zone is of transitional broken-crushed character (the "pure" crushed zone would be present as more compact rock).

Fig. 5.98: One of the small quarries of road-making material in Veliko Igrište

Fig. 5.99: Condition of rock in the quarries of Veliko Igrište

The area to the south from the broken/crushed zone is pitted with dolines. That is the lowest part of Veliko Igrište, partially encompassed by the highest closed contour of 770 m. There is a broad fissured zone with clearly visible fracture planes. Dominant fissures have the orientations 170-190/90 (followed by some 0/80, which are basically the same). This shows that the dominant fissure strike is west-east, the same as that of broken/crushed zone. Fracture orientations of secondary significance are 330/90, as well as 220/90 (the same family as 40-55/80). Dominant structures explain the W-E elongation of Veliko Igrište, but the character of the broken/crushed zone (resistance to erosion) keeps its northern part higher than the southern, dolined part.

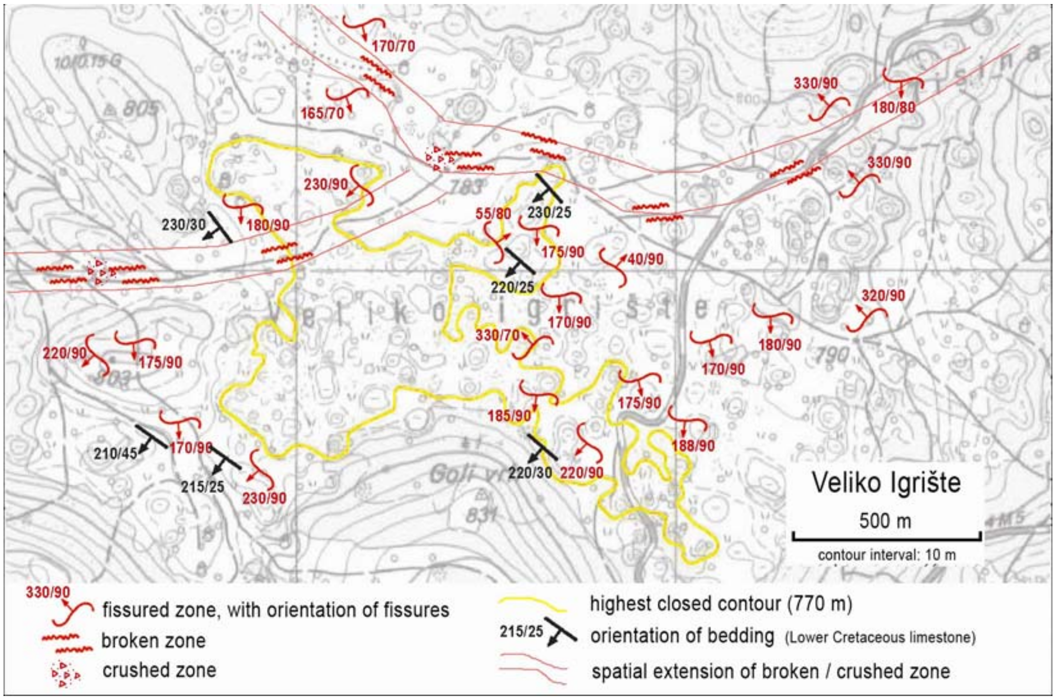

Fig. 5.100: Structural-geological sketch of Veliko Igrište

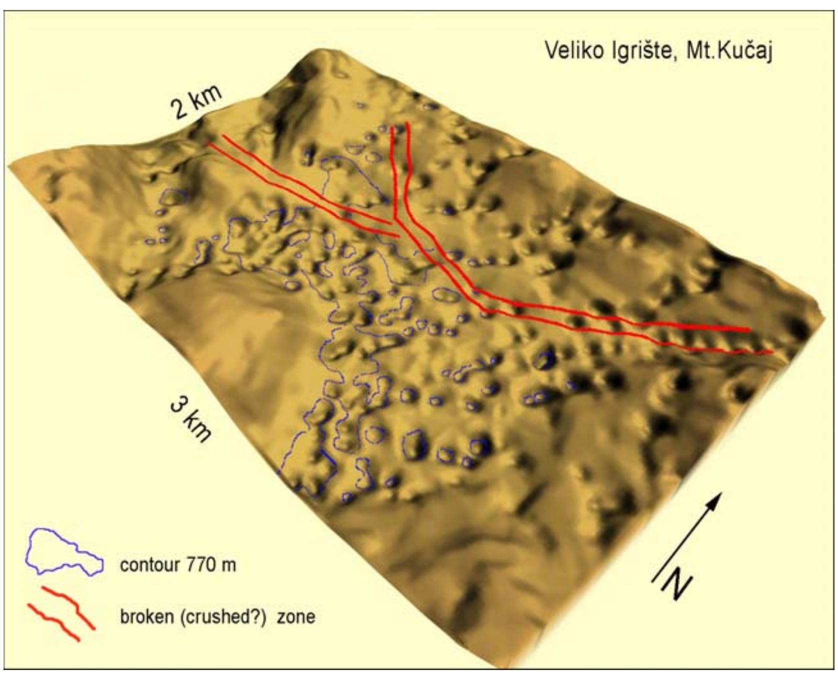

Fig. 5.101: Digital elevation model of Veliko Igrište, with the dominant tectonic structure

Petrović (1970) considers that Veliko Igrište was formed by coalescence of dolines in a dry valley, which was incised during the "pre-karstic fluvial phase". In our opinion, dry valley could have been formed only as a consequence of the existence of fluvial network on the nappe of Permian sandstones, before they were washed away.

5.2.2. Uvalas of the Tepoš plateau, Mt.Vidlič

Mt.Vidlič is a prominent ridge in the Serbian part of the mountain Stara Planina (Mt.Balkan). This ridge, together with the adjoining Tepoš plateau, exhibits fully developed karst forms, without allogenic waters, and significantly reminds of the Dinaric karst. Structurally, this unit is an overthrust of Upper Jurassic and Lower Cretaceous limestones, moving towards the north-east (Anđelković et al., 1969). Karstic waters drain mainly towards the south-west and the springs Krupačka vrela in the Pirot basin. To the east from Vidlič and Tepoš, there is the only polje in the Carpatho-Balkanides, Odorovačko polje. It originated due to tectonic subsidence, and is filled with Neogene lacustrine sediments. Western parts of the polje have a karstic drainage, through the ponors close to the village Petrlaš, while in the eastern part, the river Zabrdska Reka has regressively incised its valley into the polje area, making it a half-open polje (Gavrilović & Gavrilović, 1998).

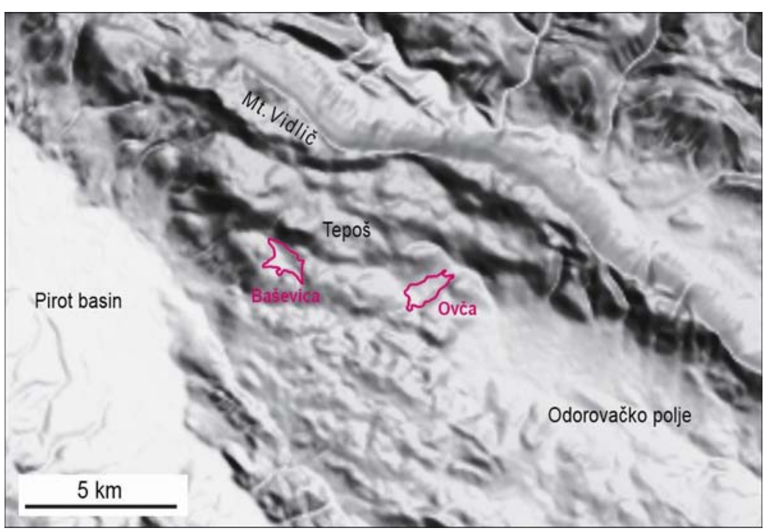

Fig. 5.102: Situation map of the uvalas Baševica and Ovča (mapped on SRTM DEM)

The uvala **Baševica (ID_42)** is situated at the rim of the Tepoš plateau towards the Pirot basin. The lowest points of the uvala have the elevation of 725 m a.s.l., while the springs in the Pirot basin are at 400 m. Star-shaped plan area of the uvala has developed due to uneven, bent strike of the leading structure, and a series of secondary structural lines striking in perpendicular direction (Fig. 5.103).

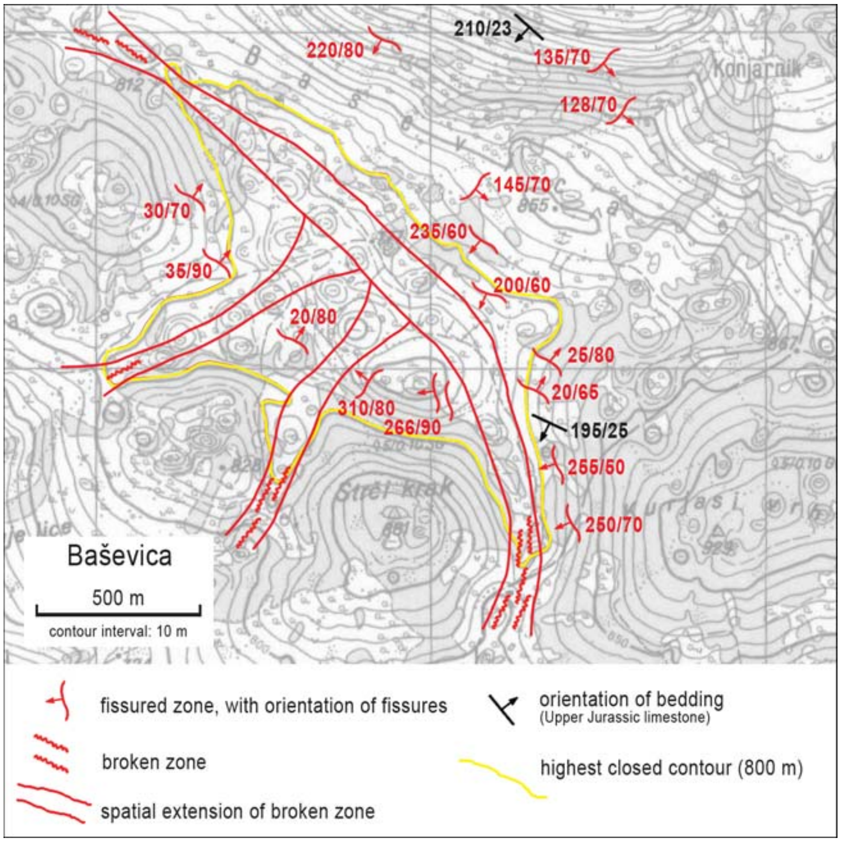

Fig. 5.103: Structural-geological sketch of the uvala Baševica

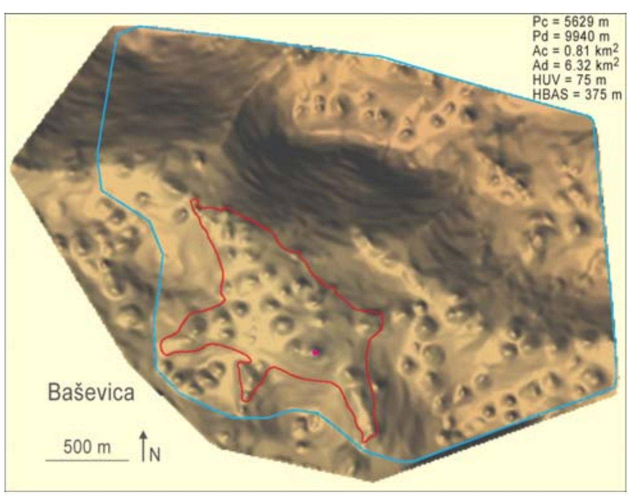

Fig. 5.104: Digital elevation model of the uvala Baševica

Fig. 5.105: Baševica, view from the north-west

The uvala **Ovča (ID_43)** is situated to the west from the Odorovačko polje. Its bottom consists of a number of shallow dolines. Gavrilović & Gavrilović (1998) consider that the uvala is located on a big fault, and wonder about its genesis with regards to the fact that an iron ore body is located close to eastern margin, and a stripe of marls and sandstone on the south-western margin. The same authors consider that uvalas are the most important karst feature on the Tepoš plateau.

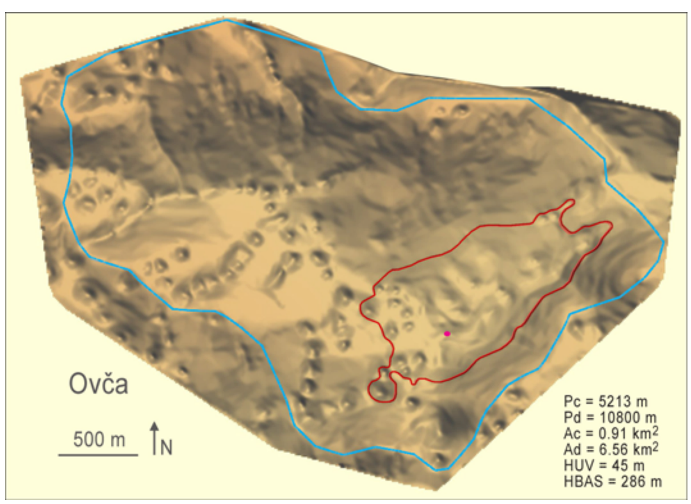

Fig. 5.106: Digital elevation model of the uvala Ovča

Fig. 5.107: Ovča, view from the south-east

6. Statistical processing

As already mentioned in Chapter 4.5, we have the reasons to believe that the sample of 43 studied uvalas is, at this stage of research, sufficient for the basic statistical analyses. Regarding the groups of data included in the processing, we can say that the greatest number of parameters, both measured and computed, is related to morphometry. Then there is a group of elevation parameters, and five qualitative parameters whose characteristics have been expressed as numerical codes (more details further in the text).

The greatest number of morphometric studies of karst depressions is related to dolines. Among many references, some of the most cited are Cramer (1941), Williams (1971, 1972), Jennings (1975), Kemmerly (1982), Day (1983), Bondesan et al. (1992), Šušteršič (1994, 2006); but the list of significant papers is much longer.

Bondesan et al. (1992) state that "morphometric analysis is possible under the following conditions: (a) the number of dolines must be high; (b) the dolines must lie over the same morphological unit; they cannot be distributed over different geological formations or in different topographical positions; (c) the dolines must not coalesce or be too irregular in shape". Furthermore, it is also said that the problems in the analyses may arise due to existence of "composite and complex forms (…) such as "multiple" dolines with lobate perimeter and more than one bottom, the dolines nested inside larger depressions as uvalas (…)".

We are aware that our sample of uvalas does not meet these requirements, and that is practically impossible to find sufficient number of uvalas in the same geological formation and topographical position. Thus, the following statistical overviews have to be taken *cum grano salis*. On the other hand, we also believe that they should not be discarded, in spite of geological and topographical diversity. Some variables are worth to be correlated, and by comparing the results to those in published analyses of dolines, it is possible to stress the differences among these forms.

6.1. Descriptive statistics

Descriptive and correlation statistics have been used for processing of morphometric and elevation data. The complete datasets for all the parameters are given in **Appendix 2**. Here we will show and discuss the selected parameters with sorted data.

Tab. 6.1: Perimeters of the uvalas (Pc and Pd), sorted decreasingly

name	ID	**Pc** (m)
Klekovačka Uvala	27	21319
Duboke Jasle	14	17309
Ljeskovi Dolovi	36	17072
Ljubodol	31	15754
Ubaljski Do	37	14127
Rupa	24	11835
Štrpca	34	11728
Čorkova Uvala	18	11498
Baljački Do	33	10955
Glibodol	16	10503
Hrastov Dol	3	9841
Ždralovac	29	8885
Razvala	28	8843
Poljica	23	8197
Ilinski Do	39	8070
Grda Draga	5	7996
Jasenova Korita	19	7665
Veliko Igrište	41	7565
Lomska Duliba	6	6835
Broćanac Nikšićki	35	6778
Duboki Dol	15	6739
Crljivica	26	6644
Crni Dabar	10	6627
Vagan Popinski	22	6380
Materića Uvala	25	6376
Razdolje	20	6125
Mrzli Log	2	5830
Baševica	42	5629
Ovča	43	5213
Brizovac	9	4957
Vagan Mazin	21	4943
Poljanica	30	4938
Dolovi	40	4761
Bilenski Padež	8	4727
Vuči Do	32	4702
Došen Dabar	12	4589
Ravan	4	4433
Dragomi Do	38	4264
Konjsko	13	3943
Mala Kapela	17	3368
Kanji Dol	1	2842
Ravni Dabar	11	2653
Veliki Lubenovac	7	2187
mean		7806
median		6644
st.dev.		4264

name	ID	**Pd** (m)
Klekovačka Uvala	27	24800
Ždralovac	29	22400
Glibodol	16	21300
Crljivica	26	18200
Duboke Jasle	14	17300
Rupa	24	16100
Veliko Igrište	41	15900
Ljubodol	31	15500
Čorkova Uvala	18	14700
Razvala	28	14500
Poljica	23	13900
Broćanac Nikšićki	35	13700
Ljeskovi Dolovi	36	12700
Ubaljski Do	37	12700
Štrpca	34	12200
Grda Draga	5	12100
Duboki Dol	15	12100
Jasenova Korita	19	11700
Razdolje	20	11700
Veliki Lubenovac	7	11100
Mala Kapela	17	11100
Hrastov Dol	3	11000
Materića Uvala	25	11000
Ovča	43	10800
Baljački Do	33	10600
Crni Dabar	10	10300
Bilenski Padež	8	10200
Lomska Duliba	6	9980
Baševica	42	9940
Konjsko	13	9660
Vuči Do	32	9350
Vagan Popinski	22	8790
Mrzli Log	2	8040
Ilinski Do	39	7680
Dolovi	40	7360
Poljanica	30	7250
Dragomi Do	38	6980
Vagan Mazin	21	6920
Došen Dabar	12	6770
Ravan	4	6610
Kanji Dol	1	6080
Brizovac	9	5990
Ravni Dabar	11	5640
mean		11689
median		11000
st.dev.		4440

Frequency distributions of both datasets related to uvala perimeter show that the data are not normally distributed. Normal distribution would signify data symmetry, meaning that there is approximately the same number of observations below and above the mean value. However, both in Pc and Pd records there are more observations below the mean, which is called the *positive skewness* of the dataset. The actual amount of skewness can be computed using a simple formula - first adding together the cubed deviations of each observation from the mean, and then dividing that sum by the product of the cubed standard deviation and the number of observations (Rogerson, 2006; equation 2.7). The skewness of the Pc dataset is 1.26, and of the Pd dataset 0.99 (if the distribution is symmetric about the mean, the skewness equals zero).

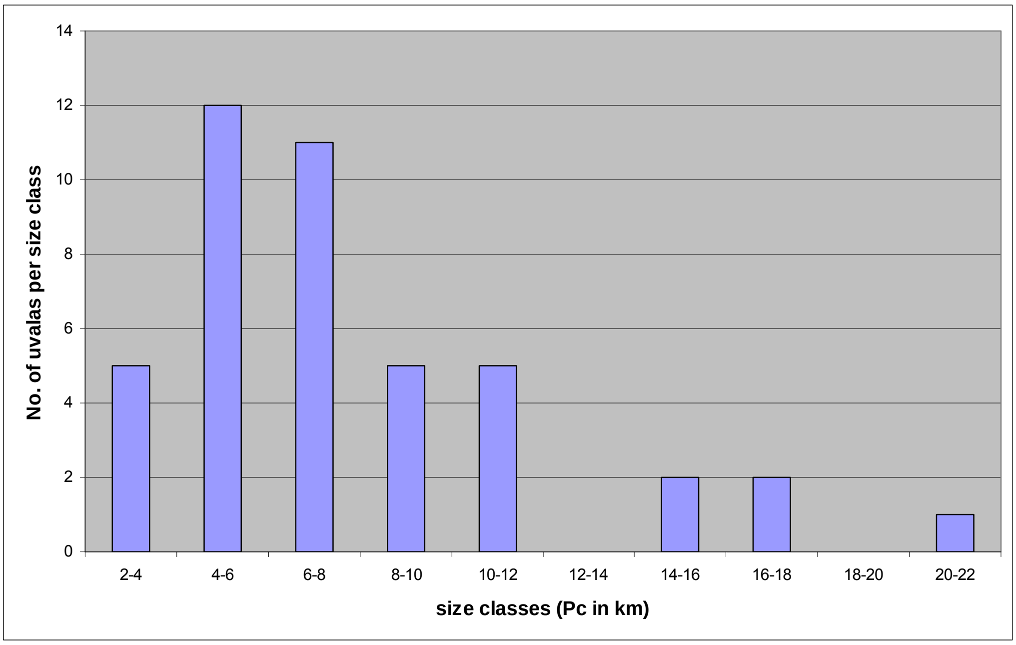

Fig. 6.1: Frequency distribution histogram of the studied uvalas, based on the perimeter along the highest closed contour (Pc)

Frequency distribution histogram based on the Pc parameter has an approximately bell shape, but with obvious asymmetry – gentler slope towards higher values (this is why positive skewness is also called the *right skewness*, because the distribution is skewed to the right). If we sort the data decreasingly, we can see that the trend is rather uniform, and that even a linear trendline shows rather high coefficient of determination (0.83)(Fig. 6.2).

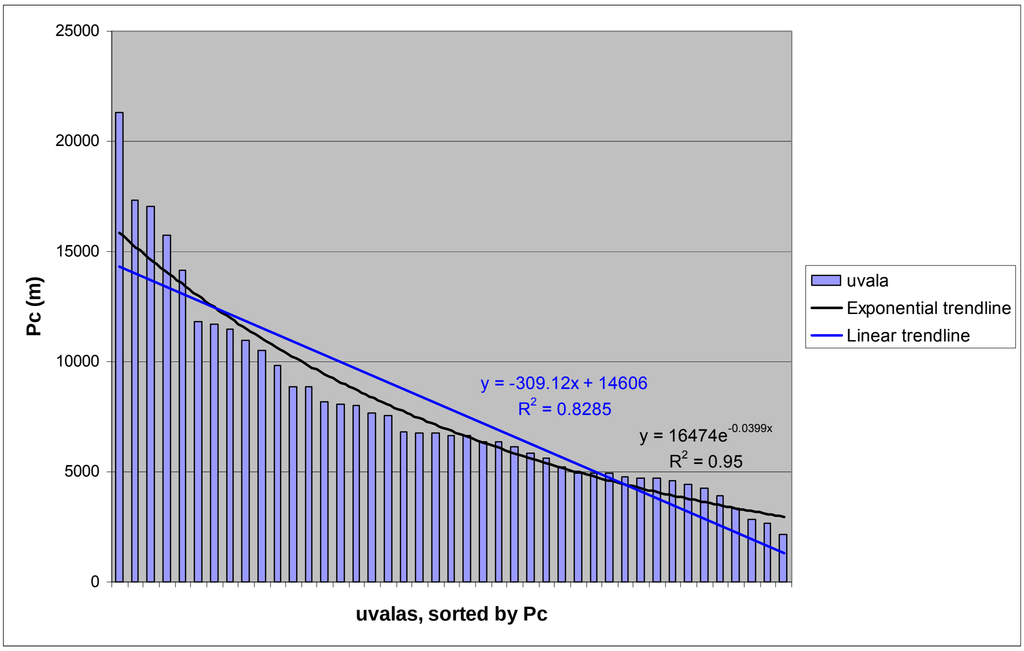

Fig. 6.2: Decreasingly sorted Pc values of the studied uvalas

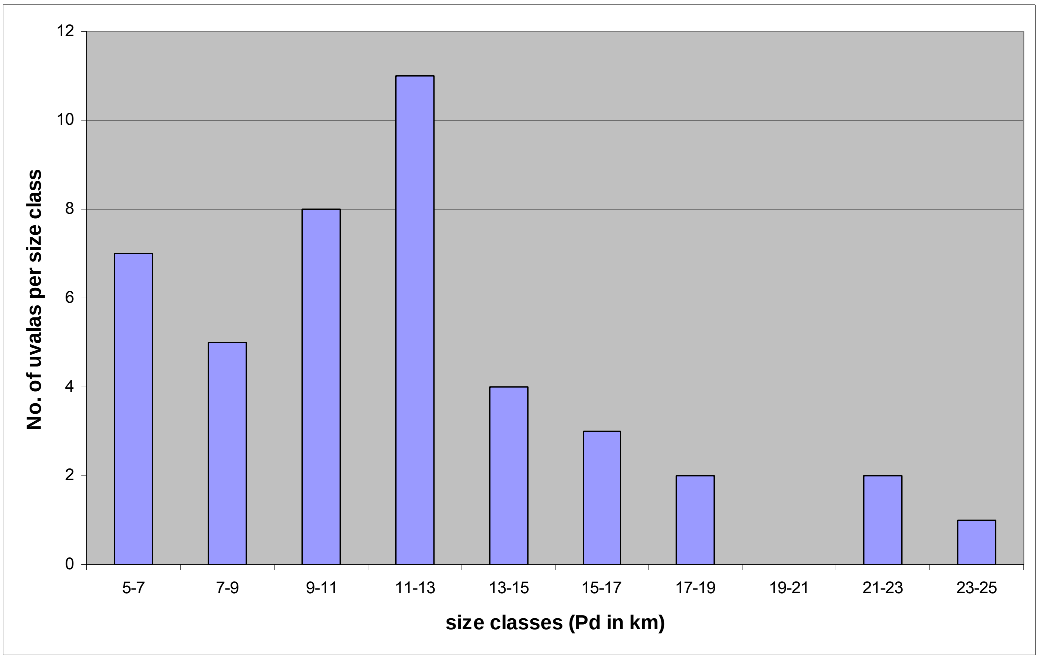

Fig. 6.3: Frequency distribution histogram of the studied uvalas, based on the perimeter along the topographical divide (Pd)

Frequency distribution histogram based on the Pd parameter is more irregular in shape (compared to that of Pc parameter), but it does show a positive skewness. Decreasingly sorted Pd values also have a rather uniform trend, and their linear trendline has a coefficient of determination of 0.88.

Tab. 6.2: Areas of the uvalas (Ac, Ad), sorted decreasingly

name	ID	**Ac** (km^2)
Klekovačka Uvala	27	11.35
Duboke Jasle	14	6.07
Rupa	24	5.17
Ljubodol	31	5.03
Ljeskovi Dolovi	36	3.60
Ždralovac	29	3.51
Ubaljski Do	37	3.31
Glibodol	16	3.22
Hrastov Dol	3	2.92
Baljački Do	33	2.25
Crni Dabar	10	2.14
Štrpca	34	1.94
Duboki Dol	15	1.89
Crljivica	26	1.87
Poljica	23	1.81
Razvala	28	1.80
Čorkova Uvala	18	1.77
Vagan Popinski	22	1.73
Materića Uvala	25	1.67
Grda Draga	5	1.59
Jasenova Korita	19	1.57
Broćanac Nikšićki	35	1.26
Lomska Duliba	6	1.17
Vagan Mazin	21	1.09
Razdolje	20	1.03
Poljanica	30	0.95
Ovča	43	0.91
Baševica	42	0.81
Ilinski Do	39	0.77
Dolovi	40	0.77
Brizovac	9	0.75
Bilenski Padež	8	0.75
Mrzli Log	2	0.75
Ravan	4	0.74
Vuči Do	32	0.66
Konjsko	13	0.61
Došen Dabar	12	0.55
Dragomi Do	38	0.51
Mala Kapela	17	0.50
Veliko Igrište	41	0.50
Ravni Dabar	11	0.45
Kanji Dol	1	0.33
Veliki Lubenovac	7	0.26
mean		1.92
median		1.26
st.dev.		2.01

name	ID	**Ad** (km^2)
Klekovačka Uvala	27	38.90
Ždralovac	29	30.30
Glibodol	16	24.30
Crljivica	26	17.70
Ljubodol	31	14.50
Veliko Igrište	41	14.40
Duboke Jasle	14	13.10
Razvala	28	12.50
Rupa	24	11.40
Broćanac Nikšićki	35	11.30
Poljica	23	11.10
Ubaljski Do	37	10.80
Ljeskovi Dolovi	36	10.40
Čorkova Uvala	18	10.10
Duboki Dol	15	8.38
Materića Uvala	25	8.01
Hrastov Dol	3	7.72
Jasenova Korita	19	7.51
Mala Kapela	17	7.26
Razdolje	20	7.16
Štrpca	34	6.84
Ovča	43	6.56
Baševica	42	6.32
Baljački Do	33	6.24
Crni Dabar	10	5.49
Lomska Duliba	6	5.44
Grda Draga	5	5.31
Bilenski Padež	8	4.90
Vagan Popinski	22	4.76
Konjsko	13	4.65
Vuči Do	32	4.26
Ilinski Do	39	4.16
Veliki Lubenovac	7	3.68
Dolovi	40	3.15
Vagan Mazin	21	3.10
Poljanica	30	2.98
Mrzli Log	2	2.84
Došen Dabar	12	2.59
Dragomi Do	38	2.59
Ravan	4	2.50
Kanji Dol	1	2.09
Ravni Dabar	11	1.85
Brizovac	9	1.84
mean		8.63
median		6.56
st.dev.		7.53

Frequencies of uvala areas (Ac) have an approximately exponential distribution (Fig. 6.4) and a positive skewness of 2.82, which is much greater than skewness of perimeters distributions. Both medians (of Ac and Ad) are smaller than the respective mean values. In such cases, the median is much more reliable measure of central tendency, because the outliers at the extreme ends of the dataset (e.g. Klekovačka Uvala, ID 27) greatly influence the mean value and distort the typical values. The values spread out so widely that in the Ac dataset the standard deviation is bigger than the mean value.

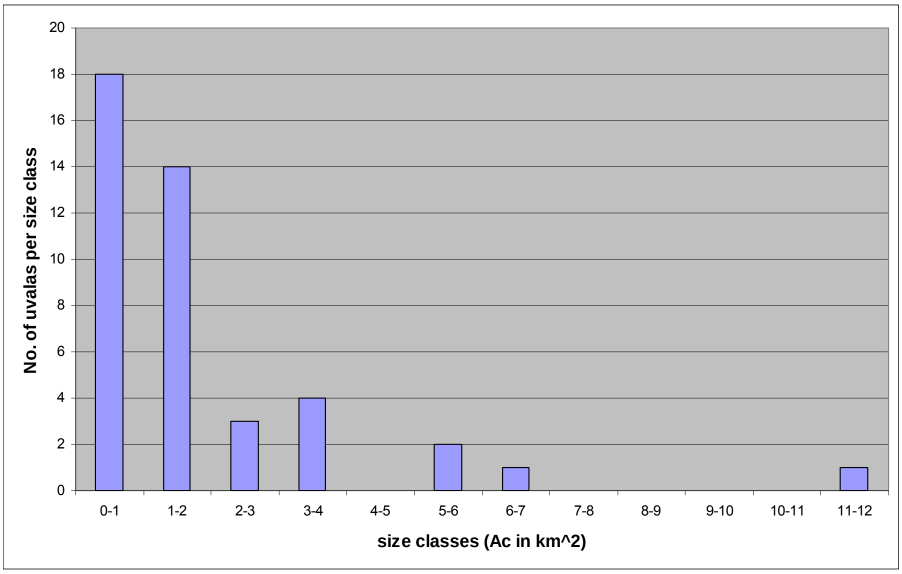

Fig. 6.4: Frequency distribution histogram of the studied uvalas, based on the area within the highest closed contour (Ac)

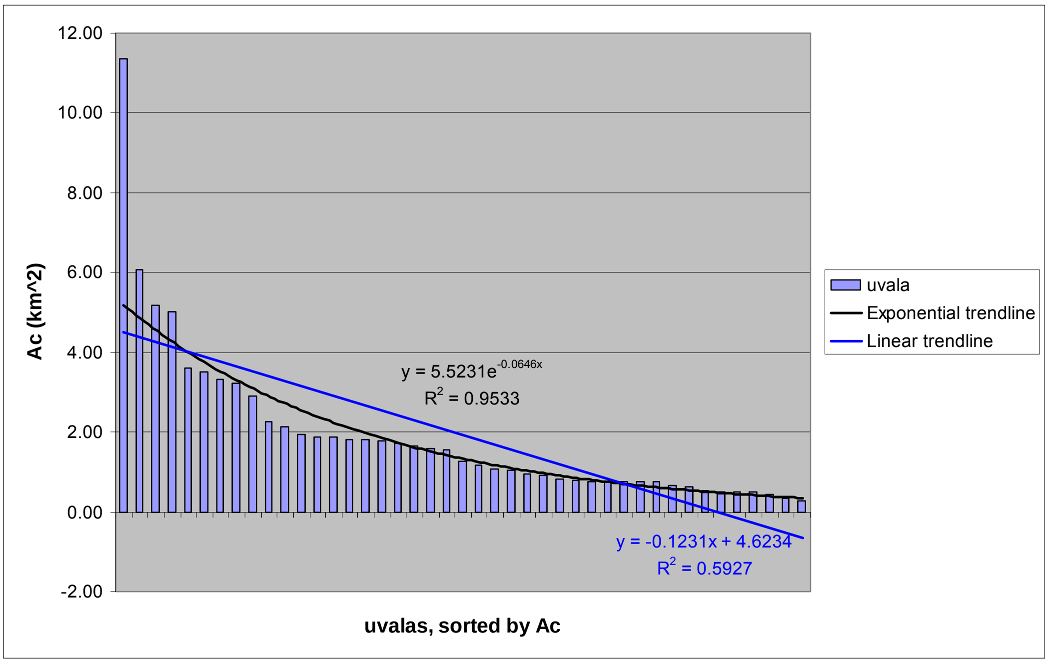

Fig. 6.5: Decreasingly sorted Ac values of the studied uvalas

As visible from the Fig. 6.5, the sorted Ac values show less uniform trend, in comparison with perimeter values. In this case, the coefficient of determination has dropped to 0.59. Similar situation can be seen if we analyze the areas within the topographical divides (Ad). Skewness of the data is a bit smaller (2.19) than that of Ac dataset, but considerably bigger than skewness of the perimeter datasets.

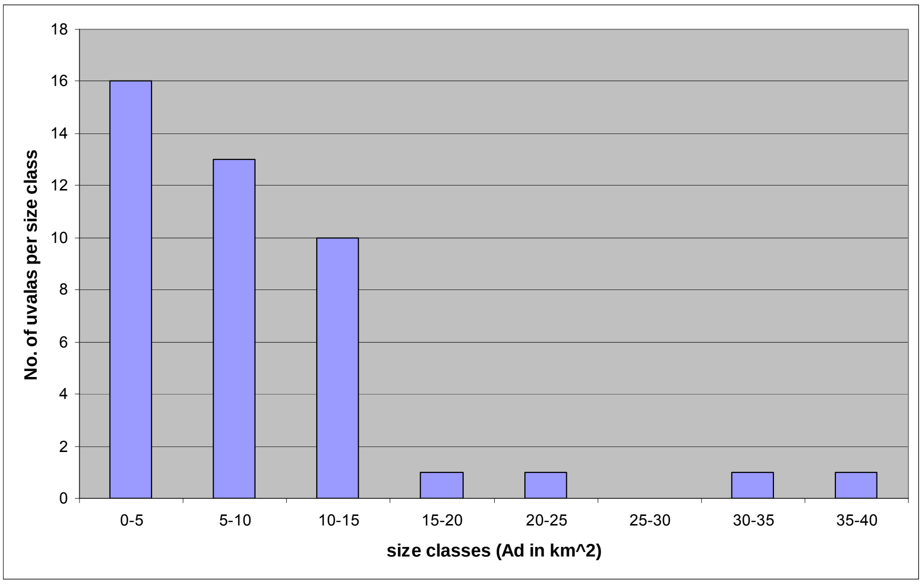

Fig. 6.6: Frequency distribution histogram of the studied uvalas, based on the area within the topographical divide (Ad)

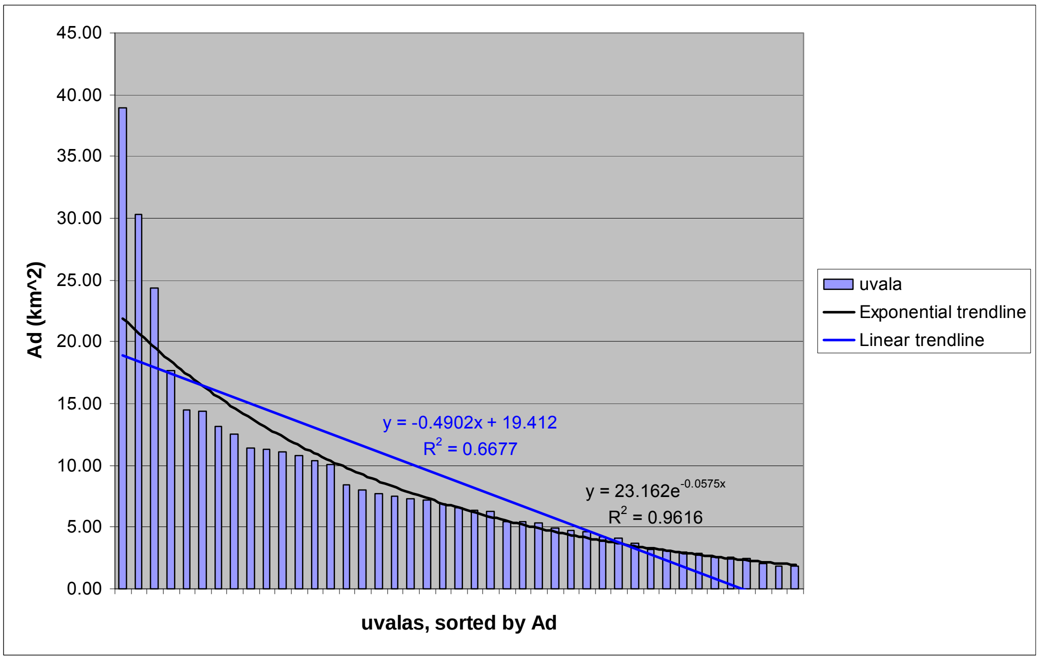

Fig. 6.7: Decreasingly sorted Ad values of the studied uvalas

As expected, the widespread character of the data increases even more in volumetric measurements, which abound in extreme values.

Tab. 6.3: Volumes of the uvalas, sorted decreasingly

name	ID	V (Mm^3)
Klekovačka Uvala	27	1053.27
Duboke Jasle	14	524.32
Rupa	24	407.34
Ljubodol	31	277.83
Crni Dabar	10	198.85
Ždralovac	29	168.81
Ljeskovi Dolovi	36	160.69
Ubaljski Do	37	134.33
Duboki Dol	15	130.95
Glibodol	16	122.71
Baljački Do	33	93.13
Materića Uvala	25	92.30
Grda Draga	5	79.74
Hrastov Dol	3	76.39
Razvala	28	56.83
Vagan Mazin	21	50.28
Vagan Popinski	22	48.03
Crljivica	26	45.67
Poljica	23	41.45
Lomska Duliba	6	40.33
Štrpca	34	36.98
Poljanica	30	35.56
Jasenova Korita	19	30.95
Čorkova Uvala	18	30.22
Bilenski Padež	8	28.66
Mrzli Log	2	26.57
Brizovac	9	23.84
Konjsko	13	22.49
Ilinski Do	39	21.85
Broćanac Nikšićki	35	21.10
Dolovi	40	18.25
Baševica	42	17.48
Ovča	43	17.44
Dragomi Do	38	17.21
Ravni Dabar	11	16.23
Ravan	4	14.89
Došen Dabar	12	14.13
Vuči Do	32	11.53
Kanji Dol	1	8.93
Razdolje	20	8.13
Mala Kapela	17	5.06
Veliki Lubenovac	7	4.34
Veliko Igrište	41	3.52
mean		98.57
median		35.56
st.dev.		183.02

The frequency distribution shows prominent domination of uvalas with relatively small volumes (up to 50 Mm^3). Skewness of the dataset abounds to as much as 3.68.

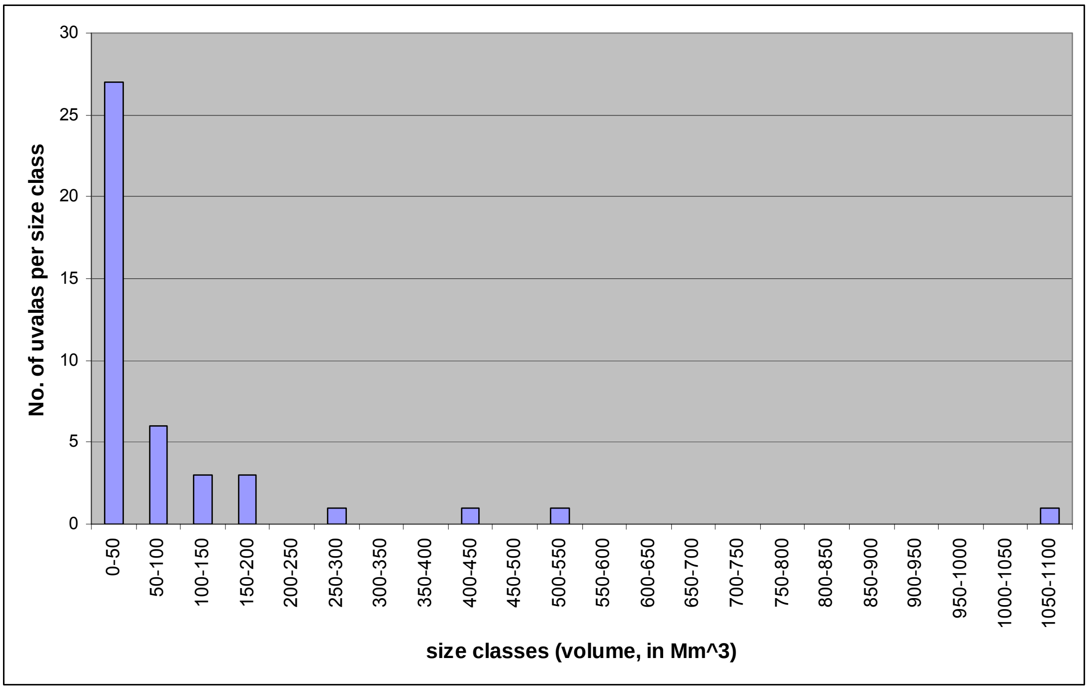

Fig. 6.8: Frequency distribution histogram of the studied uvalas, based on the volume beneath the highest closed contour

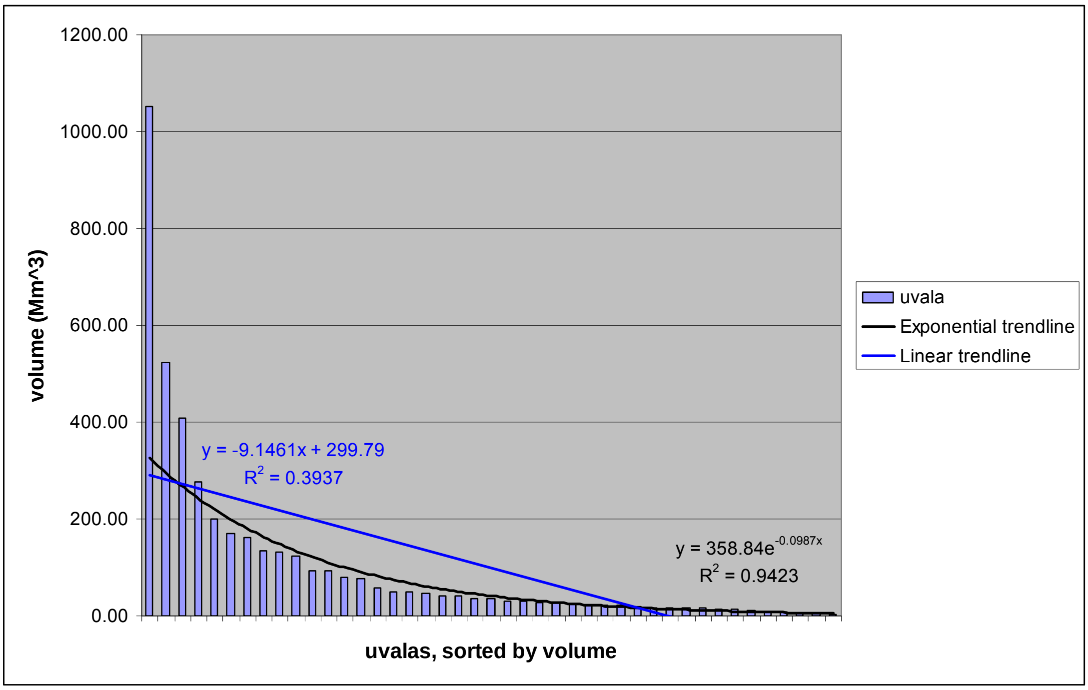

Fig. 6.9: Decreasingly sorted volumes of the studied uvalas

Due to the existence of several strong outliers – extreme values that exceed the rest of the sample by 2-3 orders of magnitude, it is necessary to discard the mean value as a measure of central tendency. In this case, only the median is the appropriate central tendency statistic, since it is robust to outliers. The graph presenting the sorted volumes of uvalas shows a rapid decrease. The values can hardly be approximated by a linear trendline, because the coefficient of determination is only 0.39.

Among the computed parameters, several are worth to be separately discussed.
VDVP stands for the parameter of volume development. It was defined by Bondesan et al. (1992), as the "ratio between the volume of the doline and the volume of a cone with a base equivalent to the planimetric doline area and the height equivalent to the maximum depth". It shows the deviation from the exact conical shape, which would have the VDVP equal to 1. If the ratio is lower than 1, the depression slopes are convex, and if greater than 1, the slopes are concave. In case of flat bottomed dolines, the volume of a truncated cone is used in calculation. Although several studied uvalas also have more or less flat bottoms, we have only used normal cones for calculation, because the flat portions are often inclined, which makes the calculation difficult. Furthermore, the area of the flat part is usually very small in comparison to total area of the uvala. The results show that only four uvalas have the predominantly convex slopes: Razdolje (ID 20), Razvala (ID 28), Ljubodol (ID 31) and Baševica (ID 42), with VDVPs slightly smaller than 1. The majority of uvalas have VDVP values above 1, indicating concave slopes, although several highest values could be discarded due to high proportion of flat bottom in relation to total area (Konjsko, ID 13; Ravni Dabar, ID 11; Hrastov Dol, ID 3).

Elongation of a depression is shown through a parameter called the elongation ratio. In Bondesan et al. (1992), this value is marked as RL/W, and computed as the ratio between the parameters LAXI and WMAX. As both of these parameters are related to the spatial position of the deepest point of the studied depression, they were not calculated within this study (because most uvalas have multiple deepest points). Therefore, we had to take the ratio of the parameters DMAX and DMNR for calculation of elongation. The new symbol ELONG was used, to make the difference towards RL/W (due to different calculation). Elongation was calculated both for perimeter along the highest closed contour, and perimeter along the topographical divide (ELONGc and ELONGd, respectively). The leaders in elongation of the highest closed contour are the uvalas Poljica (ID 23) with ELONGc=5.58, Lomska Duliba (ID 6) with 4.82, and Baljački Do (ID 33) with 3.95. This dataset is positively skewed: the median (1.85) is smaller than the mean (2.15). The situation is much more regular when topographical divide is considered. There are no extremely high ratios (max. ELONGd is 2.44, of the Brizovac Uvala; ID 9) and the distribution of data is closer to normal (mean value 1.69, median 1.64, standard deviation 0.37). This indicates, as well as the distributions of Pc and Pd data, that the topographical divide is more uniform and more regular parameter than the highest closed contour.

The ratio between depth and average diameter is an internal index of shape. In Bondesan et al. (1992), it is stated that this ratio (marked by RH/D and computed as HMAX/DAVE) can help in genesis research: narrow distribution of this parameter indicates similar genesis conditions (e.g. solution doline field), while broad distribution would stand for more various genetic factors (e.g. high quantity of collapse dolines in a population). As the parameter HMAX is not a part of this study, due to already mentioned perimeter issues, we have used the HUV instead. Therefore, the parameter RH/Dc stands for the ratio HUV/DAVEc (both related to the highest closed contour), and RH/Dd stands for the ratio HBAS/DAVEd (both related to the topographical divide). The results show that the spread of RH/Dc data is from 0.015 (min) to 0.097 (max), and the ratio of maximal and minimal value is 6.65. As for the RH/Dd, the spread is bigger, and the max/min ratio is 7.18 (0.276/0.038), which means a bit broader distribution of values. Thus, defining uvalas by their topographic divides would imply greater variety of their genetic factors. Just for comparison, the results of RH/D values analysis from Bondesan et al. (1992) show that max(RH/D)/min(RH/D) for dolines of Montello hill is 5.8, for Candaglia plateau 10.25, and for the Classical Karst of Trieste only 3.4. The narrowest distribution of RH/D values in Trieste Karst could possibly point to stable and uniform genetic conditions for doline development. When we make comparisons with the results obtained in uvala analysis, we are of course aware of the fact that the uvalas are dispersed in various lithological and topographical settings, which is a limitation for serious conclusions. However, we can conditionally accept the basic relations between certain parameters, and upgrade the data in future studies.

6.2. Correlation statistics

Correlation, most usually expressed through the correlation coefficient, shows strength and direction of a linear relationship between two variables. Graphically, the relationship is shown in a diagram called the scatterplot, with a trendline – mathematical function that best explains the relation between the datasets.

The leading references mostly state that parametric correlation analysis shows best results in datasets with approximately normal distribution (e.g. Harnett & Murphy, 1975; Rogerson 2006). When a skew in data distribution is evidenced, it is possible to use transformations which may bring the data closer to symmetry (normality). For a positive skew, it is possible to use 1/x, log(x) or square root (Easton & McColl, 1997). Being aware of the fact that most of the morphometric datasets on uvalas (especially measured parameters) do not have normal distributions, we compared the scatterplots of transformed and non-transformed data. Although there were certain differences between the respective coefficients of determination (R^2, which is actually a squared correlation coefficient *r*), they were not considerable – the transformed data showed somewhat smaller R^2 values, but mostly not smaller than about 20% when compared to the values obtained by processing of non-transformed input data. Having that in mind, and considering the fact that our aim is not directed towards precise calculations through linear regressions, but towards detection of general correlation trends, we estimated that data transformation is not essentially needed.

Correlation coefficient is generally influenced by sample size. If a sample is large enough, even the correlation coefficients noticeably smaller than 1 can have a reliable significance. Using the simple equation given in Rogerson (2006), it is possible to calculate the minimum absolute value of correlation coefficient needed to attain significance ($r_{crit} = 2 / \sqrt{n}$). For our sample size (43), the minimum *r* would be 0.305 (at the significance level $\alpha = 0.05$).

To avoid overburdening of the text with excessive number of scatterplots, the mutual correlations of the basic two-dimensional parameters is shown in the Table 6.4. The parameters of the topographical divide (Pd vs. Ad; and DMAXd vs. DMNRd)are much better correlated among themselves than the parameters of the highest closed contour (Pc vs. Ac; and DMAXc vs. DMNRc). This speaks in favour of previously mentioned supposition that topographical divide is more uniform and more regular parameter than the highest closed contour.

Tab. 6.4: Coefficients of correlation and determination between two-dimensional morphometric parameters

variable 1	variable 2	coefficient of correlation (r)	coefficient of determination (R^2)
Pd	Pc	0.68	0.47
Ad	Ac	0.78	0.61
Pc	Ac	0.88	0.77
Pd	Ad	0.95	0.89
DMAXc	DMNRc	0.67	0.45
DMAXd	DMNRd	0.87	0.75

It is interesting to show the correlation plots of volumetric data against area and depth. The linear trendline between volume and highest closed contour area (upon which the volume was calculated) points to high correlation with R^2 of as much as 0.92. Even if we took into account the above-mentioned reduction due to the fact that correlation is sensitive to outliers in a dataset, we can say that the coefficient of determination would still be considerably high.

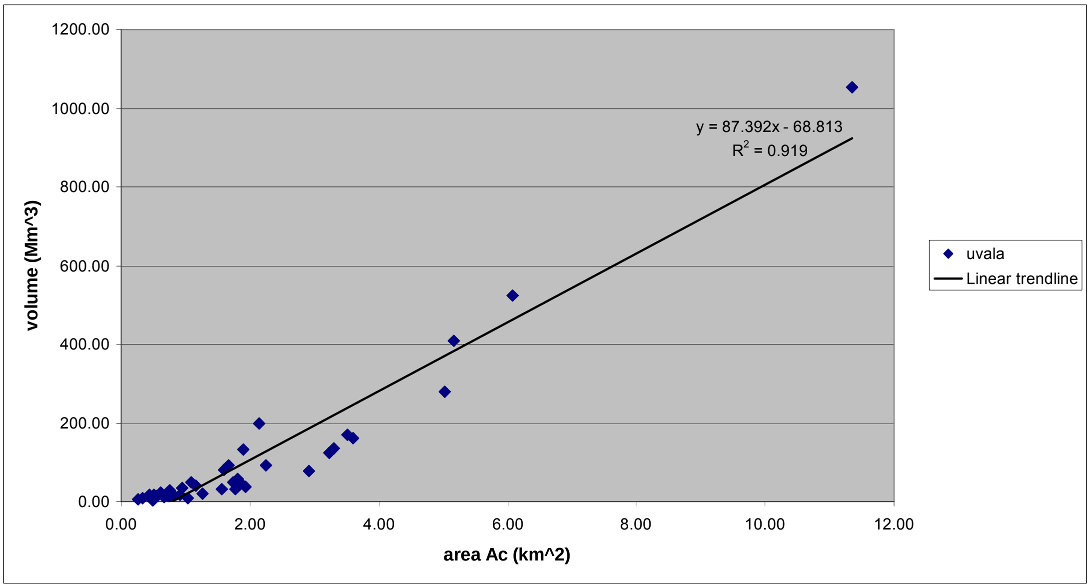

Fig. 6.10: Scatterplot of correlation between uvala areas and volumes

With the increase of uvala depth, the volumes augment following an exponential trendline with R^2 of 0.78 (Fig. 6.11).

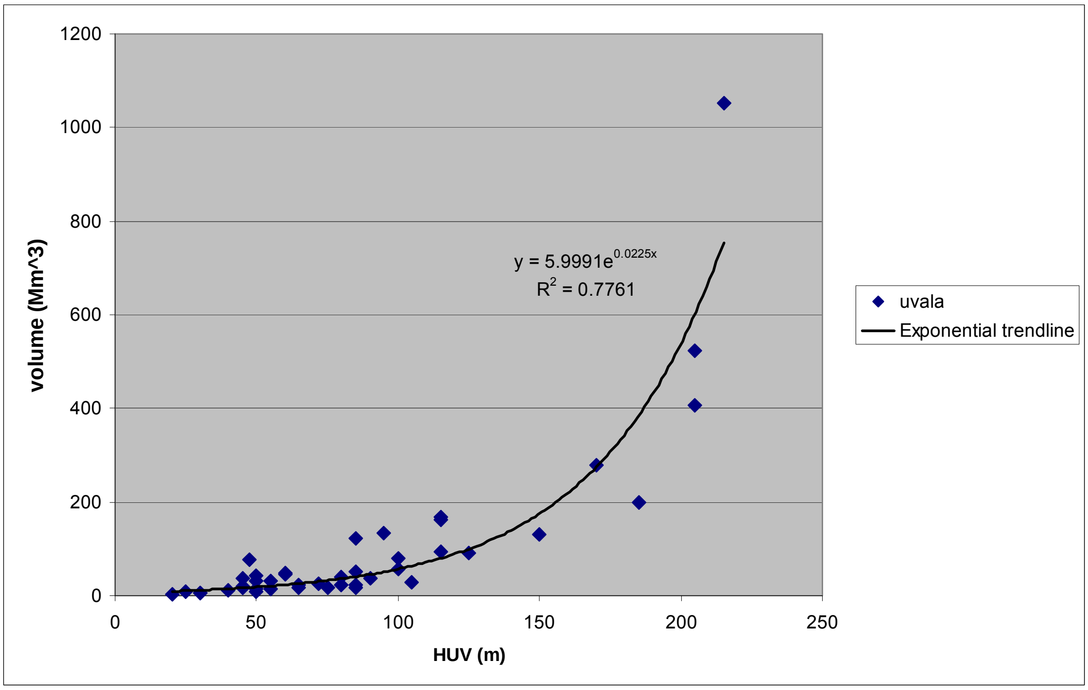

Fig. 6.11: Scatterplot of correlation between uvala depths (HUV) and volumes

In the paper on modelling the basic geometry of solution dolines, Šušteršič (2006) plotted the volumes of dolines against the product of squared radius and depth (R^2H) of a hypothetical rotational body, and got a well defined straight line. For the reasons of comparison, we have processed the data on uvalas in the same way (the value R equals the radius of the circle whose area is the same as the value Ac), and the result is shown in Fig. 6.12. The coefficient of determination is 0.99.

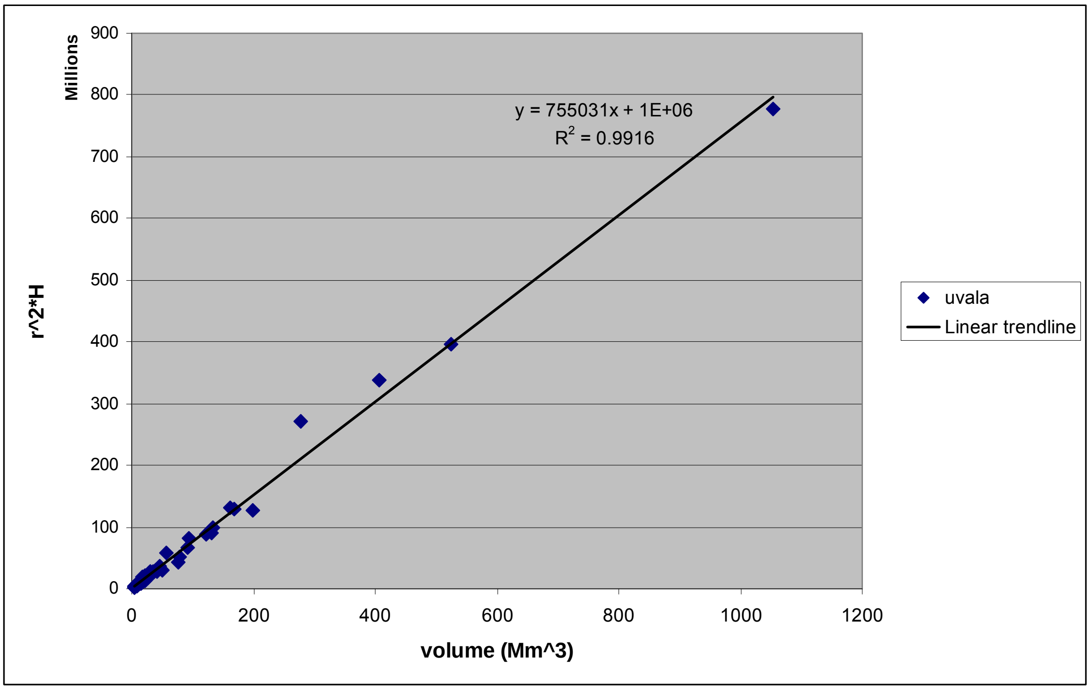

Fig. 6.12: Scatterplot of correlation between uvala volumes and R^2H (see text)

Correlations of elevation (depth) parameters with areal and linear morphometric parameters are not as high as it was expected. The reason probably lies in problematic definition of perimeter line and, subsequently, the depth which is inevitably related to perimeter. HUV value (linked to highest closed contour) may be influenced by existence of low saddles which make the uvala "open" on one side, and considerably decrease the "official" depth regardless of the overall shape of the uvala (the most indicative example is Broćanac Nikšićki, ID 35). On the other hand, the HBAS value (linked to the topographical divide) may be unobjectively influenced by high peaks along the divide, which are then taken into HBAS calculation regardless of the fact that uvala itself may be relatively shallow (the best example is Razdolje, ID 20).

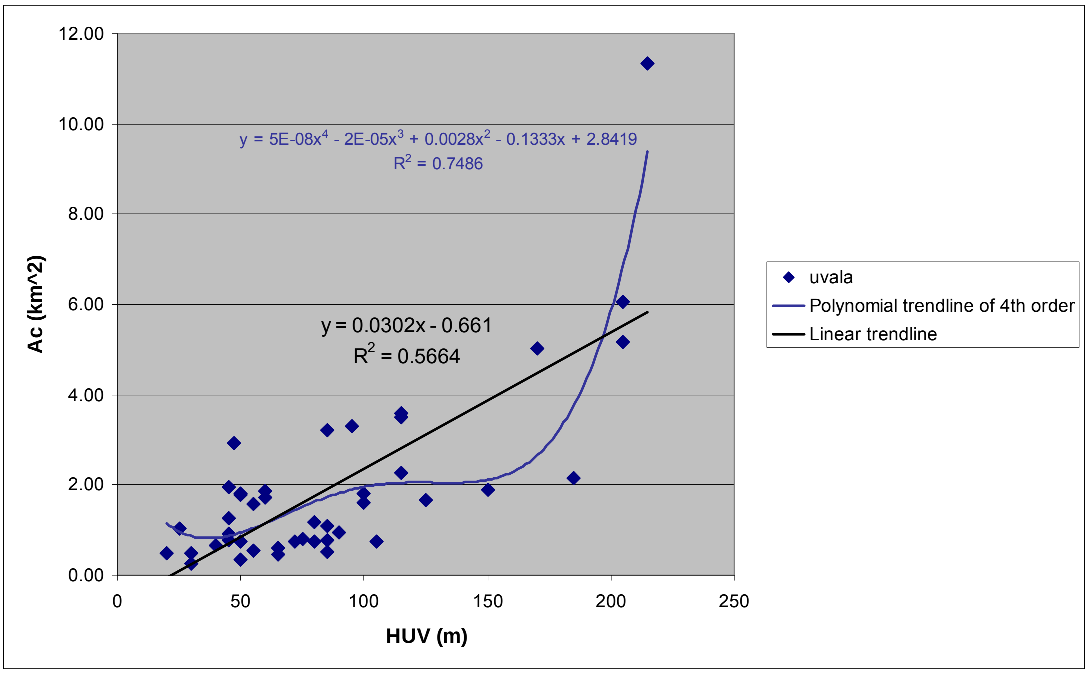

Fig. 6.13: Scatterplot of correlation between the uvala depth (HUV) and area (Ac)

Good correlation of uvala volumes with their depths and areas is understandable, because these parameters are directly used in the volume calculation. When it comes to the relations of mutually independent parameters, the correlations drop. The linear function between the variables of depth and area has a coefficient of determination 0.57. Higher coefficient could be obtained only if polynomial function of 4^{th} order is used (shown in Fig. 6.13 just for comparison). In the relation between basin depths (HBAS) and area Ad, the R^2 value is even smaller (only 0.42), due to the aforementioned problem with elevation of high peaks along the divide.

In Bondesan et al. (1992), within the case study of dolines of the Classical Karst of Trieste, the correlation plot of the parameters DAVE and HDOL is shown (Fig. 6.14).

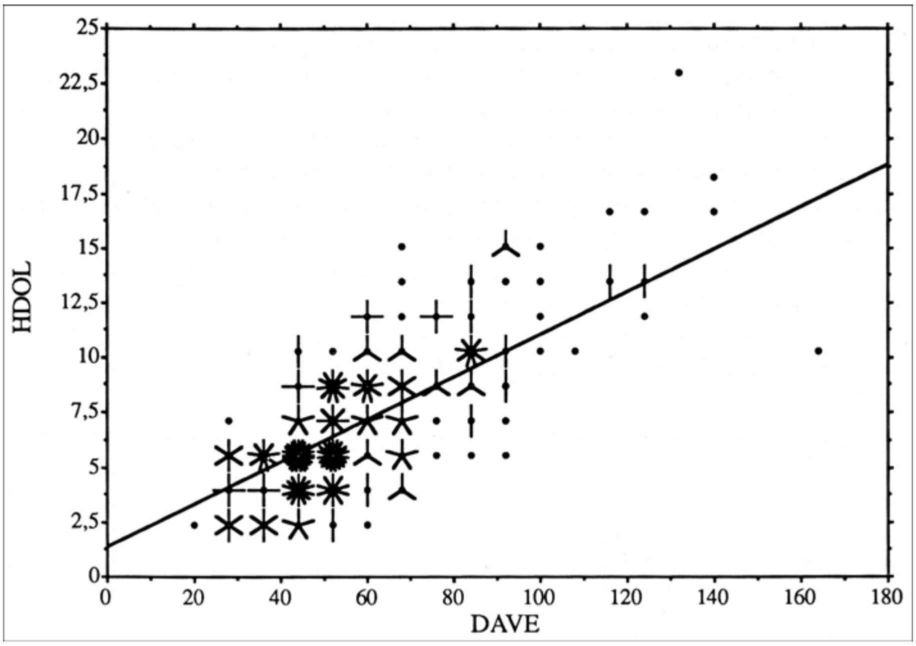

Fig. 6.14: Correlation of depth and average diameter for the dolines of the Trieste Karst. R^2 value is 0.78. (Bondesan et al., 1992)

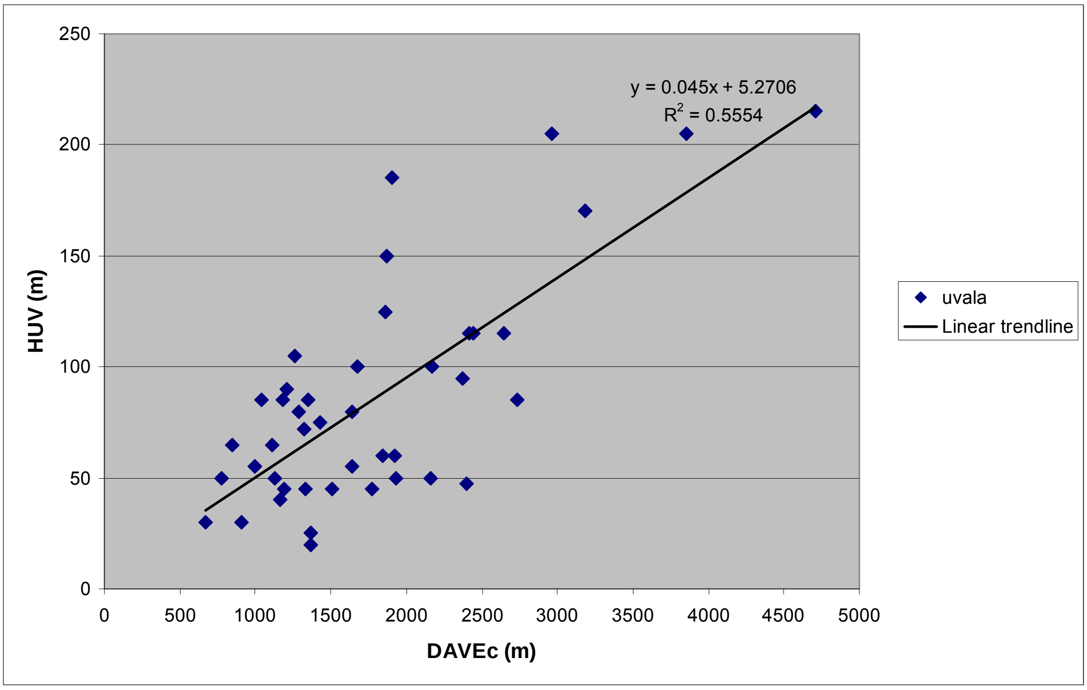

Fig. 6.15: Scatterplot of correlation between uvala average diameter (DAVEc) and depth (HUV)

It is obvious both from graphical illustration and from R^2 value that the examples of uvalas have much more dispersed values. There are several reasons for that. The first reason is the fact that the studied doline population is situated in a relatively uniform lithological unit and topographical settings, making the appropriate background for morphometrical analysis. Furthermore, the doline sample size is much greater (261) and better correlation could be established. And finally, we can suppose that the intrinsic morphological difference between dolines and uvalas influences the differences in dispersion of values, since dolines are much more regular forms.

6.3. Confirmatory data analyses

Apart from the data at the interval scale (all the morphometrical data), the analysis of uvalas have also included a set of nominal (categorical) data. This kind of data has been used for consideration of qualitative parameters of uvalas. In each group of data, numerals (codes) have been used as names for classes. The use of nominal scales as a kind of measurement has been justified by Stevens (1946).

Tab. 6.5: Codes and abbreviations for nominal data on uvalas

Lithological data	code	description	abbreviation
	1	limestones dominate	L
	2	limestones and dolomites	L+D
	3	dolomites dominate	D
Hydrological data	**code**	**description**	**abbreviation**
	1	no water	NO W
	2	weak spring(s) without flow	NO FL
	3	small pond(s)	POND
	4	short occasional flow(s)	OC FL
	5	permanent flow	PER
Bottom morphology	**code**	**description**	**abbreviation**
	1	dolines dominate	DOL
	2	rocky ridges, scattered dolines	RR
	3	undulating surface, scattered dolines	UND
	4	flat (sediments)	FLAT
Pleistocene glaciation	**code**	**description**	
	1	yes	
	2	no	
Vegetation	**code**	**description**	
	1	grass and bushes	
	2	grass on bottom, woods on slopes	
	3	bushes and woods	
	4	woods	

Each case example of uvala has been labeled by a particular code, for each specified kind of qualitative data. The complete set is given in Tab. 6.6. Being the only appropriate measure of central tendency for nominal data, the mode is given as well.

Tab. 6.6: Nominal (categorical) data on the studied uvalas. Codes from Tab. 6.5.

ID	name	lithology	hydrological status	bottom morphology	Pleistocene glaciation	vegetation
1	Kanji Dol	3	2	3	2	2
2	Mrzli Log	3	4	3	2	2
3	Hrastov Dol	1	3	3	2	2
4	Ravan	2	4	3	2	2
5	Grda Draga	2	2	3	1	4
6	Lomska Duliba	1	1	2	1	2
7	Veliki Lubenovac	2	2	3	1	2
8	Bilenski Padež	2	2	1	2	2
9	Brizovac	1	2	3	2	2
10	Crni Dabar	1	1	4	2	3
11	Ravni Dabar	1	1	4	2	2
12	Došen Dabar	1	2	3	2	2
13	Konjsko	1	1	4	2	1
14	Duboke Jasle	1	2	1	2	1
15	Duboki Dol	1	1	4	2	1
16	Glibodol	2	1	4	2	2
17	Mala Kapela	2	1	1	2	4
18	Čorkova Uvala	2	2	3	2	4
19	Jasenova Korita	2	1	1	2	2
20	Razdolje	2	1	1	2	2
21	Vagan Mazin	2	5	4	2	2
22	Vagan Popinski	3	2	1	2	1
23	Poljica	1	1	3	2	1
24	Rupa	1	1	2	2	4
25	Materića Uvala	1	1	2	2	4
26	Crljivica	1	3	3	2	1
27	Klekovačka Uvala	2	1	1	2	4
28	Razvala	1	3	1	1	1
29	Ždralovac	1	3	3	2	1
30	Poljanica	2	1	2	1	1
31	Ljubodol	1	3	1	2	1
32	Vuči Do	2	4	3	2	1
33	Baljački Do	2	1	2	2	1
34	Štrpca	2	1	1	2	1
35	Broćanac Nikšićki	2	3	2	2	2
36	Ljeskovi Dolovi	2	1	1	2	1
37	Ubaljski Do	2	2	2	2	1
38	Dragomi Do	1	3	3	2	1
39	Ilinski Do	2	1	2	2	1
40	Dolovi	2	1	2	1	2
41	Veliko Igrište	1	1	1	2	2
42	Baševica	1	1	2	2	1
43	Ovča	1	1	2	2	1
	mode	1	1	3	2	1

The data was transformed into contingency tables. In these tables, two sets of data (two categorical variables) are combined, and a number of observations is entered for each combination of variable values. In this study, we have made the contingency tables for the following data combinations: a) lithological and hydrological data; b) lithological data and bottom morphology; c) hydrological data and bottom morphology.

Tab. 6.7: Contingency table for categorical variables of lithological and hydrological data. Abbreviations from Tab. 6.5.

	L (1)	L+D (2)	D (3)	*total*
NO W (1)	**11**	**11**	**0**	22
NO FL (2)	**3**	**5**	**2**	10
POND (3)	**6**	**1**	**0**	7
OC FL (4)	**0**	**2**	**1**	3
PER (5)	**0**	**1**	**0**	1
total	20	20	3	43

To examine whether these variables are mutually dependent, we have used the Chi-square test for independence, a non-parametric test often used for processing of nominal data. The procedure requires that the hypothetical expected value is calculated for each observed value within the table. The expected values are equal to the product of the row and column totals (so-called marginal totals), divided by the overall total (in this case, 43) (Rogerson, 2006). For example: (22*20)/43 = 10.23. The new contingency table contains both observed and expected frequencies (Tab. 6.8).

Tab. 6.8: Contingency table for lithological and hydrological data, with expected frequencies included (in small font)

	L (1)	L+D (2)	D (3)	*total*
NO W (1)	**11**	**11**	**0**	22
	10.23	10.23	1.53	
NO FL (2)	**3**	**5**	**2**	10
	4.65	4.65	0.70	
POND (3)	**6**	**1**	**0**	7
	3.26	3.26	0.49	
OC FL (4)	**0**	**2**	**1**	3
	1.40	1.40	0.21	
PER (5)	**0**	**1**	**0**	1
	0.47	0.47	0.07	
total	20	20	3	43

The null hypothesis is that the variables are independent (no interaction between the rows and columns of the contingency table, i.e. between lithological and hydrological characteristics). The chi-square statistic is $\chi^2 = \Sigma\ ((O - E)^2 / E)$ (Rogerson, 2006), where O is the observed frequency, and E is an expected frequency. We also have to calculate the number of degrees of freedom (df), which equals to the product of number of rows minus one, and number of columns minus one (in this example: (3-1)(5-1)=8). The values from the Tab. 6.8 give the chi-square value of 14.8. Using the conventional table for χ^2 distribution, at the level of significance $\alpha = 0.05$, we compare the χ^2 value with the value from the table. To be significant at the 0.05 level, the value of χ^2 has to be greater than 15.507 for 8 degrees of freedom. Since the computed value 14.80 is less than this value, the null hypothesis cannot be rejected, which would mean that we cannot reject the option that lithological and hydrological parameters are mutually independent.

In performing this statistical test, we have to take care to avoid the so-called "Type II error". This error occurs if we decide to accept the null hypothesis when it is not true (Harnett & Murphy, 1975). Therefore we have to conclude only that we *cannot reject* the null hypothesis, which does not mean that we actually accept it.

The chi-square independence test has been applied also to the combination of the data on lithology and bottom morphology. The observed and expected frequencies are given in Tab. 6.9.

Tab. 6.9: Contingency table for lithological data and bottom morphology, with expected frequencies included (in small font). Abbreviations from the Tab. 6.5.

	DOL (1)	RR (2)	UND (3)	FLAT (4)	*total*
L (1)	**4**	**5**	**7**	**4**	20
	5.58	5.12	6.51	2.79	
L+D (2)	**7**	**6**	**5**	**2**	20
	5.58	5.12	6.51	2.79	
D (3)	**1**	**0**	**2**	**0**	3
	0.84	0.77	0.98	0.42	
total	12	11	14	6	43

In this example, the χ^2 value is 4.38, which is less than a critical value of 12.592, using the level of significance 0.05 and 6 degrees of freedom. Thus, in this case we again cannot reject the null hypothesis.

Finally, the dependence between hydrological characteristics and bottom morphology has been tested as well. The observed and expected frequencies are given in Tab. 6.10.

Tab. 6.10: Contingency table for hydrological data and bottom morphology, with expected frequencies included (in small font). Abbreviations from the Tab. 6.5.

	DOL (1)	RR (2)	UND (3)	FLAT (4)	*total*
NO W (1)	**7**	**9**	**1**	**5**	22
	6.14	5.63	7.16	3.07	
NO FL (2)	**3**	**1**	**6**	**0**	10
	2.79	2.56	3.26	1.40	
POND (3)	**2**	**1**	**4**	**0**	7
	1.95	1.79	2.28	0.98	
OC FL (4)	**0**	**0**	**3**	**0**	3
	0.84	0.77	0.98	0.42	
PER (5)	**0**	**0**	**0**	**1**	1
	0.28	0.26	0.33	0.14	
total	12	11	14	6	43

After the calculation, we obtain the χ^2 value of 28.29, which exceeds the critical value of 26.217 even at significance level of 0.01 (with 12 degrees of freedom). Thus, we can reject the null hypothesis that the attributes "hydrological characteristics" and "bottom morphlogy" are independent.

Although we have expected the testing to prove the dependence of all the combined sets of nominal data, the χ^2 test gave us the opportunity to accept the alternative hypothesis only in the last case. The reasons for impossibility to reject the null hypothesis in the first two cases probably lies in the fact that, by chance, our sample contains the same number of uvalas formed in limestones (20) and combination of limestones and dolomites (20). The examples developed in dolomites are, on the other hand, totally outnumbered. This combination caused the negative result in both tests containing the variable of lithology. We believe that this would change with increasing the sample size and, subsequently, variation in observed frequencies of lithological characteristics.

6.4. Exploratory statistics

The main aim of exploratory statistics, or exploratory data analysis (EDA) is to analyze the raw data in order to find the relations which are not easily noticeable, to point to subgroups of data, and thus to suggest some possible hypotheses to be tested. Usage of these methods in the present work is directed primarily towards grouping of the data and visualization of the datasets. Two kinds of analyses have been carried out: cluster analysis and multidimensional scaling, using the software package *Statistica 6*.

Cluster analysis operates with tools and methods designed to distinguish whether there are natural groups or classes within the observed data. If a data matrix contains multivariate measurements on a large number of objects, cluster analysis tends to build natural clusters by grouping the objects that are "similar" according to some criterion (Härdle & Simar, 2003). When the clusters are obtained (usually by a computer program), the researcher is expected to describe the groups and to detect the grounds on which the grouping has been done.

Within this study, the first dataset which was included in the cluster analysis consisted of the complete measured and computed data (all belonging to the interval level of measurement). The dendrogram of this analysis is shown in Fig. 6.16. Euclidean distance option was selected as a distance measure, being the most commonly chosen type of distance in cluster analyses. The selected linkage rule was a Ward's method. We may conclude that the measured morphometric parameters, directly indicating dimensions of the features, have had a dominant role in the process of clustering. This was expected in some way, having in mind that the majority of data is related to the dimensional values of uvalas. It is noticeable that the most conspicuous outliers (Klekovačka Uvala – ID 27; Ljubodol – ID 31; Rupa – ID 24; and Duboke Jasle – ID 14) stand out so sharply that their linkage distances (among themselves) exceed by far the distances towards other examples. The largest and the most coherent group is, thus, the one containing mostly the shallow uvalas with relatively small areas. Although the established criterion value ("threshold") of 2E8 linkage distance divides the group of outliers into three parts, we can actually consider them as a single group of extreme cases. If we exclude these cases from the dataset and process only 39 uvalas, the relations in the dendrogram remain the same, only the readability for closely-spaced cases is better. Maximum linkage distance is in that case 1.16E9, instead of 2.8E9 from the initial dendrogram on Fig. 6.16.

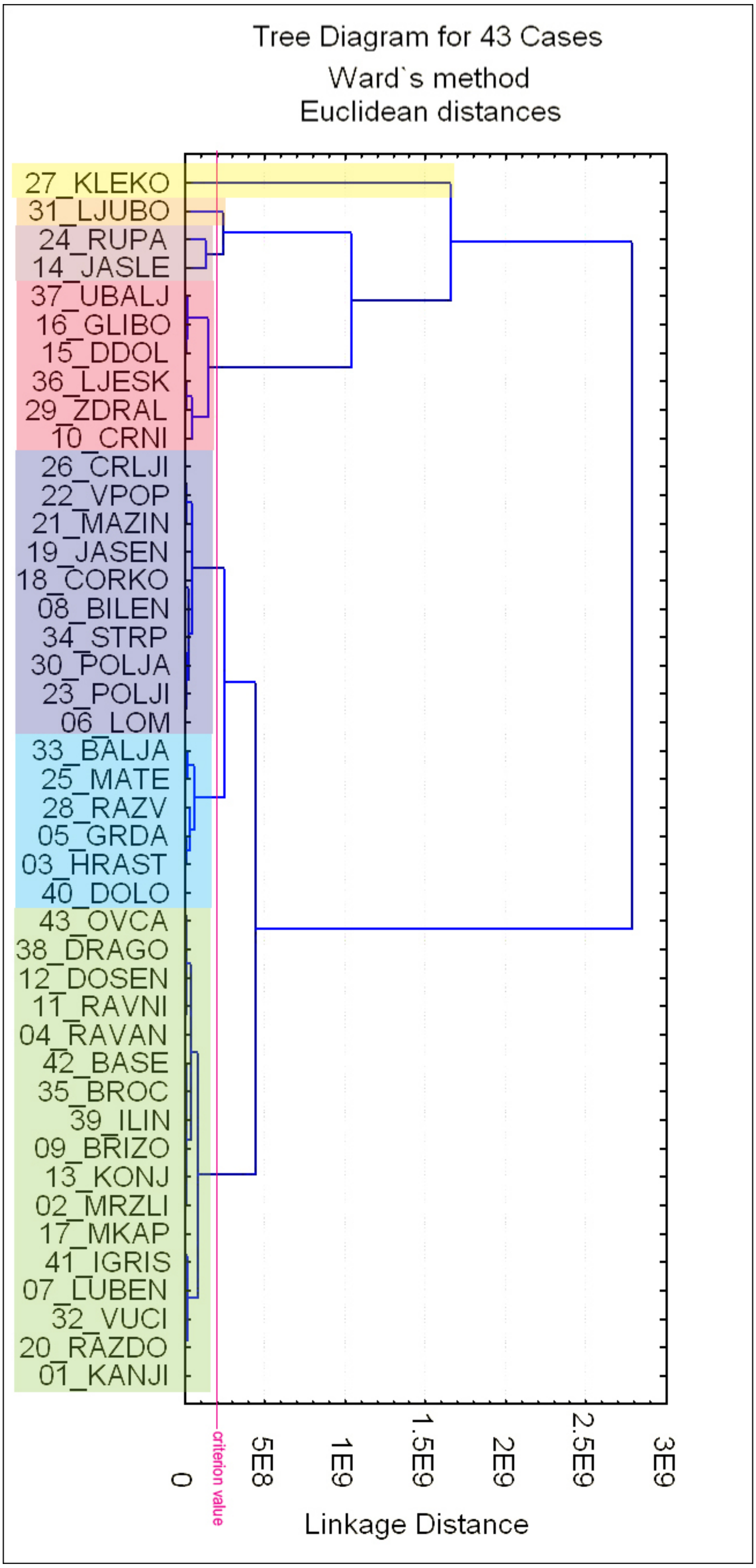

*Fig. 6.16: Dendrogram formed by cluster analysis of **complete** morphometrical data*

After excluding the measured morphometrical data from the dataset, and leaving only the computed data (which is dimensionless), the dendrogram changed completely. Although the same linkage rule and measure distance were applied, the linkage distances decreased by several orders of magnitude. It seems that the indices of perimeter sinuosity took the priority place in the process of clustering. The uvalas in the first group have extremely high ISINc values, while in the last group they are smallest.

Multidimensional scaling (MDS) is another method in exploratory statistics, within the group of multivariate statistics. Similarly as the cluster analysis, it is based on detecting proximities between objects, but MDS also produces a spatial representation of these items. Proximities express the similarity or dissimilarity between data objects. MDS is a dimension reduction technique since the aim is to find a set of points in low dimension that reflect the relative configuration of the high-dimensional data objects (Härdle & Simar, 2003).

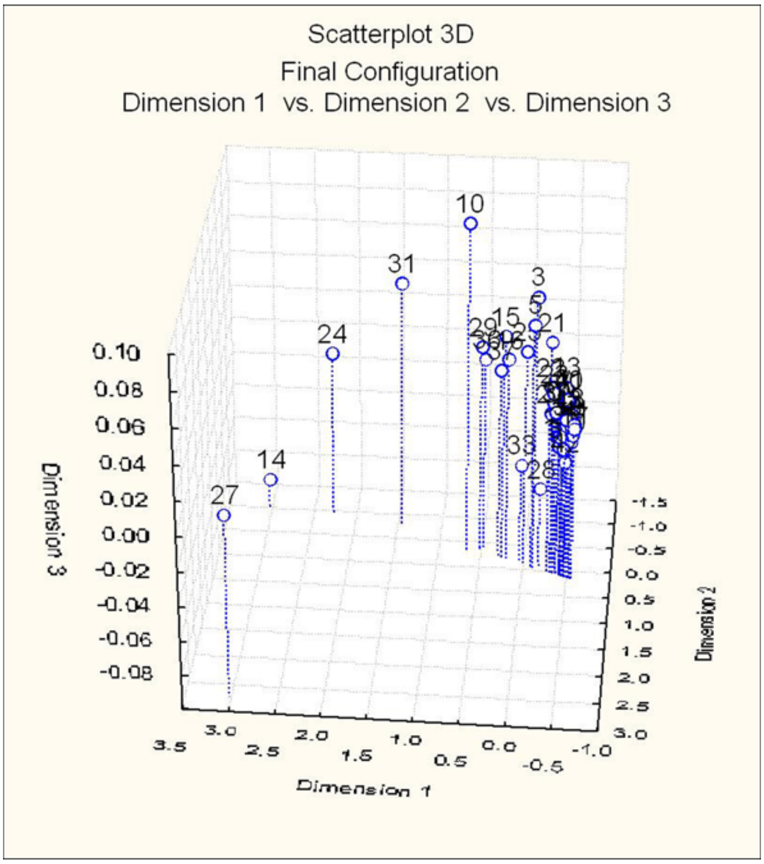

Fig. 6.17: Three-dimensional scaling of all 43 examples (complete morphometrical dataset)

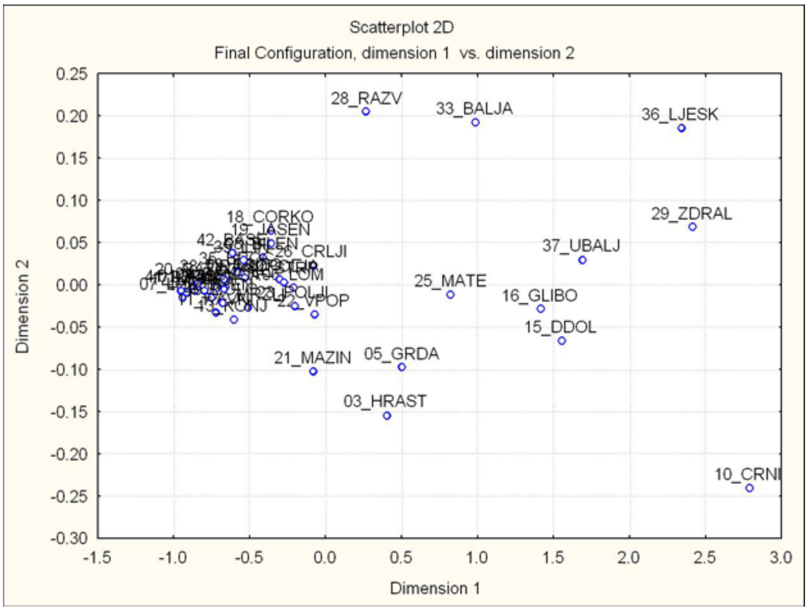

Fig. 6.18: Two-dimensional scaling of 39 examples, largest 4 excluded (complete morphometrical dataset)

In the 3D scatterplot shown in Fig. 6.17, the same outliers are still visible, but their position within the plot greatly varies. It was very difficult to make the interpretation with regards to the meaning of the particular dimensions.

In order to obtain the better insight to the mutual positions of the uvalas which are not outliers in the sample, we excluded the extremely large uvalas (ID_27, 31, 24 and 14). The obtained two-dimensional scatterplot reveals new coherent grouping in the area of small values along dimension 1, while again the remaining uvalas of bigger dimensions are scattered on the outskirts (Fig. 6.18).

We can conclude that, at this moment, the opportunities for making full use of exploratory statistics were rather scarce. The analyses were highly influenced by dimensional parameters, which dominate in the dataset. Therefore the main use of exploratory methods was in visualization of the data, and the opportunity to recognize degrees of statistical distance between the studied examples. The more meaningful grouping (classification) would have to include the nominal data, which depict other important characteristics of uvalas, apart from morphometry. However, processing of nominal data using exploratory and multivariant statistics is questionable (Harris, 2001). Possibly some adaptations of this segment of statistics could be taken from social and behavioral sciences, which use greater deal of nominal data (Van de Geer, 1993), but this would require additional attention in interpretation of the results.

7. Geographical Information System

At the end of the 20th century, the powerful development of information technologies has enabled their increasing use in various spatial studies. The computers turned out to be necessary to fulfill the increasing needs for spatial data and the needs for their better analyses and processing. Computer information systems containing the spatial distribution of analyzed objects and their characteristics are called Geographical Information Systems, or GIS. There are many various definitions of GIS, depending on the approach or way of organization, but we can select the one by Burrough & McDonnell (1998): "Geographical information system is a powerful set of means for collecting, saving, querying, transformations and presentations of spatial information from the real world, for particular purposes".

Geographical information systems are based either on vector representation of data, or on raster representation of data. Vector based GIS consists of points, lines or arcs positioned precisely in a selected coordinate system, and defining the area of interest. Each line has its beginning point and end point, thus forming a vertex, which enables the vectorial representation of data. Areal features form polygons, that are defined by their boundaries. The system contains the objects (entities), attributes of those objects (not related to their positions), and their spatial interrelations defining the way they are connected. In raster based GIS, the areas of interest are divided into rows and columns forming a regular grid structure. The grid cells (or pixels) are rectangular coordinate-defined units, containing information (attributes) on a particular field unit they refer to.

As GIS technologies were entering all fields of Earth sciences, they also started to be used in karst studies, both for particular research projects, and in large-scale projects like the Karst map of the US (joint project of USGS and National Cave and Karst Research Institute; Gao & Zhou, 2008). Examples of comprehensive approach in regional karst GIS are Florea et al. (2002), Gao et al. (2002), Litwin (2008); Green et al. (2002), etc. Usage of GIS technologies in solving particular problems related to karst includes applications in hydrogeological research (Croskrey & Groves, 2008), sinkhole hazard assessment (Gao & Calvin Alexander, 2008; Lamelas et al., 2008), suffosion-related hazards (Koutepov et al., 2008), and others. Processing in karst Geographic information systems is being constantly upgraded with methodological innovations (Gao, 2008; Wu et al., 2008).

Similarly as in other fields of karst research, the GIS technologies have been used in the studies of karst depressions, mostly dolines. In the majority of cases, the GIS methods are used in the analyses of spatial distribution of dolines (e.g. Faivre & Reiffsteck, 1999; Denizman, 2003; etc.).

Within the present study, both raster-based and vector-based GIS have been used. The segment of raster-based GIS is more simple, and it has been processed using the software *Idrisi Andes*. Each uvala was treated as a separate project (area of interest), except those that are situated very close to each other, thus having a single area of interest. Raster based GIS tools were used to produce digital elevation models from vector data (rasterization of digitized contours), calculations of volumes, producing slope inclination maps and extraction of selected slope profiles. This has been a relatively simple GIS application because it was used only for calculations and map generation, without complex overlapping of information and subsequent procedures, which are usually included in raster-based GIS projects.

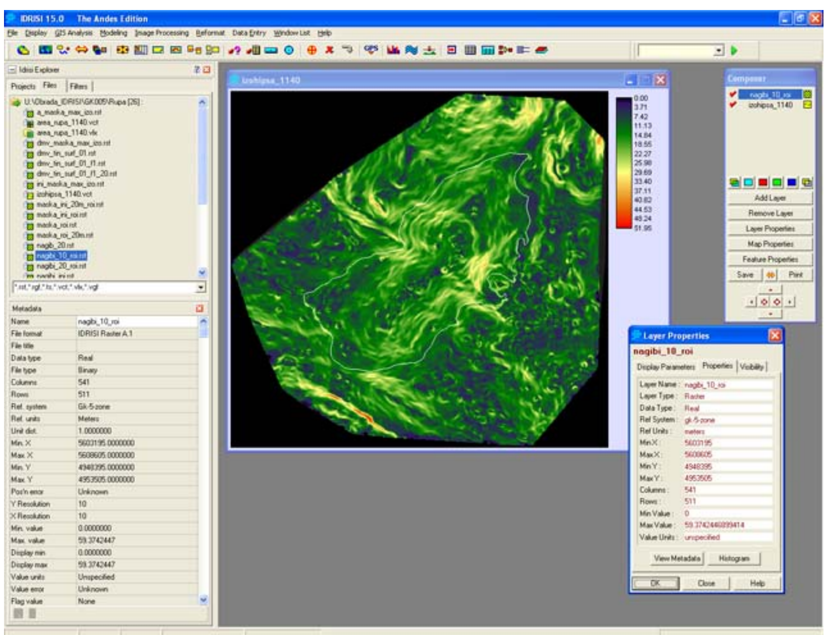

Fig. 7.1: Screenshot showing an Idrisi Andes desktop with generated slope inclination map of the uvala Rupa (ID_24)

The vector-based GIS has been created using the software *GeoMedia Professional 04* (designed by the *Intergraph Corporation*). Areas of uvalas (both Ac and Ad) are representing the entities within the system, while the attributes are all morphometrical and nominal data, as well as the orientations of the major axes. Sets of various data are organized as a relational database, accessible both from *GeoMedia* and *MS Access*. Queries and selections of various kinds are possible. Operations related to the analysis of spatial distribution of uvalas have to wait until more examples are included, because the studied uvalas represent just a sample in a much wider population.

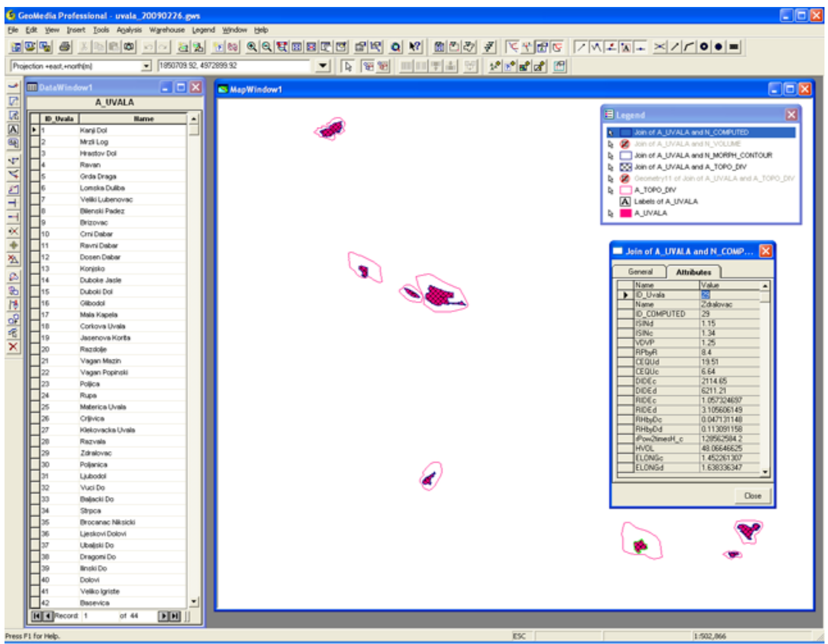

Fig. 7.2: Screenshot showing a GeoMedia desktop,
with the map-window zoomed on western Bosnian uvalas

8. Discussion

8.1. Terminological inconsistencies

“Every field of science has to determine the subject it treats and discusses, the methodologies it uses, as well as the symbolically, semantically and informationally pure terminology. Terminology is therefore an indicator of development, structure, integrational and communicational skills of the branch of science” (Pediček, 1984, cit. by Kunaver, 2003).

Naming a particular form with a group term which is used also for a variety of several different forms is logically unsustainable. “Karst depression” is a common group term for dolines, uvalas and poljes. Therefore, if one aims to exclude the term uvala and call uvala-like features just “karst depressions” instead, we see a terminological inconsistency. It is possible only in general considerations, when more precise determination is not important for the subject of discussion. However, such practice should not be considered acceptable in particular karstological studies.

On the other hand, the same inconsistency issue applies in the situation when we have one particular term (uvala) which is used for so many different forms that it creates doubts about its true meaning. If we aim to keep the term, we have to keep it clear. If we use it for many forms which are so much different among themselves (not by shape, but by the geomorphological processes involved), the resulting effect is a terminological chaos. The authors then try to avoid the chaos by avoiding the unclear term completely, which downgrades the general terminology. Therefore it is necessary to abandon the redundant usages, and concentrate on the objective of defining an undisputed, clear usage, if possible.

8.2. Planar shape

Discussion on planar shapes of uvalas greatly depends on the understanding of complicated issue of uvala perimeter, explained more in detail in chapter 4.2.1.1.

Generally, planar shape of uvalas is very rarely circular. Even if it happens to be close to circular, the cross section is conspicuously asymmetrical (e.g. Ždralovac, ID_29). Great majority of uvalas are in planar shape either elongated or lobate. Compound uvalas, which show noticeable dual planar shape, have been formed by joining of two to three (rarely more) similar forms (uvalas as well). A good example of such case is the uvala Ljeskovi Dolovi (ID_36) in Montenegro. Some uvalas are neither circular, nor elongated, nor lobate, but structural guidance is again obvious in their planar shape (e.g. Vagan Popinski, ID_22, with its rhomboidal area).

When arguing in favour of the role of vertical shafts (domepits) in development of dolines (instead of structural weak-points causing accelerated corrosion), Šušteršič (1994) wonders: "If the weak-points on the surface are geological structures, which are linear as a rule, then, why are dolines so very circular, even if ranged along tectonical lines…" (p. 151). Without entering a debate on doline development, we can just remind that, as opposed to typical dolines, the uvalas *are* elongated, as a proof of the crucial role of geological structures in their development.

8.3. Coalescence issue

Formation of uvalas by coalescence of dolines is questionable theory. The nature of karstic process is not planation, but dissection, because vertical drainage, which is normal in karst, generally does not result in significant lateral erosion (except at the water table level, e.g. in some poljes). If we imagine a karstic surface pitted with dolines (above groundwater level) it is less possible that karstic erosion would be directed laterally, so that the dolines would coalesce without deepening. If we imagine that they do coalesce, why would they coalesce towards some central point and form bigger depression? Explanation of this hypothetical process with a specific structural pattern which would enable coalescence towards a central point is untenable. In that case the structural pattern would be responsible for the initial formation of uvala (large depression as a whole) in the first place, instead of primary formation of regular dolines and their subsequent coalescence with large-scale central tendency. Instead, dolines on relatively flat plateaus or mild inclinations develop in vertical sense, while ridges are simultaneously (but not faster!) being lowered by a general process of karst surface lowering. If we accept Šušteršič's (2006) model of doline enlargement, growth of a doline always has a vertical component (deepening). In hypothetical case where a plateau with already formed dolines is newly tectonically activated and there are

conditions for formation of larger centric depressions, its formation would again take place regardless of the existing dolines – by the time needed for formation of large depression, dolines would anyway be removed or smoothed by karst surface lowering.
According to many authors (e.g. Williams, 1972), enlargement of dolines leads to the development of polygonal karst, with remnant cones, and not to formation of huge depressions in which the remnant ridges would be eroded. Similar opinion is expressed by Bondesan et al. (1992) as well (Fig. 8.1).

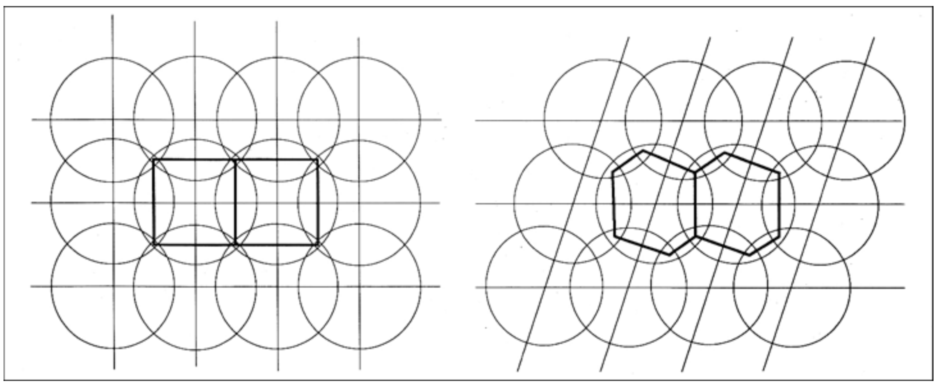

Fig. 8.1: Patterns of doline enlargement, forming a honeycomb or polygonal karst (Bondesan et al, 1992)

Coalescence of dolines on smaller scale (several of them) is of course possible, but it creates only twin or triple dolines, not a large depression with dolines at the bottom. Coalescence of dolines can lead to delineation of relatively small, shallow closed depressions whose depths hardly exceed the depths of average dolines in the area, while the planimetric areas usually match the areas of several average dolines in total. Such closed depressions are not morphologically distinct, and are mostly detected from topographical maps. It is questionable whether we really need a particular name for such features, considering the fact that they are usually not particularly prominent nor specific; we suggest that for such forms it is possible to use the term twin- , triple- , or compound doline. Among thousands of such examples, Fig. 8.2 shows a form on Mt.Miroč, in the Carpatho-Balkanides of Eastern Serbia. Speaking about twin dolines, a nice example is situated in south-western part of the uvala Jasenova Korita (ID_19).

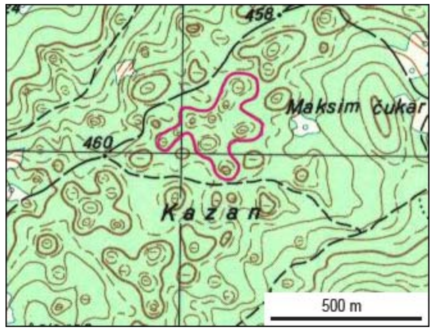

Fig. 8.2: Compound dolines on Mt.Miroč

(see also the .kmz file of the outlined feature, in the Appendix 1)

Formation of uvalas from coalescing dolines would perhaps be possible in the conditions of permanently shallow water table, when karstic process would not be able to progress vertically, and lithological controls would contribute to the existence of the major positive relief forms. In such a conditions, lateral enlargement of depressions would have substantial impact on general relief development. Only in this case it could be possible that an uvala evolves into a polje (polje in piezometric level in classification of Gams (1978), or baselevel polje in classification of Ford & Williams (2007)), by reaching the water table level and subsequent flooding, including sediment infill and lateral corrosion. Similar viewpoint on coalescence was expressed by Cramer (1941), who noticed the importance of hydraulic potential of karst, stating that depressions on high karst plateaus tend to deepen, while the low areas with dolines can reach the stadium of uvalas. However, it is rather rare case, especially in tectonically active regions, that the permanent, stagnating shallow water table can last long enough for completion of such scenario.

8.4. Inherited forms

If we keep in mind the process of constant lowering of karst surface (corrosion, karst denudation), which, according to Gams (1966), averages about 65 m per million years (calculated for the karsts of Slovenia, but we can approximately apply this value for temperate karsts generally, at least for the Dinaric karst), it is clear that the forms we presently see in a karstic landscape may be the “imprints” of former relief forms. In the studies of karst landforms evolution, especially those of great dimensions which needed relatively long time for their development, we must take into account that in the time of landform genesis many conditions might have been rather different than today – surface relief, hydrological settings, local water table level, even the lithological settings (some lithological units may have been eroded in the meantime). From that perspective, initial genetic factors of a particular form turn out to be less relevant for classification. An example of the erroneous interpretation of genetic factors is a deduction of Katzer (1909), already mentioned in chapter 3.4, where he argues that any karst depression whose formation is guided by tectonic activity is in fact a polje. In reality, it is subsequent development (and the processes taking part in it) that gain the dominant importance for definition of the present landform. Such understanding of inherited depressions, and discussion on their classification, was given by Sauro (2003), within a case example of a doline in Monti Lessini (Venetian Prealps), which originated as a collapse doline, but its subsequent evolution turned it into a drawdown doline. The author favors the present status for the needs of basic classification, but stresses the need for understanding the genetic aspects as well ("I believe that it is more correct to consider the present day situation, but, anyway, without the formulation of an evolutionary model it is also difficult to understand such a form."; Sauro, 2003). Gams (2000) discussed inheritance issue related to dolines as well, but commenting only the transformations of shape: "Having in mind the dolines as inherited from many hundred thousand of years or so, we have to assume that a kettle-like collapsed doline due to mechanical weathering of the steep slopes with time diverts into a bowl-like doline". Considerations of permanently changing genetic and evolutional conditions are communicated also by Čar (1986, 2001): "Such conditions (…) exist at certain places only, and by a progress of denudation lowering of the terrain they move over the 'spatial structural grid' ". The observed karstic forms are all in various stages of development, some being in active development phases, while other represent just remnants of former features. "What we observe today is only the actual state in a continuous process of permanent lowering, shaping and changing of karst surface" (Čar, 2001).

Very similar genetic factors can lead to development of different forms, depending on the conditions within a karst area. In some period of the past, the same type of tectonic movements could have resulted in formation of a polje, if a subsided (lowered) block reached the piezometric level, and development close to the water table followed; or an uvala might have developed if it stayed high in the vadose zone, with completely different surface processes. The dominant triggering factor for both of these hypothetical forms was tectonic activity, but the settings in which they continued their evolution were crucial for their present character.

8.5. Genetic issue

If we temporarily leave aside the succession of various landforms in karst surface evolution, it is necessary to give some most important observations related to genesis and evolution of uvalas. Although it may sound trivial at a first glance, it must be said that uvalas have a very strong tectonic guidance, which is much more evident and significant than in the case of dolines. While dolines tend to *distribute* along tectonic lines, mostly preserving its internal sub-circular to mildly elliptical form, planar shapes of uvalas clearly reveal orientation along linear structures, and field mapping of 12 examples has verified this observation. Great majority of uvalas is developed along broken zones, which cross the depressions either through the centers or through the lobes (or both). In many cases, two or more broken zones are crossing an uvala. Crushed zones may be present, but this is not a necessary condition. Although the influence of particular zones of rock fracturing is determined for dolines as well, affecting their shape (Čar, 2001), in case of uvalas, the guiding broken zones are of greater significance, and can usually be traced on a regional scale. Dolines in broken zones (in structural classification of Čar (2001), are developed *inside* broken zones with their entire diameters, while uvalas are much larger, and their form is guided by spatial extension of broken zones.

Among the studied examples, there were no indications of recent collapse processes characteristic for collapse dolines. Almost no portions of horizontal caves are known in the vicinity of these uvalas (except the cave Križna Jama, which is situated about 3 km from the uvala Ravan, ID_4). In the vicinity of uvalas of Mt.Velebit, many caves are known, but they are all vertical.

Mechanism of uvala development, in the sense of karstic process, is most similar to mechanisms functioning in drawdown solution dolines. Being situated in vadose zone (this is also a condition for uvala formation), the developing depression already has an available conduit network which enables karstic drainage and corrosion. Broken zones, highly permeable, are additional pathways for vertical water percolation, in which fragmented rock corrodes more intensively (Gams, 2000).

8.6. Boundary examples

Even in studies like this, when the main subjects are irregular features which are difficult to be categorized within existing classifications, there are even more extreme, boundary examples which, by their particularity, do not fit into any of the usually defined groups.

Depression of Vagan (ID_21) close to the village of Mazin in Lika, Croatia, has some characteristics of a very large doline (W margin with a line of inclination change), some of uvala (general morphology, size, position between two poljes), and a hydrological characteristic typical of poljes – a permanent sinking stream. Its bottom is at lower position than the bottom of the adjoining Mazinsko polje. We have treated it as an uvala within this study, but its complex characteristics do not allow a clear categorization. It can also be considered (loosely, of course) as a kind of a "karst window" to permanent waters, even in dry season, when the surrounding poljes lack water.

The uvala Dragomi Do (ID_38) in Montenegro could possibly be regarded as a very large doline. At some segments along its perimeter, there is a line of sudden inclination change, which is normally the characteristic of dolines. The highest closed contour enclose an area on the south-east, which is higher than the main depression, and generally does not represent an integral part of Dragomi Do. On the other hand, the south-western extension of the main depression can be regarded as an integral part of Dragomi Do, in spite of the fact that they do not share any closed contour.

In the same region, Katunska Nahija in Montenegro, there are several depressions of enormous dimensions, which generally have several typical characteristics of uvalas (irregular, elongated shape, development along prominent tectonic lines, uneven floor, lack of water), but due to their exceptionality, categorizations have to be done cautiously. In our opinion, there are enough reasons to consider them karstic uvalas, but further discussions might come out with some other suggestion as well. The best examples are Ržani Do, Podbukovica – Zaljut, Pejovići – Čevo, Velestovo (see positions in Fig. 5.80, and .kmz files in the Appendix 1). Šerko (1948), in his list of karst depressions in the Dinarides, categorizes Ržani Do as an uvala. Some of these uvalas are assigned compound toponymes, after the names of the existing villages, because due to elongation, internal dissection, and dimensions, the single toponymes for these depressions do not exist.

The polje of Homoljac, situated in Croatian part of the Dinarides, within the tectonic unit Mala Kapela – Plješevica (see Fig. 5.44) could possibly be categorized as a dry polje. Genetically, it probably originated as a polje, functioning close to the water table, which facilitated the development of its generally flat floor. However, the hydrological conditions in the area have subsequently changed, and water table is presently about 70 m lower. Only a very weak occasional brook exists during the wet season. Numerous dolines have developed at the bottom, which still appears flat from remote locations, but any closer look reveals the undulating floor with dolines and rocky outcrops. Scarce sediments do not have a uniform spread, and the “polje” cannot support any agriculture except for pasturing.

Fig. 8.3: Panorama view of the polje of Homoljac

Fig. 8.4: Dolines with rocky outcrops in the polje of Homoljac

Further development will probably lead to more uvala-like characteristics: (1) karst denudation in combination with frost shattering will keep smoothing the bottom/slope angle; (2) soil and colluvial sediments will be increasingly washed down to underground conduits, because the permanent spring Vrelo in the Krbavica polje is 70 m lower in denivellation; (3) dolines will increase and deepen, thus dominating the bottom relief.

8.7. Slopes

Evolution of slopes within karst depressions depends on hydrological processes characteristic for karst depressions and subsequent karst denudation rates, as well as frost shattering (Pleistocene gelifraction, and present frost action where existent), and gravitational mass movements (on the slopes having steep inclinations, bare rock and screes). Hydrological processes and types of flow within dolines were elaborated by Gunn (1981), who distinguished six flow components: overland flow, throughflow, subcutaneous flow, shaft flow, vadose flow, and vadose seepage (Fig. 8.5).

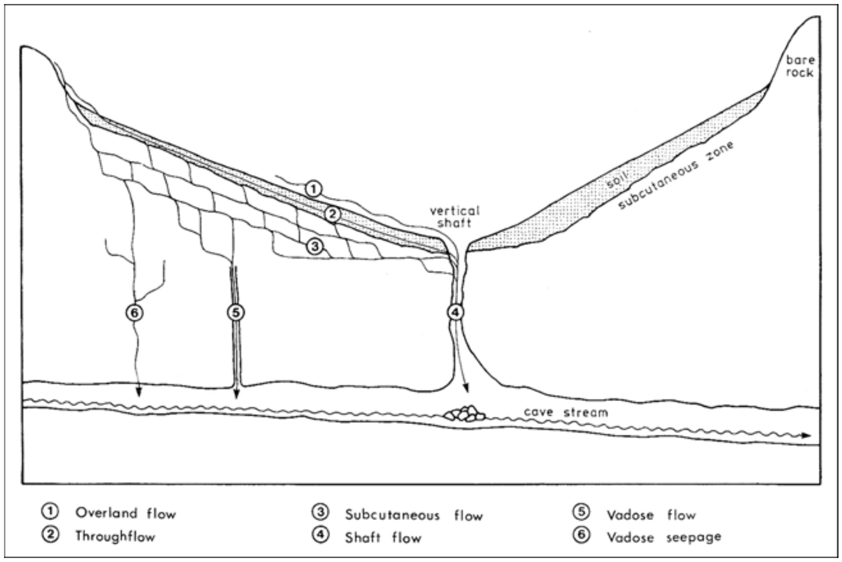

Fig. 8.5: Flow components in karst depressions, defined by Gunn (1981)

Karst depression slopes have been studied most extensively in tropical karst; the research of Day (1987) could be selected as a representative. He states that slopes play an important role in maintaining the form of a depression, by controlling the water entry into the subcutaneous zone. Within the study, the slopes of seven relatively small depressions (mean diameter 139 m) in tropical karst of Belize were mapped, distinguishing four broad types: staircases (located mostly close to cockpit summits), broken cliffs (mostly in midslopes), inclined bedrock slopes, and talus cones (the latter two are typical for areas near the depression bases). On each particular type, surface runoff was monitored during the storms in wet season, and the results showed that the runoff was of short distance and duration (max. 5,5 m in length, and up to 20 minutes on sedimented bottoms). Poor surface runoff indicates rapid penetration of water into the subcutaneous zone and epikarstic aquifer (Day, 1987).

Gams (2000) explained different dynamics of slope retreat for different geometric types of temperate dolines. Funnel shaped dolines tend to deepen without changing the diameter (1), while other shapes are characterized by parallel slope retreat and increasing width (2-4) – bowl-like dolines (2), dolines with circle profiles (3) and kettle-like dolines (4) (Fig. 8.6).

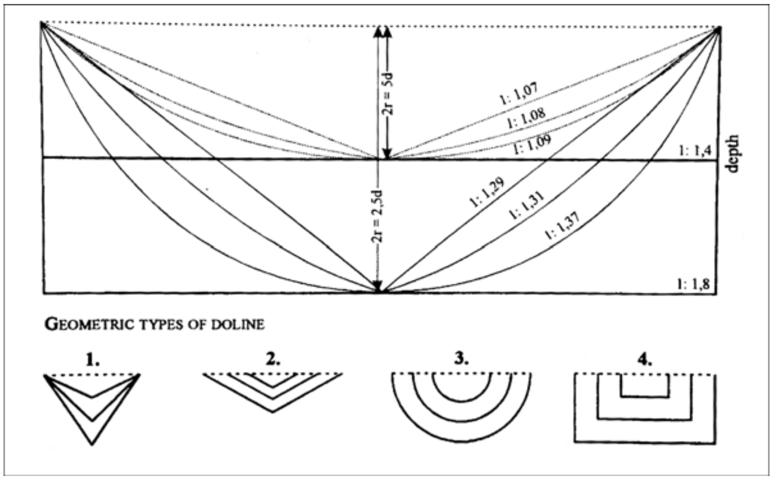

Fig. 8.6: Schematic cross-sections of dolines, and their slope retreat (Gams, 2000)

Gams states that equal growth of radius and depth is most frequent in nature, and that bowl-like types prevail among larger dolines. Regarding the processes on slopes, they tend to change above the threshold value of 30º inclination: "Once the slope inclination exceeds 30º, the creeping of the clastic sediments is intensified, and the slope is getting stony, loosing the soil/rock interface" (Gams, 2000).

Modelling of several types of temperate solution doline growth (examples from Hungary, Croatia, and Romania), with various types of slope retreat, has been done by Péntek et al. (2007). The authors distinguish the processes of doline widening (1) at rim and base; (2) at base; (3) at rim; and (4) dolines deepening but not widening (Fig. 8.7), which is very similar to the mechanisms shown by Gams (2000), but obtained by sophisticated procedures.

During these growth patterns, the slope "becomes gentler or steeper, or it recedes parallel to itself" (op.cit.). According to the shapes (cross sections) of most of the studied uvalas, it can be roughly concluded that the development of uvalas mostly follows either the scenario (1) or the scenario (3), while the examples in which there is no widening of the rim (scenarios 2 and 4) are rather rare.

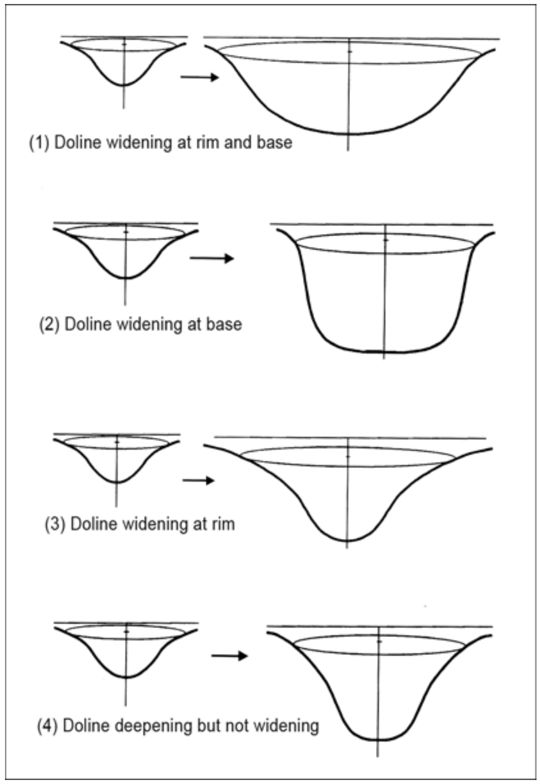

Fig. 8.7: Four evolutionary paths of solution dolines, according to Péntek et al. (2007)

Slope processes in collapse dolines were studied by Stepišnik (2006), on the examples from the Slovenian karst. Within the study, the relation between mechanical and chemical weathering, and consequences of domination of one or another, are discussed. Chemical weathering tend to preserve the initial slopes, while intense mechanical weathering leads to formation of concave slopes. Stepišnik recognized that within collapsed dolines, slope retreat is more intense in tectonically damaged zones, due to more intense mechanical weathering. In uvalas, this rule applies as well, but with a modification: due to generally small slope inclinations in uvalas (as opposed to slopes of collapse dolines), broken zones stimulate slope retreat due to the fact that chemical erosion is intensified, thanks to rock fragmentation. In that way, the saddles which are the lowest points along the perimeters (Pd) are formed. Stepišnik (op.cit.) mapped the slopes in the studied collapse dolines, distinguishing several types according to dominant geomorphological processes and slope angles: (1) bare rock, with inclinations above 60º; (2) scree slopes, with inclinations 35-40º (up to 47º) and gravitational movements; (3) active slopes, with inclinations mostly above 30º and visible traces of mechanical transport (slanting trees, unstable rock fragments in thin soils, etc); and (4) steady state slopes, inclined up to 25º, where chemical weathering dominates and no signs of mechanical transport are visible (e.g. rock fragments are rounded, which indicates that they are situated at the same place for longer time, exposed to precipitation corrosion) (Stepišnik, 2006). We did not carry out any similar mapping within this study of uvalas, because the great majority of slopes are in steady state condition. Only some segments of slopes in high-mountain uvalas are in bare rock or covered with screes, but this is not the dominant process. Slope inclinations rarely exceed 30º, and if present, they are restricted to higher portions, close to summits along topographical divides. Mechanical denudation was more intense in the colder periods of the Pleistocene, when larger quantities of debris were transported to the bottom parts, making colluvial sediment covers. Presently, mechanical weathering is still active to some extent, but chemical weathering dominates, due to prevailingly mild slope inclinations.

8.8. The role of hydrological function

In our opinion, hydrological function is of great importance when distinguishing the uvalas from the poljes. It is directly related to the processes which take place in the depression. Inundations considerably contribute to flattening of the floor, through sedimentation, preserving the sharp transitions from the flat floor to the bordering slopes (often mentioned in polje studies), etc. This indicates that most of the crucial "requirements" for a polje (Gams, 1978) are a direct consequence of hydrological activity of the depression. In uvalas, which lack surface waters, karst denudation tend to smooth the sharp "bottom-slopes" transitions, sediments are scarce, bottoms mostly undulating or pitted with dolines. Even in cases where bottoms are nearly flat, their transition into slopes is gradual. Therefore, so called "dry poljes" are about to lose the attributes of poljes due to typical geomorphological processes taking place in dry depressions. As already said in the chapter 8.4, the long chronologies of development of karst landscapes oblige us to give the appropriate significance to the actual processes in a depression, because their genetic factors may date back to the times when the investigated depression was of different kind than it is today.

8.9. Relation to other geomorphological processes

In several references that deal with types of uvalas (or compound depressions), the main classifications generally include the types formed under the influence of other geomorphological processes. While all classifications include one type formed by coalescence of dolines, as a pure-karstic type, other types somewhat vary: tectonic and fluvial (Cocean & Petrescu, 1989), fluvio-karstic, karst-fluvial, and glacio-karstic (Petrović, 1994), while Sauro (2004) uses the term "polygenetic sink" and distinguishes three types: tecto-karstic hollows, fluvio-karstic hollows, and glacio-karstic hollows.

If we accept the fact that tectonic activity and its consequences are in very tight relation with karstic process in almost all karsts, fluvial and glacial process remain as two main "alien" processes which may influence or cause the uvala formation.

8.9.1. Fluvial process

Influence of fluvial process on uvala formation is usually linked to re-shaping of dry valleys and blind valleys. In our opinion, **blind valleys** should not be called uvalas. If they become so much morphologically distinct and protrude significantly into the karst unit so that the term "blind valley" is no longer appropriate, they are in fact becoming border poljes (genesis fits into the model, there is a sinking stream, inundations in wet seasons, great quantities of sediments on the bottom, even marginal corrosion is possible). An example of a border polje which in fact originated as a blind valley is Lipovo polje in Lika, Croatia, which is a sinking area of the Lika River, as a particular segment of the Ličko polje. A number of karst forms in Eastern Serbia which have been called uvalas by some authors (Velika Brezovica, Mala Brezovica, Gajine Mlake on Mt.Kučaj; Rečke and Busovata on Mt.Beljanica, etc; Petrović, 1970, 1994) are nothing else but regular blind valleys. The cited references even contain completely unnecessary terminological inconsistencies ("The uvala represents a conspicuous blind valley cut by the stream Gajine Mlake" – Petrović, 1970). If we need to distinguish among different morphological manifestations of blind valleys, then it would be more proper to conduct detailed studies of blind valleys and try to define their variations and/or classification, without mixing up the term uvala.

Parts of **dry valleys** which are sometimes called uvalas are often hardly distinctive in relief. It is natural for dry valleys that they do not have continuous bottom, but are dissected by smaller or larger depressions, mostly dolines. It is questionable whether there is a need to introduce a separate geomorphological term in cases when somewhat longer or wider portion of a dry valley is enclosed within one contour. In that case, it is still a dry valley, so it would be possible to use an expression like "widened / deeper segment of a dry valley", or it might be a larger doline within a dry valley. In the dry valley of Mali Dol on the Kras in Slovenia, there are several "extremely wide irregular dolines" (Košutnik, 2007), but since they do not significantly exceed the width and depth of the dry valley, there is no need to call them uvalas. If wider segments (depressions) are really conspicuous, then we can suppose that other factors, like internal conditions within the karst system, or tectonic structures, had a dominant impact on their formation, so the influence of other geomorphological process was not of crucial significance. Previous fluvial process on covered karst, which have lead to formation of dry valleys cannot by itself trigger the formation of a large depression unless conditions for its formation had been anyway present in a particular karst area. Dry valleys, being just imprints of former process (fluvial, on an impermeable cover) which have intersected the area susceptible for formation of an uvala, are then only the coincidental location where the uvala is formed. Similarly as we do not distinguish types of dolines by the places where they occur[1], but by their essential characteristics, there is no need to distinguish uvalas which are located at intersections with dry valleys as separate type of uvalas. A touch of subjective decision is needed, of course, in resolving whether a depression along a dry valley is just a slightly re-shaped part of a valley (e.g. Veliko Igrište, ID_41), or a particular form, uvala, with its own genetic factors regardless of dry valley incision (e.g. Baševica, ID_42). In doubtful cases, the decision has to be reached by application of more detailed study, field mapping, etc.

[1] In Bondesan et al. (1992), division of dolines according to their topographical context is given, but it is clear from the whole text that this is just one of the alternative options of classification, when needed for some particular purposes. Otherwise, such classifications generally do not appear in literature. The uvalas could also be distinguished alternatively by their topographical context, but that cannot be their basic classification.

8.9.2. Glacial process

Pleistocene glacial process took place when most of the studied limestone surfaces were already subject to karstification. Therefore, glaciers favored the previously existing depressions for location of cirques and glacial valleys. Uvalas in the zone of Pleistocene glaciation are re-modeled by glacial activity, and the traces of glaciation are often visible even nowadays (moraines, inactive rock glaciers, roches moutonnées, etc.). However, we cannot say that the glacial activity was the leading factor in their formation. Again we come to tectonic structures, and karst process in combination with them. Glaciation was just one stage in their development, a modification which was neither a genetic factor, nor it is active nowadays. Significant morphological differences in comparison to "normal", low-elevation uvalas are not a rule: some uvalas which have passed through a glacial phase in their development do show conspicuous marks of that phase (e.g. deep glacial incision of Lomska Duliba, ID_06), but others do not (e.g. Dolovi, ID_40; Razvala, ID_28). Existence of some quantities of moraine material in high-mountain uvalas is definitely an evidence of a glacial phase, but not a substantial morphological distinction in comparison to lower elevation uvalas. Here we can add a comparison with classification of dolines: in spite of the fact that most authors agree that Pleistocene periglacial environment and gelifraction process had a significant impact on shaping of dolines, there are no attempts to distinguish "Pleistocene periglacial dolines" in the overall population, if the process is no longer active.

Particular kind of karst depression defined in the Alpine karst of Slovenia – "konta" (Kunaver, 1983) may at first glance be similar to the uvalas which had been subject to glaciation at some stage of their development. However, kontas are considerably smaller than uvalas – the largest konta on Mt.Kanin, Veliki Dol, has the dimensions 680 x 450 m, which is smaller than the smallest uvala from the present study. Moreover, Kunaver (op.cit.) states that kontas of Mt.Kanin are situated at the levelled plateaus above 1600 m a.s.l., mostly between 1700 and 2150 m, which is considerably higher than the Dinaric uvalas. This means that the impact of the Pleistocene glaciation was much stronger in kontas than in uvalas, and it probably lasted much longer, since all of them were above the snowline. At the moment, differentiation between kontas and uvalas can be made only through obvious characteristics – size, elevation, and duration and strength of glaciation phase. Essential differentiation requires more detailed studies and inventarization of kontas.

8.10. Direction of further research

8.10.1. Database filling and GIS improvement

As already said in the introductory chapter, we consider this thesis as a starting point for more extensive and more comprehensive study of uvalas and similar features. In this sense, filling of the founded database with new examples must be a permanent process. Although the performed statistical processing of 43 examples gave only modest results, due to great morphometrical variety of uvalas, it is expected that enlargement of the sample will lead to better effectiveness of statistical procedures. Furthermore, collecting the examples from other temperate karsts is very important. Although this study was focused on the Dinaric karst, and, to some extent, the karst of the Carpatho-Balkanides, comparisons with uvalas from other areas will speak in favour of (or possibly against?) the usage of the term uvala as a particular form of karst closed depressions. Within this process, it is important to include the depressions which are “vague”, irregular, non-defineable, difficult to categorize, etc.

Along with the new study examples, there is the need for continuation of structural mapping. Up to now, 12 mapped uvalas have revealed a huge influence of tectonically broken zones upon their formation. If this turns out to be proven in further mappings, it will mean more grounds to define a regular relation between these two elements.

Position of particular uvalas within their regional geomorphological settings is very significant. Similarly as in case of doline research, it is “essential to extend beyond a simple analysis of the shape” (Sauro et al., 2009). Definition of morphostratigraphical sequences for individual geomorphological units defines a place of uvalas within relief evolution. In the present study, some regions have unfortunately been poorly geomorphologically explained due to insufficient previous studies and scarce available literature. Filling of this gap, either by taking part in general geomorphological research of particular areas, or from new published studies, will lead to covering up the regional deficiencies within the present thesis.

Improvement of the geographical information system is also linked to the enlargement of the database and greater number of samples, as well as with inclusion of new types of data (not only morphometric and nominal). These data should refer to results of new research methods discussed further in the text.

8.10.2. Sedimentological studies

We are aware that the lack of sedimentological research of uvala bottom deposits is one of the shortcomings of the present study. It was logistically rather difficult to carry them out, because sampling always requires the need for official permissions. Since the studied examples are situated in several countries, this would be rather difficult to obtain. The best option for future studies of this kind would be joint projects with the scientists from particular countries where the uvalas are situated.

Sedimentological studies should comprise sediment type detection (composition, granulation), which is supposed to indicate the sediment origin (colluvial or other). Thickness of sediments can be detected by application of electric resistivity tomography (ERT), already widely used in karst studies (e.g. Stepišnik, 2006; Ravbar, 2007; Stepišnik & Mihevc, 2008; Sauro et al., 2009, etc.). Palynological analyses are a useful component of such studies as well.

Detailed sedimentological studies of karst dolines have shown that karst drainage tends to wash down the fine-grained material from the dolines down to the subterranean conduit system (Sauro et al., 2009). Therefore, some reliable material for paleo-environmental reconstructions may be missing from karst depression fillings. In spite of that, the remaining material may provide indications at least for dominant geomorphological processes active throughout morphological evolution.

8.10.3. Fourier analyses of vertical and horizontal components

Application of Fourier analysis has been present in the study of karst surface depressions in the last few decades. Brook and Mitchelson (1981, cit. by Bondesan et al., 1992) have used it for the study of cockpit karst area of Puerto Rico, where they detected the most significant "wave lengths" characteristic for that type of karst relief. Transformation of doline semi-profiles into Fourier coefficients has been extensively elaborated by

Šušteršič (1985, 1987, 1994). By processing the natural semi-profiles (obtained in field measurements) by Fourier transform, and selecting only particular harmonics for the reverse transform, he obtained the "smoothed" semi-profile lines, which are free of various micro-relief distortions and thus more appropriate for comparisons.

Having in mind that the uvalas are much more complex features than dolines, it would possibly be useful to process their semi-profiles in the same way, to see to which extent the Fourier techniques would be capable of distinguishing the "noise" elements from the "basic" forms, i.e. undistorted semiprofile shape. Detection of uvalas with mutually similar basic forms (similar profiles) might help in determination of their common factors of development. It would probably be possible to use the methodology established by Šušteršič (op.cit.), but some difficulties would have to be discussed and decided in advance: (1) which line would be adopted as perimeter line (discussed more in detail in the chapter 4.2.1.1); and (2) which location would be taken as the central point, in cases where multiple lowest points exist. Due to very large sizes of uvalas, field measurements would be impossible, and in our opinion unnecessary – accuracy of 1:25.000 maps data would be sufficient, considering the size difference between dolines and uvalas.

Apart from application of Fourier analysis for the processing of semi-profiles, another possibility is to consider the processing of horizontal component, in this case the shape of Pc perimeter (defined by the highest closed contour). With full awareness of the limitations of Pc perimeter discussed in chapter 4.2.1.1, but in absence of a better solution, it might be worth to apply the analysis to obtain simplified forms, and to examine the irregularity of the perimeter line. This idea is only in the test phase, so only the two most opposite examples have been processed: Materića Uvala (ID_25) and Ljeskovi Dolovi (ID_36). The computer program for this analysis, made in Scilab environment, has been developed at the Geographical Institute "Jovan Cvijić" (Štrbac, 2009). The perimeter line extracted from the raster files in Idrisi Andes is defined as a series of points, with X and Y coordinates for each point. Series of values for each coordinate (X and Y, respectively) are processed by direct Fourier transform. After selection of certain number of harmonics with highest magnitudes, the data is processed by inverse Fourier transform, and simplified shapes are obtained (Fig. 8.8)

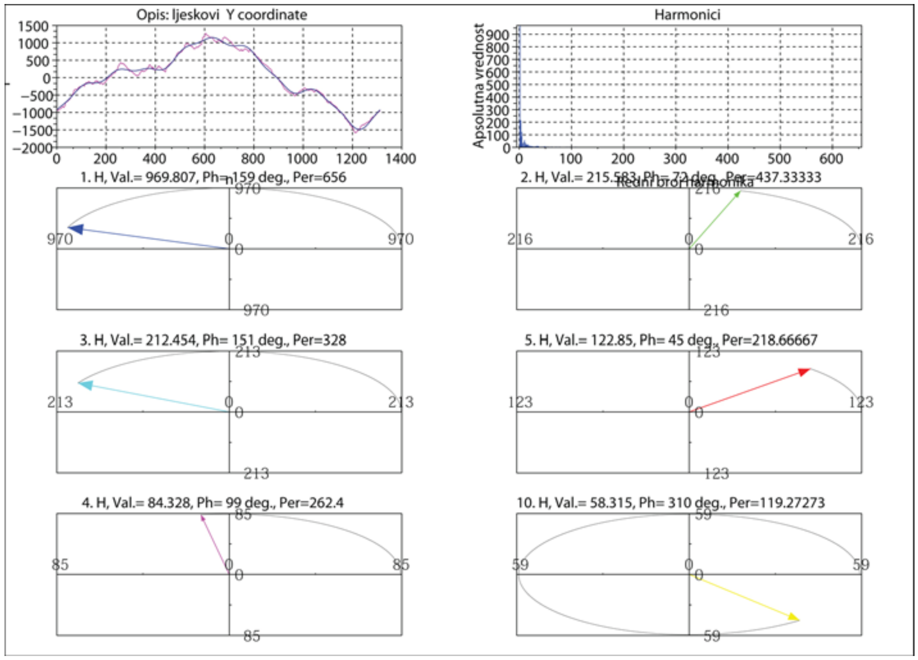

Fig. 8.8: Processing of series of Y coordinates by discrete Fourier transform, and smoothing (blue line) of the initial perimeter values (pink line) by inclusion of only six non-zero harmonics of highest magnitudes

Absolute number of included harmonics needed to obtain a particular level of similarity with the original perimeter, indicates the degree of perimeter sinuosity (numerical value was obtained by different calculation, as ISINc within morphometrical analysis). Precise measure of similarity has yet to be defined, by usage of statistical methods. If great number of harmonics has to be included to obtain a needed level of similarity, it means that a karst surface is highly subjected to doline pitting and to other surface processes which caused significant irregularities on the slopes. For the smoothed perimeter of the Materića Uvala (ID_25; ISINc=1.39; perimeter defined by 629 points), whose slopes are rather uniform, only one non-zero harmonic was sufficient to delineate its approximate shape (Fig. 8.9). In case of the uvala Ljeskovi Dolovi (ID_36), whose ISINc is considerably higher (2.54) and perimeter defined by 1313 points, six non-zero harmonics are needed for approximate delineation of the Pc perimeter (Fig. 8.10). We again have to stress that these procedures are only in the initial, preliminary phase, and that most details regarding the methodology are yet to be defined.

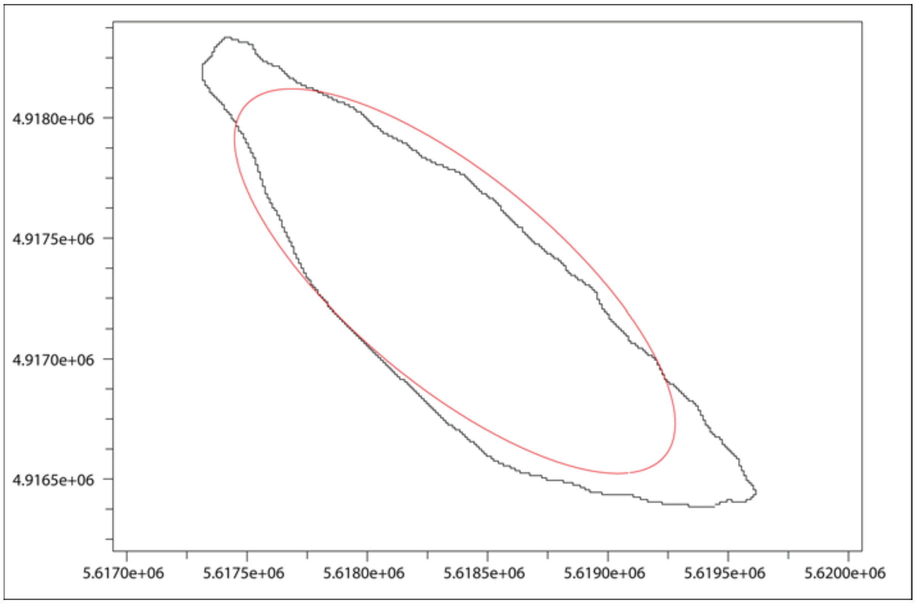

Fig. 8.9: Smoothing of the Pc perimeter of the Materića Uvala (ID_25) by discrete Fourier transform, using only one non-zero harmonic (with highest magnitude)

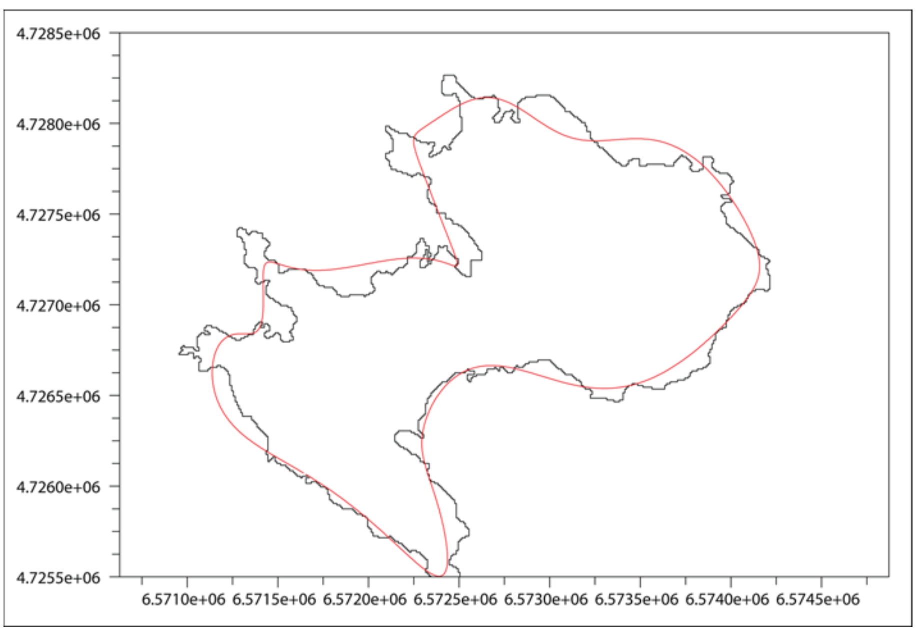

Fig. 8.10: Smoothing of the Pc perimeter of the uvala Ljeskovi Dolovi (ID_36) by discrete Fourier transform, using six non-zero harmonics (with highest magnitudes)

8.10.4. Application of fuzzy sets theory for classifications of karst surface depressions

In classical theory of sets, there are precise borders that separate the elements belonging to different sets. These ordinary sets are also called crisp sets, or Boolean sets, and an object can either belong to a set (value 1) or not belong to a set (value 0). As opposed to a crisp set, a fuzzy set has a continuum of grades of membership, ranging from 0 (not a member) to 1 (full member). Fuzzy set theory was first suggested by Zadeh (1965) and has been extensively used in various fields of science ever since. According to Ventura & Irvin (2000), it "relaxes the condition of all-or-nothing membership, so that individuals are allowed to be partial members of a class"

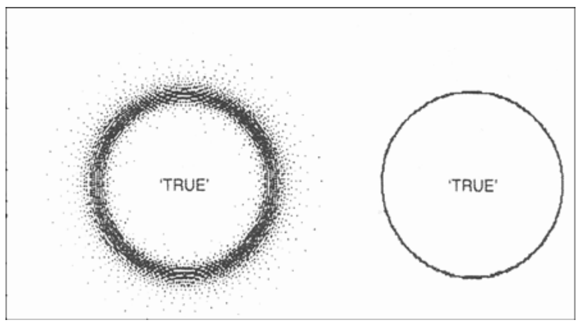

Fig. 8.11: Left: Borders of a fuzzy set; Right: Boolean (crisp) set (Burrough & McDonnell, 1998)

In earth sciences, this theory is extensively used in hydrology and soil science, as well as in environmental studies. The most effective use is related to the occurrences of unclear spatial extension of particular objects or characteristics (Cheng & Molenaar, 1999; Ercanoglu & Gokceoglu, 2002). In that sense, fuzzy logic (also called a continuous classification) is particularly useful in thematic cartography, when the mapped features have vague boundaries (Foody, 1999).

Possible usage of the principles of continuous classification in the study of karst depressions could be directed towards better definition of the depressions which contain mixed characteristics of two depression types. In our case, uvala can be fuzzy towards dolines, poljes and possibly towards enlargements within dry valleys (if they are morphologically distinct to a considerable point, and of adequate size).

The procedure would require some kind of quantification of nominal (categorical) data, like hydrographic characteristics, bottom morphology, regularity of slopes, etc. With inclusion of numerical characteristics, like dimensions or shape regularity, and by introduction of a calculation method, it would be possible to categorize certain depressions on a continuous scale from 0 to 1. For example, 0 value can be assigned to typical, full-member of doline class, and 1 value for typical, full-member of uvala class, with a range of values for the features in between the two. Sub-classifications within the particular types could be carried out in this way as well.

Fuzzy features among closed karst depressions are (1) very large dolines with uneven slopes and/or irregular shape; (2) multiple and/or large compound dolines; (3) widened parts of dry valleys; (4) dry poljes with protruding bedrock, scattered dolines and mild transitions between floor and slopes.

Examples of these forms could be included in an additional database consisting of fuzzy depressions. They are often left out from analyses, because they threat to spoil statistical operations, but our opinion is that they deserve particular attention and should not be left out from karstological studies.

9. Conclusions

9.1. General remarks

One of the initial objectives of this work was to pick a group of karst depressions which cannot be classified either as dolines or as poljes, and to find out whether there are solid reasons to categorize them as karst uvalas – a form of karst surface relief which is subject to decreasing usage, due to some misinterpretations of their development and evolution.

After analyzing the study examples, some common general characteristics can be noted: (a) the depressions have internal (karstic, endorheic) drainage; (b) the perimeters are of irregular shape in a majority of cases; (c) the plan dimensions are varying from approximately 1 km up to several kilometers along longer axis, while the depths below the highest closed contours are at least 40-50 m, reaching even more than 200 m; (d) inclinations of slopes are generally smaller than those of dolines; (e) bottoms of depressions are always above the karst water table; (f) uvalas are usually waterless; occurrences of small seasonal sinking streams or ponds are very rare, an exception rather than a rule; (g) sediments at the bottoms are usually scarce, but if present, their origin is from denudation from the slopes; (h) sediment infill, if present, is not threatening to fill up a depression completely – a system of drainage preserves the depression; (i) the depressions of this kind are not present on karst levelled surfaces, but only in areas with more or less dissected relief; (j) in a majority of cases, the uvalas are developed along tectonically broken zones of regional extension.

9.2. Typical examples

This form is, by its essence, very complex and irregular in size and shape. Therefore, it would be very difficult, and methodically incorrect, to select just one location as a typical example. Within the group of medium-sized uvalas, we could point to Jasenova Korita (ID_19) and Vagan Popinski (ID_22) as typical examples. Hrastov Dol (ID_3) is typical for the conditions of shallow karst, which is in a way reflected in its dimensions – large area with relatively small depth (highest Ac/HUV ratio among all the studied examples). Regarding high-mountain uvalas (with bottoms above 1000 m a.s.l, which were mostly subject to the Pleistocene glaciation), Lomska Duliba (ID_6) and Dolovi (ID_40) are the most outstanding examples. As for the extreme outliers within the sample, the uvalas of giant sizes, their exceptionality does not allow for the selection of one particular example. Klekovačka Uvala (ID_27), Rupa (ID_24), Duboke Jasle (ID_14), and Ljubodol (ID_31) each speak for itself, regarding their outstanding characteristics.

9.3. Classification(s)

In the published references treating the issue of uvalas or uvala-like depressions, there were some attempts for classifications, which mostly included both genetic factors and modification factors. Purely karstic uvalas have been thought to develop from coalescing dolines, while other groups have included those which were modified by glacial or fluvial process. In the previous chapter, we have stated that most studied uvalas have been formed by basically karstic process, not by coalescence of dolines, but due to strong structural influence. Regarding the impact of other geomorphological processes, in our opinion they cannot be the criteria for any basic classifications, because their influence was not essential for the existence of the uvalas: they were either active only in one segment of uvala development (glacial process), or represent only a modification factor (fluvial process, related to dry valleys).

If we wanted to make a *structural* classification, we could distinguish:

(1) simple uvalas formed along a single prominent fault (e.g. Materića Uvala, ID_25);

(2) compound uvalas formed at the crossing of two or more broken zones (e.g. Mrzli Log, ID_2);

(3) uvalas whose guiding element is a syncline-like structure (e.g. Dolovi, ID_40);

(4) uvalas without well expressed structural guidance (e.g. Hrastov Dol, ID_3).

If the *hydrogeological* conditions are a criterion, the three end-member cases would be:

(1) uvalas with deep vadose zone, with practically unconstrained possibilities of vertical development (e.g. Lomska Duliba, ID_6, with the vadose zone almost 1300 m deep);

(2) uvalas with local aquicludes, causing shallow local water table, but with general drainage to lower, more distant springs (e.g. Vagan Mazin, ID_21);

(3) uvalas in shallow karst, where regional water table is close to the bottom of the uvala, causing its characteristic evolution (widening without deepening) (e.g. Hrastov Dol, ID_3).

However, these classifications are restricted to particular, narrow criteria, while wide-ranging, essential criterion cannot be defined yet. The classification problem has to remain open, until more examples are processed and compared, or until some new findings give the grounds for general genetic classifications, as in the case of dolines.

9.4. Towards a new definition

Uvalas are large (in km scale) karst closed depressions of elongated or irregular plan form. Their bottoms are undulating or pitted with dolines, seldom flattened by colluvial sediments. Uvalas are always situated above the karst water table. Origin and development is strongly guided by tectonics.

This rather rough definition, together with the whole study, are an attempt to prevent the abandoning of the term uvala in karstology. No cyclic concept doline-uvala-polje (in the sense of Cvijić, 1900) can be approved. The term uvala must be excluded from such contexts, because they discredit its true meaning. Our view is closest to the view of Poljak (1951). Although Šušteršič (1986) remarked that Poljak's type of uvalas are "a droplet in a flood of different examples", it seems that they are more numerous than expected, and that the right way to make the term clear is to exclude the unnecessary identification of uvalas with other forms (e.g. blind valleys).

No final answer is achieved, but the issue has been analyzed up to a point, theoretically and in the field, and is being put forward to the karstological community. All segments are open for discussions, which are not only expected, but necessary.

10. Povzetek

10.1. Uvod

Zaprte globeli na splošno veljajo za največjo značilnost kraške površinske morfologije. V številnih zapisih, zlasti v jugovzhodni Evropi, se v klasifikacijah kraških površinskih globeli običajno omenjajo tri oblike: vrtača, uvala in kraško polje. Po drugi strani pa je uvala v zahodnoevropski in severnoameriški literaturi pogosto izključena iz takšnih klasifikacij ali pa ima le obroben pomen.

Vrtače se večinoma obravnavajo kot »diagnostične« kraške reliefne oblike. Večina običajnih definicij trdi, da so vrtače globeli »s krožnim ali polkrožnim tlorisom in premerom, ki lahko znaša od nekaj metrov do približno enega kilometra« (Ford & Williams, 1989). Po drugi strani so definicije kraškega polja običajno bolj kompleksne, vendar se večina avtorjev strinja, da so to velike zaprte kraške globeli z ravnim dnom, prekritim z nekonsolidiranimi sedimenti, ki se nahajajo tik ob nivoju podtalnice.

Definicije uval pa se med seboj precej razlikujejo. V večini referenc so opredeljene kot kraške globeli, ki nastanejo zaradi združevanja več vrtač. Tu in tam genetski dejavnik sploh ni upoštevan in se uvale omenjajo le kot oblike, ki so po velikosti »nekje med« vrtačami in polji. Avtorji včasih citirajo Jovana Cvijića, ki je ta izraz uvedel v krasoslovno literaturo (najprej leta 1893, bolj natančno pa leta 1899), vendar je bila njegova genetska teorija žal napačna – menil je, da so uvale prehodni evolucijski elementi med vrtačami in polji. Ta napaka je odločilno vplivala na nadaljnjo uporabo izraza uvala: ker je bila ciklična teorija razvoja krasa (da se vrtače razvijejo v uvale, uvale pa v polja) opuščena, so uvale postopoma izgubile status uveljavljene oblike kraškega površinskega reliefa. To je morda še najbolj razvidno iz razlage izraza uvala v glosarju na znanem krasoslovnem spletnem portalu *speleogenesis.info:* »Izraz opisuje značilnosti, ki predvidoma predstavljajo drugi korak v 3-stopenjskem procesu razvoja polj, v okviru katerega naj bi se vrtače združevale v uvale. Ta mehanizem ni več sprejemljiv in izraz uvala se ne uporablja več.« (definicija prevzeta po Lowe & Waltham (1995)).

Začetna zamisel tega dela je, da obstajajo precejšnji razlogi za vnovično uvedbo uval v sodobno krasoslovje. To zahteva poglobljeno geomorfološko analizo, ki bi pripomogla k popravljanju napačnih pogledov iz preteklosti in po možnosti vplivala na preoblikovanje definicije izraza uvala.

Splošni cilj disertacije je preusmeriti pozornost krasoslovne znanstvene skupnosti k uvalam – »pozabljeni« in pogosto napačno definirani obliki kraškega površinskega reliefa.

Osnovna hipoteza je, da obstaja vrsta kraških površinskih globeli, ki so po velikosti večje od vrtač in običajno manjše od polj, vendar se od teh dveh oblik razlikujejo po morfologiji in kombinaciji genetskih dejavnikov, kar jim daje status posebne kraške reliefne oblike. Splošno znano dejstvo je, da vse kraške značilnosti nastanejo zaradi kombinacije korozije in mehanske erozije ter bolj ali manj izrazitega vpliva litoloških in strukturnih elementov. Pri različnih značilnostih prevladujejo različni elementi - tektonski premiki naj bi bili tako prevladujoči razlog za nastanek polj, medtem ko je litologija pomembna za razvoj oblik, kot so škraplje in kamenice. Eden od ciljev disertacije je preučiti vlogo teh posameznih dejavnikov pri nastanku uval.

Cilje lahko povzamemo v nekaj točkah:

- Podroben pregled uporabe izraza uvala od njegove uvedbe do danes; predstavitev različnih mnenj o izrazu (reference, ki se z njim strinjajo in tiste, ki ga ne sprejemajo ali ga namenoma spregledajo).
- Natančna določitev približno 40 uval (končno število je 43) v dinarskih in Karpato-balkanskih gorah, ki predstavljajo različne oblike te značilnosti v različnih litoloških, strukturnih in geomorfoloških pogojih.
- Izvedba podrobnega strukturno-geološkega terenskega kartiranja nekaterih izbranih uval (12 primerov), s čimer lahko dobimo koristne podatke o vplivu tektonike na njihov nastanek.
- Izvedba morfometričnih analiz preučenih uval.
- Vzpostavitev geografskega informacijskega sistema, ki vsebuje vse pomembne podatke o preučenih primerih in olajša statistično obdelavo in primerjavo. Še

- Predlog klasifikacije preučenih uval in spremenjene definicije, s čimer želimo prispevati k vnovični uvedbi uval v sistem zaprtih kraških globeli.

Zelo pomembno je vzpostaviti natančno in dosledno zbirko podatkov, ne le za namen raziskave v tej disertaciji, temveč – in to je še pomembneje – za nadaljnje študije tega področja, ki bodo sledile in za katere predvidevamo, da bodo veliko obsežnejše in podrobnejše. Izbrali smo natančno umeščanje kartografskih virov v prostor, da bi tako pridobili kar najbolj natančen položaj preučenih območij. Vse primere smo metodološko obdelali na povsem enak način, da bi zagotovili popolno zanesljivost primerjav.

Ker so bile uvale in uvalam podobni pojavi v preteklosti redko obravnavane v krasoslovni literaturi, je bilo v to delo nemogoče vključiti vse segmente, potrebne za podrobno raziskavo. Tako na primer ni bilo mogoče uporabiti vseh metod, ki se jih običajno uporablja pri raziskavah drugih vrst kraških globeli.

Posebno pozornost smo namenili razvoju osnovnega ozadja in standardizaciji temeljnih metodoloških postopkov, ki bodo v prihodnosti nadgrajene s podrobnejšimi raziskovalnimi tehnikami iz različnih strok geo-znanosti. Na nek način lahko rečemo, da se precejšen del te disertacije bolj kot na samo podrobno raziskavo nanaša na njeno *organizacijo,* in da smo morali zaradi omejenega obsega nekatera vprašanja pustiti odprta za nadaljnje študije. Idejam za nadaljnjo raziskavo te teme je namenjeno posebno poglavje (8.10).

Naš namen ni bilo iskanje končnih rešitev in odgovorov, saj je ustrezneje in bolj realno, če disertacijo opredelimo kot uvodno raziskavo problema kraških uval.

10.2. Metodologija

V splošni metodologiji te študije je mogoče ločiti več kronoloških faz dela. Ko smo preverili in pregledali najpomembnejše reference v literaturi, smo uporabili topografske karte velikega merila in tako določili nekaj najočitnejših primerov uval na območju, ki smo ga preučevali. Večino teh lokacij smo si ogledali tudi na terenu in s tem dobili boljšo predstavo o njihovih oblikah in dimenzijah, obenem pa smo lahko opravili ustrezne geomorfološke preglede in kartirali, kjer je bilo to potrebno. Izdelali smo tudi fotografsko dokumentacijo. Na podlagi analiz kart in terenskega dela smo za to raziskavo izbrali skupno 43 uval, pri čemer smo upoštevali to, da je treba uporabiti raznolike primere, ki se med seboj razlikujejo po merah, geološkem in topografskem ozadju ter morfoloških značilnostih. Od 43 primerov smo jih 12 izbrali za podrobno strukturno-geološko terensko kartiranje, za kar smo uporabili Čarjevo metodo (1982, 1986, 2001). Izbor teh 12 primerov je temeljil na raznolikosti uval in dostopnosti določenih lokacij. Zaradi nevarnosti min smo morali iz podrobne terenske raziskave izključiti nekaj sicer zanimivih uval v Dinaridih. Digitalizacija izohips in oblikovanje digitalnih modelov reliefa pomenita začetno točko v digitalni obdelavi, v katero smo kasneje vključili še kvantifikacijo morfometričnih parametrov (navedenih v preglednicah 4.1 in 4.2), pripravo kart naklonov in presekov, statistične analize in vzpostavitev geografskega informacijskega sistema.

10.3. Izbrani primeri

Za namen te študije je bilo treba izbrati določeno število vzorčnih primerov. Odločili smo se, da izberemo Dinarski kras kot območje značilnega razvoja krasa v zmernem podnebnem pasu in regijo, od koder izhaja izraz uvala. Po drugi strani smo se zaradi krasoslovnih (kraške značilnosti) in zgodovinskih razlogov (Cvijićeve raziskave) odločili še za del Karpato-Balkanske gorske verige. Kras Karpato-Balkanidov v vzhodni Srbiji se v veliki meri razlikuje od Dinarskega krasa – apnenec je precej tanjši in porazdeljen v majhne zaplate, zaradi česar pogosto naletimo na značilnosti kontaktnega krasa in fluviokrasa. Na podlagi literature, topografskih kart in opažanj s terena smo sestavili končni seznam 43 kraških uval. Vsi vzorčni primeri so navedeni v preglednici 5.1.

Vsak primer je opisan ločeno, vključene pa so tako glavne značilnosti kot tudi položaj v okviru širše morfološke enote. Žal so območja, kjer se nahajajo uvale, zelo redko obravnavana v geomorfološki literaturi, ki je na voljo. Pomanjkanje objavljenih referenc je v nekaterih primerih oviralo ustrezno geomorfološko oznako lokacije. Kadar je bilo le možno, smo se odločili za obširen pregled, vključno s približno razlago morfo-stratigrafije območja (podobno kot Sauro, 2002). V primerih, kjer predhodnih študij ni, celotne geomorfološke študije območja ni bilo mogoče izvesti, zato smo zapisali le nekaj splošnih zamisli o razvoju reliefov.

Morfometrični podatki so le tu in tam vključeni v preglede vzorčnih primerov, saj nismo želeli, da bi besedilo postalo preobsežno. Slikam digitalnih modelov reliefa smo dodali tudi vrednosti izbranih parametrov (Pc, Pd, Ac, Ad, HUV, HBAS), da si bralci lažje predstavljajo dimenzije uvale. Pri slikah DMR so najnižje točke uval označene s pikami roza barve, najvišja zaprta izohipsa je rdeča črta, modra črta pa predstavlja topografsko ločnico. Podrobnejši morfometrični podatki so vključeni v Prilogo 2, kjer so v preglednici navedeni vsi izmerjeni in izračunani parametri.

10.4. Zaključki

10.4.1. Splošne pripombe

Eden od osnovnih ciljev tega dela je bilo izbrati skupino kraških globeli, ki jih ni mogoče uvrstiti med vrtače ali polja, in ugotoviti, ali obstajajo trdni razlogi, na podlagi katerih bi jih lahko označili za kraške uvale - oblike kraških površinskih reliefov, ki se zaradi napačnih razlag njihovega razvoja vedno redkeje omenjajo.

Po analizi preučenih primerov je mogoče opaziti nekaj skupnih splošnih značilnosti: (a) globeli imajo interno drenažo (kraško, endoreično); (b) obsegi so v večini primerov nepravilnih oblik; (c) dimenzije tlorisov so različne in obsegajo od približno 1 km v krajši osi do več kilometrov vzdolž daljše osi, medtem ko je globina pod najvišjimi zaprtimi izohipsami najmanj 40-50 m, lahko pa tudi več kot 200 m; (d) nakloni pobočij so na splošno manjši kot pri vrtačah; (e) dna globeli so vedno nad nivojem kraške podtalnice; (f) v uvalah ponavadi ni vode; zelo redko pride do pojava majhnih sezonskih presihajočih potokov ali jezerc, ki so bolj izjema kot pravilo; (g) sedimenti na dnu so ponavadi redki, če pa so prisotni, nastanejo zaradi odvodnjavanja s pobočij; (h) ni nevarnosti, da bi nanos sedimenta, če je prisoten, popolnoma napolnil globel – drenažni sistem jo ščiti pred tem; (i) tovrstne globeli ne obstajajo na ravnih kraških površinah, ampak le na območjih z bolj ali manj razčlenjenim reliefom; (j) uvale v večini primerov nastanejo vzdolž tektonsko porušenih con na regionalni ravni.

10.4.2. Značilni primeri

Uvala je že v osnovi zelo kompleksna in nepravilna tako po velikosti kot tudi po obliki. Zato bi kot značilen primer zelo težko izbrati le eno lokacijo, poleg tega pa bi bilo to tudi metodološko nepravilno. V okviru skupine srednje velikih uval lahko kot značilna primera izpostavimo Jasenova Korita (ID_19) in Vagan Popinski (ID_22). Hrastov Dol (ID_3) ima značilne pogoje plitvega krasa, kar je na nek način razvidno iz njegovih dimenzij - veliko območje relativno majhne globine (najvišje razmerje Ac/HUV med vsemi preučenimi primeri). Med visokogorskimi uvalami (z dnom nad 1000 m nad. viš., ki so bile večinoma podvržene pleistocenski poledenitvi) najbolj izstopata Lomska Duliba (ID_6) in Dolovi (ID_40). Ker so ekstremni primeri v vzorcu uvale ogromnih dimenzij bolj izjeme, med njimi nismo izbrali nobenega določenega primera. Klekovačka Uvala (ID_27), Rupa (ID_24), Duboke Jasle (ID_14) in uvala Ljubodol (ID_31) imajo izstopajoče značilnosti in pravzaprav govorijo vsaka zase

10.4.3. Klasifikacija/-e

V objavljenih referencah, ki obravnavajo problem uval ali uvalam podobnih globeli, je nekaj poskusov klasifikacij, ki pa večinoma vključujejo tako genetske kot tudi modifikacijske dejavnike. Prevladovalo je mišljenje, da so se izrazito kraške uvale razvile iz združevanja vrtač, medtem ko v druge skupine sodijo tiste, na katere sta vplivala glacialni ali fluvialni proces. V poglavju 8. smo trdili, da je večina preučenih uval nastala na podlagi osnovnega kraškega procesa, ne zaradi združevanja vrtač, ampak zaradi močnega strukturnega vpliva. Kar zadeva učinek drugih geomorfoloških procesov – ti po našem mnenju ne morejo predstavljati kriterija za kakršno koli osnovno klasifikacijo, saj njihov vpliv ni bil bistvenega pomena za obstoj uval: dejavni so bili le v določenem segmentu razvoja uval (glacialni proces) ali pa predstavljajo le modifikacijski dejavnik (fluvialni proces, ki se nanaša na suhe doline).

Če bi želeli izdelati *strukturalno* klasifikacijo, bi lahko določili:

(1) enostavne uvale, ki so nastale vzdolž ene izrazite prelomnice (npr. Materića Uvala, ID_25);

(2) sestavljene uvale, ki so nastale ob preseku dveh ali več porušenih con (npr. Mrzli Log, ID_2);

(3) uvale s sinklinalno strukturo kot vodilnim elementom (npr. Dolovi, ID_40);
(4) uvale brez izrazite strukturne smernice (npr. Hrastov Dol, ID_3).

Če so merilo *hidrogeološki* pogoji, potem lahko govorimo o naslednjih treh skrajnih primerih: (1) uvale z globoko vadozno cono s praktično neomejenimi možnostmi navpičnega razvoja (npr. Lomska Duliba, ID_6, s skoraj 1300 m globoko vadozno cono);
(2) uvale z lokalnimi vododržnimi plastmi, ki povzročajo nizek lokalni nivo podtalnice, s splošnim odvodnjavanjem v nižje, bolj oddaljene izvire (npr. Vagan Mazin, ID_21);
(3) uvale na plitvem krasu, kjer je regionalni nivo podtalnice blizu dna uvale in tako vpliva na njen značilni razvoj (širitev brez poglobitve) (npr. Hrastov Dol, ID_3).
Vendar pa so te klasifikacije omejene na določene ozke kriterije, medtem ko širokih, osnovnih kriterijev še ni mogoče opredeliti. Problem klasifikacije mora ostati odprt, dokler ne obdelamo in primerjamo več vzorcev ali dokler neka nova odkritja ne omogočijo osnove za splošno genetsko klasifikacijo, kot je to v primeru vrtač.

10.4.4. Proti novi definiciji

Uvale so velike (v km merilu) zaprte kraške globeli s podaljšanim ali nepravilnim tlorisom. Njihova dna so valovita ali posejana z vrtačami, le redko so izravnana z nanosom koluvialnih sedimentov. Uvale se vedno nahajajo nad nivojem kraške podtalnice. Na izvor in razvoj močno vpliva tektonika.
S to precej grobo definicijo in s samo študijo želimo preprečiti, da bi izraz uvala popolnoma izginil iz krasoslovja. Cikličnega koncepta vrtača-uvala-polje (v smislu Cvijića, 1900) ne moremo sprejeti. Izraz uvala je treba izključiti iz takšnih kontekstov, ker izkrivljajo njegov pravi pomen. Naš pogled je še najbližji Poljakovemu (1951). Čeprav je Šušteršič (1986) pripomnil, da je Poljakova vrsta uval »kaplja v poplavi drugačnih«, se zdi, da so številnejše, kot bi pričakovali, in da izraz lahko razjasnimo, če uvale prenehamo zamenjevati z drugimi oblikami (npr. slepimi dolinami).
Čeprav nismo dosegli nobenega končnega odgovora, smo vprašanje v teoriji in na terenu preučili do neke točke in ga nato prepustili krasoslovni skupnosti. Vsi segmenti so odprti za razpravo, ki ni le pričakovana, ampak nujna.

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APPENDIX 1

.kmz files for use with Google Earth

APPENDIX 2

The complete dataset of morphometrical parameters

ID	Pc (m)	Ac (km^2)	DMAXc (m)	DMNRc (m)	Pd (m)	Ad (km^2)	DMAXd (m)	DMNRd (m)	DDIRd (0-180)	V (Mm^3)	Emin (m)	Ec (m)	HUV (m)	Emaxd (m)	HBAS (m)	CEQUd (km)	ISINd	CEQUc (km)	ISINc	VDVP	RP/R	DIDEc (m)	DIDEd (m)	RH/Dc	RH/Dd	ELONGc	ELONGd	DAVEc (m)	DAVEd (m)	HVOL
1	2842	0.33	962	590	6080	2.09	2190	1440	14	8.93	880.0	930	50	1176	296	5.12	1.19	2.04	1.39	1.62	8.76	649	1631	0.06	0.16	1.63	1.52	776	1815	27.00
2	5830	0.75	1630	1020	8040	2.84	3030	1790	144	26.57	768.0	840	72	1069	301	5.97	1.35	3.07	1.90	1.47	11.92	979	1902	0.05	0.12	1.60	1.69	1325	2410	35.33
3	9841	2.92	3130	1660	11000	7.72	4110	2540	158	76.39	287.5	335	47.5	545	258	9.85	1.12	6.05	1.63	1.66	10.22	1927	3135	0.02	0.08	1.89	1.62	2395	3325	26.21
4	4433	0.74	1310	949	6610	2.50	2540	1270	167	14.89	740.0	790	50	1022	282	5.60	1.18	3.05	1.45	1.20	9.12	972	1784	0.04	0.15	1.38	2.00	1130	1905	20.08
5	7996	1.59	2000	1350	12100	5.31	3420	3340	151	79.74	1120.0	1220	100	1694	574	8.17	1.48	4.48	1.79	1.50	11.22	1425	2600	0.06	0.17	1.48	1.02	1675	3380	50.02
6	6835	1.17	2720	564	9980	5.44	3300	2230	125	40.33	1230.0	1310	80	1667	437	8.27	1.21	3.83	1.79	1.30	11.22	1218	2632	0.05	0.16	4.82	1.48	1642	2765	34.60
7	2187	0.26	718	620	11100	3.68	3560	1510	162	4.34	1260.0	1290	30	1565	305	6.80	1.63	1.82	1.20	1.64	7.53	581	2165	0.04	0.12	1.16	2.36	669	2535	16.39
8	4727	0.75	1970	544	10200	4.90	3690	2280	139	28.66	1215.0	1320	105	1605	390	7.85	1.30	3.08	1.54	1.09	9.66	979	2498	0.08	0.13	3.62	1.62	1257	2985	38.08
9	4957	0.75	1820	756	5990	1.84	2440	1000	145	23.84	820.0	900	80	1102	282	4.81	1.25	3.08	1.61	1.18	10.11	980	1531	0.06	0.16	2.41	2.44	1288	1720	31.57
10	6627	2.14	2710	1100	10300	5.49	3780	2170	90	198.85	655.0	840	185	1274	619	8.31	1.24	5.19	1.28	1.51	8.03	1651	2644	0.10	0.21	2.46	1.74	1905	2975	92.89
11	2653	0.45	957	731	5640	1.85	1970	1330	125	16.23	705.0	770	65	1160	455	4.82	1.17	2.37	1.12	1.68	7.03	754	1535	0.08	0.28	1.31	1.48	844	1650	36.30
12	4589	0.55	1360	631	6770	2.59	2600	1180	111	14.13	715.0	770	55	1126	411	5.70	1.19	2.62	1.75	1.41	11.01	833	1816	0.06	0.22	2.16	2.20	996	1890	25.90
13	3943	0.61	1460	762	9660	4.65	3270	2080	114	22.49	585.0	650	65	1130	545	7.64	1.26	2.78	1.42	1.69	8.92	884	2433	0.06	0.20	1.92	1.57	1111	2675	36.65
14	17309	6.07	5970	1730	17300	13.10	6920	2880	104	524.32	645.0	850	205	1198	553	12.83	1.35	8.73	1.98	1.26	12.45	2780	4084	0.05	0.11	3.45	2.40	3850	4900	86.37
15	6739	1.89	2160	1580	12100	8.38	4190	2690	154	130.95	520.0	670	150	1187	667	10.26	1.18	4.87	1.38	1.39	8.69	1551	3266	0.08	0.19	1.37	1.56	1870	3440	69.29
16	10503	3.22	4110	1350	21300	24.30	8400	4820	108	122.71	515.0	600	85	1070	555	17.47	1.22	6.37	1.65	1.34	10.37	2026	5562	0.06	0.08	3.04	1.74	2730	6610	38.06
17	3368	0.50	1230	591	11100	7.26	4370	2270	129	5.06	770.0	800	30	1142	372	9.55	1.16	2.51	1.34	1.01	8.42	800	3040	0.03	0.11	2.08	1.93	911	3320	10.08
18	11498	1.77	2480	1390	14700	10.10	5340	2570	133	30.22	810.0	860	50	1252	442	11.27	1.30	4.72	2.44	1.02	15.30	1503	3586	0.03	0.11	1.78	2.08	1935	3955	17.04
19	7665	1.57	2220	1060	11700	7.51	3740	3210	148	30.95	735.0	790	55	1040	305	9.71	1.20	4.44	1.73	1.08	10.86	1412	3092	0.03	0.09	2.09	1.17	1640	3475	19.77
20	6125	1.03	1710	1020	11700	7.16	4200	2540	85	8.13	675.0	700	25	1163	488	9.49	1.23	3.60	1.70	0.94	10.68	1147	3019	0.02	0.14	1.68	1.65	1365	3370	7.87
21	4943	1.09	1920	776	6920	3.10	2520	1730	179	50.28	735.0	820	85	1207	472	6.24	1.11	3.70	1.34	1.63	8.40	1177	1987	0.06	0.22	2.47	1.46	1348	2125	46.23
22	6380	1.73	2100	1740	8790	4.76	3300	2260	141	48.03	620.0	680	60	984	364	7.73	1.14	4.67	1.37	1.39	8.59	1485	2462	0.03	0.13	1.21	1.46	1920	2780	27.73
23	8197	1.81	3660	656	13900	11.10	5470	2630	117	41.45	345.0	395	50	868	523	11.81	1.18	4.77	1.72	1.37	10.79	1520	3759	0.02	0.13	5.58	2.08	2158	4050	22.85
24	11835	5.17	4040	1890	16100	11.40	4900	3290	41	407.34	935.0	1140	205	1480	545	11.97	1.35	8.06	1.47	1.15	9.23	2565	3810	0.07	0.13	2.14	1.49	2965	4095	78.81
25	6376	1.67	2910	804	11000	8.01	4140	2340	143	92.30	945.0	1070	125	1707	762	10.03	1.10	4.58	1.39	1.33	8.75	1457	3194	0.07	0.24	3.62	1.77	1857	3240	55.36
26	6644	1.87	2440	1240	18200	17.70	7770	3540	143	45.67	740.0	800	60	1300	560	14.91	1.22	4.84	1.37	1.22	8.62	1542	4747	0.03	0.10	1.97	2.19	1840	5655	24.46
27	21319	11.35	6120	3300	24800	38.90	9830	5980	130	1053.27	865.0	1080	215	1870	1005	22.11	1.12	11.94	1.79	1.30	11.22	3801	7038	0.05	0.13	1.85	1.64	4710	7905	92.81
28	8843	1.80	2940	1400	14500	12.50	5930	2770	19	56.83	1460.0	1560	100	1830	370	12.53	1.16	4.76	1.86	0.95	11.67	1515	3989	0.05	0.09	2.10	2.14	2170	4350	31.51
29	8885	3.51	2890	1990	22400	30.30	9060	5530	142	168.81	895.0	1010	115	1720	825	19.51	1.15	6.64	1.34	1.25	8.40	2115	6211	0.05	0.11	1.45	1.64	2440	7295	48.07
30	4938	0.95	1530	878	7250	2.98	2800	1560	101	35.56	1510.0	1600	90	2006	496	6.12	1.18	3.45	1.43	1.25	8.99	1099	1948	0.07	0.23	1.74	1.79	1204	2180	37.52
31	15754	5.03	3440	2920	15500	14.50	5360	4280	149	277.83	1090.0	1260	170	1798	708	13.50	1.15	7.95	1.98	0.97	12.45	2531	4297	0.05	0.15	1.18	1.25	3180	4820	55.24
32	4702	0.66	1440	891	9350	4.26	3170	2140	65	11.53	1030.0	1070	40	1367	337	7.32	1.28	2.89	1.63	1.30	10.22	920	2329	0.03	0.13	1.62	1.48	1166	2655	17.35
33	10955	2.25	3860	976	10600	6.24	4330	1890	128	93.13	975.0	1090	115	1246	271	8.86	1.20	5.32	2.06	1.08	12.93	1694	2819	0.05	0.09	3.95	2.29	2418	3110	41.30
34	11728	1.94	2270	1280	12200	6.84	3800	2940	126	36.98	765.0	810	45	991	226	9.27	1.32	4.94	2.38	1.27	14.93	1571	2951	0.03	0.07	1.77	1.29	1775	3370	19.07
35	6778	1.26	2140	869	13700	11.30	5120	2590	169	21.10	665.0	710	45	1184	519	11.92	1.15	3.98	1.70	1.11	10.69	1268	3793	0.03	0.13	2.46	1.98	1505	3855	16.72
36	17072	3.60	2960	2330	12700	10.40	4120	3310	54	160.69	865.0	980	115	1140	275	11.43	1.11	6.73	2.54	1.16	15.95	2141	3639	0.04	0.07	1.27	1.24	2645	3715	44.62
37	14127	3.31	2850	1890	12700	10.80	4520	3470	126	134.33	785.0	880	95	1123	338	11.65	1.09	6.45	2.19	1.28	13.76	2053	3708	0.04	0.08	1.51	1.30	2370	3995	40.59
38	4264	0.51	1340	738	6980	2.59	2450	1750	122	17.21	805.0	890	85	1139	334	5.70	1.22	2.52	1.69	1.20	10.61	803	1816	0.08	0.16	1.82	1.40	1039	2100	33.95
39	8070	0.77	1650	712	7680	4.16	2600	2150	5	21.85	715.0	800	85	1102	387	7.23	1.06	3.12	2.59	1.00	16.26	993	2301	0.07	0.16	2.32	1.21	1181	2375	28.23
40	4761	0.77	1310	1070	7360	3.15	2890	1440	152	18.25	1255.0	1300	45	1604	349	6.29	1.17	3.11	1.53	1.58	9.61	991	2003	0.04	0.16	1.22	2.01	1190	2165	23.67
41	7565	0.50	1680	1050	15900	14.40	5430	4450	61	3.52	750.0	770	20	940	190	13.45	1.18	2.51	3.02	1.06	18.97	797	4282	0.01	0.04	1.60	1.22	1365	4940	7.04
42	5629	0.81	1820	1030	9940	6.32	3730	2490	127	17.48	725.0	800	75	1100	375	8.91	1.12	3.18	1.77	0.87	11.12	1013	2837	0.05	0.12	1.77	1.50	1425	3110	21.70
43	5213	0.91	1870	792	10800	6.56	3940	2350	104	17.44	725.0	770	45	1011	286	9.08	1.19	3.39	1.54	1.27	9.66	1079	2890	0.03	0.09	2.36	1.68	1331	3145	19.07
mean	7806	1.92	2368	1191	11689	8.63	4285	2605	117	98.57	834	919	85	1277	443	9.70	1.21	4.47	1.72	1.28	10.78	1423	3088	0.05	0.14	2.15	1.69	1779	3445	36.13
median	6644	1.26	2100	1020	11000	6.56	3800	2350	127	35.56	768	840	75	1176	390	9.08	1.19	3.98	1.65	1.27	10.37	1268	2890	0.05	0.13	1.85	1.64	1640	3240	31.57
st.dev.	4264.42	2.0077	1179.54	616.402	4440.451	7.53	1823.36	1112.66	42.244	183.02	260.19	270.102	50.0465	310.923	171.83	3.8301	0.106	2.05	0.4046	0.2224	2.54	651.316	1219.16	0.0198	0.0513	0.9694	0.3653	828.919	1420.13	21.40
min	2187	0.26	718	544	5640	1.84	1970	1000	5.00	3.52	287.50	335	20	545	190	4.81	1.06	1.82	1.12	0.87	7.03	581	1531	0.01	0.04	1.16	1.02	669	1650	7.04
max	21319	11.35	6120	3300	24800	38.90	9830	5980	179	1053.27	1510	1600	215	2006	1005	22.11	1.63	11.94	3.02	1.69	18.97	3801	7038	0.10	0.28	5.58	2.44	4710	7905	92.89