COBISS: 1.01

NEW DATA ON THE DOLINES OF VELEBIT MOUNTAIN: AN EVALUATION OF THEIR SEDIMENTARY ARCHIVE POTENTIAL IN THE RECONSTRUCTION OF LANDSCAPE EVOLUTION

NOVI PODATKI Z VRTAČ VELEBITA: VREDNOTENJE USEDLINSKIH ARHIVSKIH MOŽNOSTI ZA REKONSTRUKCIJO RAZVOJA POVRŠJA

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Abstract UDC 551.435.82(497.5)

Christèle Ballut & Sanja Faivre: New data on the dolines of Velebit Mountain: An evaluation of their sedimentary archive potential in the reconstruction of landscape evolution

The first approach to the relationships between societies and physical environments on Velebit Mountain shows narrow correlations between spatial distribution of dolines, soil formation, hydric resources, vegetation and land occupation. In 2002, sediment cores have been obtained from different dolines of Velebit Mountain to evaluate the potential of their sedimentary archives in order to reconstruct the landscape history. On the littoral slopes and on the top parts of the mountain, the dolines were difficult to dig due to the presence of rocks in depth. Nevertheless, the cores have been sampled and soil analyses have been made (physical and chemical analyses: colour, grain size, pH, $CaCO_3$, C, N, P, K, Mg, CEC). No dating materials were found. The first results attest to rather homogeneous pedologic processes in each area studied (Kamenica, Stinica, Baške Oštarije and Bilensko Mirevo), but they also indicate colluvial contributions. These contributions differ from one doline to another according to their location and morphology. Dolines reveal themselves to be not very good traps, as the representative nature of their sedimentary archives could be very local. However, the best profile has been obtained at Bilensko Mirevo, which shows a change in the soil nutrient content from an impoverishment in its middle part toward an increase of the soil nutrients in recent parts. Those environmental changes could not be precisely dated, but could be correlated with the 17^{th} to 20^{th} century phase of strong human impact on the Velebit environment and with the rural depopulation observed since the second half of the 20^{th} century.

Keywords: karst, dolines, Mediterranean soils, Velebit Mountain, Dinarides, Croatia.

Izvleček UDK 551.435.82(497.5)

Christèle Ballut & Sanja Faivre: Novi podatki z vrtač Velebita: Vrednotenje usedlinskih arhivskih možnosti za rekonstrukcijo razvoja površja

Prvi pristop k razmerjem med družbo in naravnim okoljem na Velebitu kaže ozko korelacijo med prostorsko razporeditvijo vrtač, tvorbo prsti, vodnih virov, vegetacijo ter rabo tal. Leta 2002 so bila iz različnih vrtač Velebita vzeta jedra sedimenta, da bi ovrednotili možnosti usedlinskih arhivov za rekonstrukcijo razvoja površja. Na obmorskih pobočjih in na zgornjih območjih gorovja je bilo v vrtače težko kopati, saj so bila njihova dna zapolnjena s skalami. Vseeno so bila jedra izkopana in analize prsti narejene (fizikalne in kemične analize: barva, velikost zrn, pH, $CaCO_3$, C, N, P, K, Mg, CEC). Najdenega ni bilo nobenega gradiva za datiranje. Prvi rezultati potrjujejo razmeroma homogene pedološke procese v posameznih proučevanih območjih (Kamenica, Stinica, Baške Oštarije in Bilensko Mirevo), kažejo pa tudi na vpliv koluvialnih procesov. Ti vplivi se sicer razlikujejo med vrtačami glede na njihovo lokacijo in morfologijo. Vrtače se niso izkazale za dobro izbiro, ker je lahko reprezentativna narava usedlinskih arhivov precej lokalna. Najboljši profil je bil narejen pri Bilenskem Mirevem, ki kaže spremembo v vsebini nutrientov v prsti od osiromašenih prsti v sredinskem delu profila do porasta nutrientov v prsti v recentnih plasteh. Teh okoljskih sprememb se ne da natančno datirati, vendar se jih da povezati z obdobjem večjega človekovega vpliva na Velebitu med 17. in 20. stoletjem in z ruralno depopulacijo koncem druge polovice 20. stoletja.

Ključne besede: kras, vrtače, sredozemske prsti, Velebit, Dinaridi, Hrvaška.

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Received/Prejeto: 10.3.2011

INTRODUCTION

According to its climatic, vegetation, pedologic and ecological properties, Velebit is a typical Mediterranean mountain. It is formed in carbonates which have provided predisposition for the development of rich karstic relief. Owing to the lithological and structural differences, different human impacts, but also due to different climatologic conditions that interchange from colder to warmer periods, the Mediterranean mountains have experienced diverse evolutions (Salomon 2000).

As the soil in karst is sparse it can be found principally in karst depressions like dolines, uvalas and poljes, which represent traps for sediments. The most numerous such forms on Velebit Mt. are the dolines. They are karst landforms that are not only a result of karst dissolution, but also derive from other processes: pedogenetic processes, weathering, collapse, alluvial, aeolian, periglacial processes (Sauro 2003, 2004; Meneghel & Sauro 2006), and also from glacial processes on Velebit Mt. (Bognar *et al*. 1991; Bognar & Faivre 2006). Consequently, in many cases the sediment content at the bottom of the doline more or less masks the rock form.

The study of the Velebit Mt. dolines has started with the analyses of their main morphological properties (Faivre 1992, 1994), where the doline disposition, shape and size were related to the structural properties of the area. Furthermore, we have attempted to establish the connection between spatial distribution of dolines and recent deformations (Faivre & Bocquet 1999; Faivre & Reiffsteck 1999a, 1999b, 2002; Faivre 2000; Faivre & Pahernik 2007). The doline fills (soil) study, which was started in 2002, is a logical continuation of this work.

From prehistoric times, Velebit has been a mountain with a pastoral economy and the dolines (karst depressions) have been used for agrarian activity (Faber 1984, 1995a; Faber 2000). Therefore, we have tried in this work to estimate the potential of the sedimentary archives of Velebit Mt., localised in the dolines, seeking to reconstruct a longer socio-environmental history by relating geomorphological, climatic, pedological and environmental conditions.

The studies of soils in the dolines have been conducted by numerous authors (e.g. Lovrenčak 1977; Barany 1980; Magaldi & Sauro 1982; Bayonnette 1998; Hoyk 1999; Sauro *et al.* 2009). The question of whether the fills can constitute important records for the reconstruction of climatic-environmental evolution has also been raised recently by Sauro *et al.* (2009). Their results indicate that the dolines are "filters" for sediments rather than good traps, archiving only some of the climatic and environmental changes.

Detailed analyses of the soil on Velebit Mt. have started long ago. For example, soils from Senjska draga have been studied by Gračanin (1931). Bertović (1975) has presented relations between plant communities and pedosystematic units of soil in the frame of the ecological-vegetational study of the Zavižan area. Systematic investigations of the larger area soil properties were primarily related to the creation of the Main Pedological Map on the scale 1: 50 000, Senj 1 (Vranković 1973) and Senj 3 (Vranković 1974). More recent soil investigations of the Štirovača area have been made by Vrbek & Pilaš in 2007. Red soils on Velebit Mt. have been also studied by Urushibara (1976, 1981) in the broader study frame, while general aspects have been presented by numerous authors (e.g. Rogić 1958; Perica *et al*. 2002a).

STUDY AREA - GEOMORPHOLOGICAL AND ENVIRONMENTAL PROPERTIES

Velebit Mountain extends along the Adriatic coast in a NW–SE direction (Fig. 1). It is the longest mountain of the Dinarides mountainous system and of the Republic of Croatia. Velebit Mt. is characterised by anticlinal folding and high degree fracturing. In its different parts they differ in strike, in their inter-relations and in the degree of fracturing. Consequently, three major zones can be distinguished in the structural sense: north Velebit with Senjsko bilo, and central and south Velebit.

Velebit Mt. is mainly constituted of Mesozoic carbonate sequences, from Triassic to Upper Cretaceous, upon which synorogenetic calcareous Jelar breccia can be found, particularly on the littoral side. The whole succession ranges from Middle Permian to Quaternary deposits. The impermeable layers outcrop on central and south Velebit. The significant prevalence of carbonate rocks (limestones and, to a lesser extent, dolomites), which are strongly broken up by tectonic movements, enables the formation of typical karstic relief.

The littoral slope of the Velebit Mt. reveals its bulky character. It is represented by a huge area of rocky karst. Generally, the littoral slope has a particular step-like morphology. After the steep littoral area of about 100 m high, the first levelled surface appears at 100 to 300 m above sea level. After the steep rise, there is another more or less levelled surface at 700–900 metres a.s.l. This shallow depression is composed of a series of karstic uvalas, some of which have merged together into big ones with large flat bottoms. The genesis of both levelled surfaces is still under debate (Bognar 1992, 2006; Prelogović 1995).

The top parts of Velebit Mt. are characterised by numerous particularly deep karstic forms due to strong tectonic influence, long-lasting karstification as well as to past glacial processes. Well-preserved moraine material has been found at the top parts of the mountain, as well as fluvioglacial sediments on its lower parts (Bognar *et al.* 1991; Bognar *et al.* 1997; Bočić *et al.* 2008; Bočić *et al* in press). At present, together with the karstic processes, periglacial and nival processes (Perica *et al.* 2002a) strongly influence relief development.

Velebit is poor with water, but the foot of the NE slope is characterised by frequent springs. Their appearance is the consequence of the complete hydrological barrier of Velebit Mt. The water flows up to the contact with a broken carbonate base, where it sinks and then flows below the surface towards the sea and towards the Zrmanja River (Biondić 1981). The carbonate base, tectonically broken up, results in rivers being rare. The surface flows are linked with the poljes that occupy a large area at the foot of the inland Velebit slope.

Numerous factors influence the development of pedological cover. On Velebit Mt. those are climatological, lithological, geomorphological, vegetational and, in more recent times, zoogenic and anthropogenic factors (Perica *et al.* 2002b). In the upper parts of the mountain, above 900 m, the rendzina and calcomelanosol dominate. Calcocambisol and litosol are often found on the SW slope of the mountain, particularly in its lower parts.

Terra rossa is widespread at low altitude, but rarely continuous (Urushibara 1981). In most cases, *terra rossa* has polygenetic origin and was formed by mixing of insoluble residue of carbonate rocks with other weathered and eroded sediments (Durn 1996; Durn *et al.* 1999). The thickness of the *terra rossa* deposits depends on its position with respect to the relief (Benac & Durn 1997). At the same time, *terra rossa* is a paleosoil, a residual soil and a very old and very eroded soil. It can be totally uncarbonated (Nicod 2003b).

As karst processes operate in the atmosphere-soil-epikarst system (Barany Kevei 1993, 1995; Pfeffer 1995), the climatological properties are very important. Velebit Mt. represents a barrier that does not allow mixing of the lowest air masses on both slopes up to 1,000 m altitude. The lowest part of the sea side slope has an average temperature around 15°C and the inland area around 8.8°C. The relief influence becomes distinct in the amount of precipitations. Even if the lowest parts on the sea side receive around 1,100 mm of precipitations per year, the summer months are dry (⅓ of yearly precipitation is in the warmer part of the year). The amount of precipitations grows with altitude so that precipitation stands at over 2,000 mm per year above 900 m, with more uniform distribution (Perica & Orešić 1997).

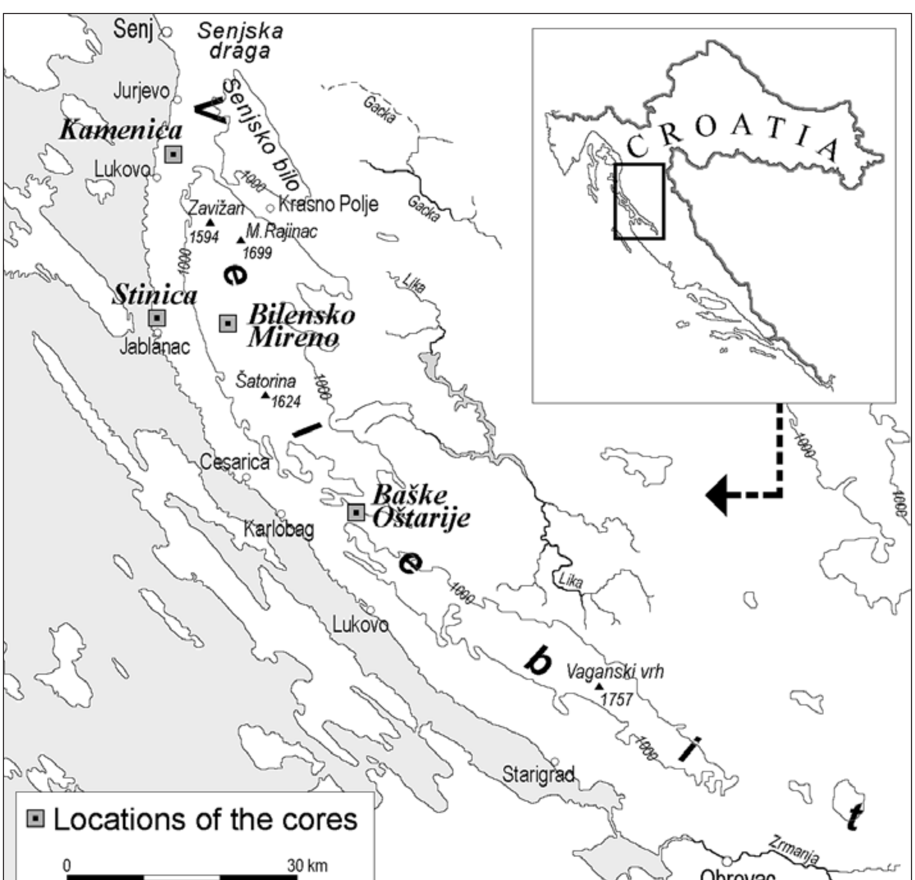

Fig. 1: Study area.

The soil and climatic properties reflect that of the vegetation, which succession is classic for the Mediterranean mountains (Horvat 1949). On the littoral side, forest cover is significantly degraded and is completely degraded to pastures in some areas, what can be partly explained by the economic activities that have occurred in the area (Rogić 1958).

The natural properties of Velebit Mt. did not provide predispositions for considerable settlement. However, archaeological findings point to the existence of numerous prehistorical (Mesolithic to Iron Age) settlements on the littoral Velebit side (Glavičić 1995). The existence of coastal settlements in Roman times is known from the Tabula Peutingeriana, Ptolemai map (Marković 1993; Kozličić 1995) and archaeological findings (Zaninović 1980; Nedved 1995; Fadić 1995; Gluščević 1995). All the Roman settlements were located at the foot of the mountain passes, which allowed communication with the inland.

The absence of cartographic documentation and sources make the geographical reconstruction for this early period very difficult but the relatively slow degradation of the landscape during the 18th century indicates that the littoral slope was most probably already denuded before the 16th century. The number of inhabitants on the Velebit littoral slope during the 14th and 15th centuries cannot be estimated, even roughly. Nevertheless, various documents confirm the small number of sedentary population. The local community lived from agriculture, but cattle breeding were the basis of the economy (Rogić 1958). In the second half of the 15th century, the invasion by the Turks in Lika and north Dalmatia result in almost complete depopulation of the littoral slope. Later, at the end of the 17th century, there were around 2,000–2,500 inhabitants in the northern part and 1,205 in the southern part of the Velebit littoral slope (Rogić 1958).

The continuity of settlement on the Velebit littoral slope can be followed from the end of the 17th century. Some well-conserved Venetian cadastral maps of the area (Disegno delle ville di Starigard di Zara 1709; Rubriche delle ville del Contado Superiore di Zara 1709), published in 1709, show that the landscape was generally similar to the present-day one. Those maps also show that the settlements were located on the first levelled surface and confirm the existence of the summer habitats on the upper levels of the Mountain (Rogić 1958). The basis of the economy was still cattle breeding. In the 18th century, the number of inhabitants increased along with the number of cattle, which generated the problem of exhaustion of pastures that first appeared on the lower part of the Velebit littoral slope. From the beginning of the 18th century till the year 1850, the number of inhabitants on the southern littoral slope had quadrupled from 1,205 to 4,194. The number of cattle increased at the same time as well, which directly influenced the degradation of the landscape. At the end of the 18th century, the settlements were finally stabilised, so that the population reached 8,400 inhabitants by the mid-19th century, which resulted in general poverty and a more intensively degraded landscape.

In 1850, the population rose to 12,600 inhabitants (Rogić 1958). In the period between 1850 and 1955, the settlements on the Velebit littoral slope were still very small. Most of them (86%) were located at the contact zone between the first levelled surface with a steep slope, since the littoral zone is not attractive for agricultural and farming communities. This area with local Promina conglomerates and Pleistocene marls (Rogić 1958) allows the existence of ponds, which give water for cattle and provide small depressions suitable for agriculture. The uvalas of the upper levelled surface are much less inhabited, even though there is more arable land at this level – 46% compared to 39% at the lower level. 15% of the arable land can be also found in the high mountainous zone dispersed in the wood clearings of North Velebit.

The majority of the agricultural land-owners from the lower levelled surface – 67% – had their properties composed of several parcels at the lower levelled surface, a larger arable part at the upper uvalas, and several isolated fields at the upper mountainous level (Rogić 1958). This kind of dispersed land property resulted in periodical settlement. Such vertical control of space allowed acquisition of enough land for survival and production of different crops: cereals at the lower levelled surface, cereals and potatoes on the upper uvalas and potatoes up to 900 m altitude.

In the first half of the 19th century, the number of inhabitants and cattle greatly increased. As the value of pasture-land was generally very low and as the number of inhabitants became too high for this karstic area so, the degradation of pastures occurred in the second half of the 19th century. From the regular census in the second half of the 19th century, it can be observed that the population constantly grew till the 1910's, followed by regression till 1948 with a small increase in the 1948–1953 period. Later, in the second half of the 20th century, depopulation followed; the agrarian activity decreased and reforestation began (Rogić 1958).

Beginning in the Neolithic age and recurring regularly, deforestation resulted in the baring of the soil cover, soil erosion by flowing water, its infiltration into the endokarst and baring of rundkarren. Deforestation principally occurred during the 17th–19th centuries (Fürst–Bjeliš *et al*. 2001; Fürst-Bjeliš & Lozić 2006) while clearing in the mountain areas was carried out later, in the 18th and 19th centuries, by burning the land and managing the dolines.

This karstic environment has had a direct influence on the type of settlement and on the particular agrarian structure of the area. During the historical evolution, the topographical surface was modified with the aim to obtain arable land. This was achieved in various ways: by clearing out stones and creating stony piles in parcels, by creating terraces for cultivation, filling up the doline bottoms, or even arranging more open fields in the areas of open karst (Nicod 2003b). The removed stones were often used for the construction of dry walls, which were built for many different purposes: delimitation of transhumance paths, enclosure of wooded areas, as enclosures for domestic animals, for enclosure (protection) of the land parcels, and stone walls terraces and plantation squares (Faber 1984; Nicod 2003a; Aničić & Perica 2003; Aničić *et al.* 2004).

Small karstic depressions, mainly dolines, have therefore resulted in various human modifications. One of the basic landscape and cultural elements in the Velebit area are the small dolines bordered with dry stone walls, some of which have been analysed in this paper.

METHODS

On the 3,000 km^2 of the larger Velebit Mt. area, there are around ~40,000 dolines (Faivre 2000). As the ecological properties differ along the mountain, we have chosen dolines on the littoral slope at between 30–300 m altitude, and dolines on the top parts of the mountain at between 900 and 1,300 m altitude. According to the aims of this study, we have also selected dolines which were or still are under anthropogenic influences. From the study of the dolines, many different types of forms can be distinguished resulting from different genetical mechanisms (Sauro 2003). The dolines along the coast (Stinica and Kamenica), are classical corrosional dolines, which appear singly and are rare, while the dolines sampled in the upper parts (Baške Oštarije and Bilensko Mirevo) are located at the bottom of large uvalas and poljes and represent parts of doline fields whose morphogenesis is also related to glacial, periglacial and alluvial processes.

Cores and sediment observations have been carried out in 15 dolines with a soil auger: 1 core at Kamenica, 3 cores at Stinica, 7 cores at Baške Oštarije, 4 cores at Bilensko Mirevo and two doline interspaces (1 at Baške Oštarije and 1 at Bilensko Mirevo). Usually, most of the dolines studied are shallow, but the compaction of the sediment and/or the presence of rocks in depth were a problem for digging through the fill. Consequently, we cannot be sure if the complete stratigraphies of the dolines have been obtained. The soils have been described during the field investigation, specifying: depth, thickness, main macroscopic characteristics of the horizons as well as the vegetation cover. Then, each layer has been sampled to find differences in soil properties related to parent material or environmental evolution (colluvial contributions in particular). Sediment analyses in the laboratory have been made on the more representative and deepest ones: six dolines localised on the top (4 at Baške Oštarije and 2 at Bilensko Mirevo) and two dolines in the lower part near the coast (1 at Kamenica and 1 at Stinica) (Fig. 1). As a whole, the sedimentary fills of 8 dolines have been analysed in more detail and 2 doline inter-spaces. Physical and chemical analyses were done (colour, grain size, pH, $CaCO_3$, C, N, P, K, Mg, CEC). Colours have been determined on dry soils using standard soil colour charts (Munsell Soils Color Charts 1994). Particles size analyses have been determined with a laser granulometer (LS 350, Beckman Coulter), after organic matter destruction and prior sodium pyrophosphat dispersion of the clay particles. The pH (water) was obtained according to the French norms (NF) ISO 10390. Calcium carbonates content was determined by hydrochloric acid (HCl) using a calcimeter of Bernard (NF ISO 10693). The proportion of carbon and nitrogen was determined after dry combustion (NF ISO 10694 and ISO 13878). The phosphorus rate was analysed by spectrocolorimetry (Joret & Hebert 1955), the rates of potassium and magnesium by an extraction with ammonium acetate (Thomas 1982) and the cation exchange capacity (CEC) by the Metson method (Metson 1956). No paleoecological remains and good material for radiocarbon dating have been found.

RESULTS

THE DOLINES LOCATED NEAR THE COAST

There are almost no dolines on the littoral side of the mountain as it is characterised by the lack of vegetation and the lack of water. Nicod (1967) has demonstrated on the karst of Provence that dolines do not develop on rocky karst because there is no soil and no vegetation. On the lower part of the slope, some rare small shallow pen-shaped dolines can be observed, 5–10 m deep, which indicates their feeble vertical development.

Among the rare and isolated dolines, two sites, Kamenica at 280 m and Stinica 30 m above sea level, have been selected for this study. Both dolines have been formed on the Palaeogene calcareous breccias, that is, on Jelar deposits (Mamužić *et al.* 1969).

A) Kamenica

Kamenica is positioned on the foot slope. It is formed slightly above the lower levelled surface (Fig. 2). Kamenica is ~1.5 km far from the sea and it is at 280 m above sea level. It is like a small uvala around 100 m wide with dolines, in which small settlements with only several houses can be found.

After a few tests, the best core is obtained from the edge of Kamenica (Kamenica 1). It was only 25 cm long (stopped by rock). The analyses showed a brown clear (7.5YR4/4) clayey soil (clay: 60%, fine loam: 27%), with a grumous to polyhedral structure. The soil is decalcified. The pH is not very high in comparison with other context, but the nutrient elements are well-represented (Tab. 1). The sedimentary sequence is shallow and does not allow efficient observations of environmental dynamics.

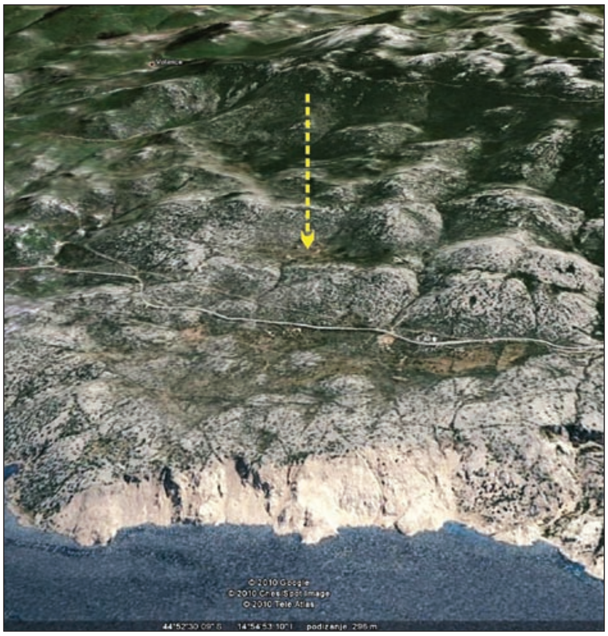

Fig. 2: Kamenica doline (Google Earth).

B) Stinica

Stinica is quite large; it is more than 100 m in diameter and is 70 m deep. It is located near the sea, less than 100 m away (Fig. 3). Today, Stinica is characterised by cultivated terraces around the doline. According to its size and position, Stinica has surely had a long-lasting evolution. According to inscriptions from Antiquity the main trail probably started near Stinica close to the seashore, as a several kilometres long boundary wall starts right there and continues on towards the upper Velebit area. Another Roman inscription found near this wall speaks about an agreement, probably referring to grazing boundaries between the Ortoplins (Illyrian tribe from today's Stinica) and the neighbouring Begos tribe (Faber 1984). Thus, this doline was probably used long ago, since cattle-breeding developed together with land cultivation in prehistoric times (Faber 1984, 1995a, 1995b).

Fig. 3: Stinica doline (yellow arrow) and Bay of M. Stinica (green arrow) – today submerged doline.

One core at the bottom and two cores on the first terrace have been made. Most of the time, the calcareous fragments were too numerous to dig after 20 or 30 cm of depth. At the bottom, as on the first terrace (Stinica 1), the soil is brown on the surface (3 cm of humiferous horizon) and reddish (5YR4/6) at depth (Tab. 1). The sediment has the same characteristics everywhere. It is very clayey (74%) with a small proportion of fine loam (17–18%). It presents the finest texture we observed. It has a polyhedral to grumous structure. The sediment is decalcified. The organic matter and the proportion of nutrients is higher on the surface (N, Mg and K) (Tab. 1).

It contains numerous angular calcareous fragments (1 to 2 cm in diameter on average) that attest to colluvial contribution.

Another similar doline has been observed southwestwards from the Stinica doline, the former being submerged today as a consequence of glacioeustatic changes and tectonic movements during the Holocene (Fig. 3).

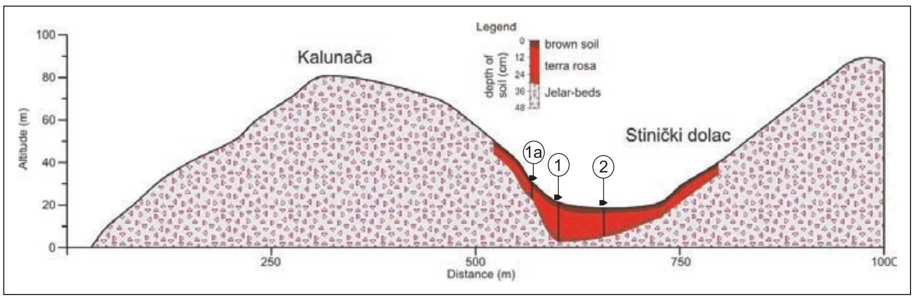

Fig. 4: The cross section of the Stinica doline with sampling locations.

THE DOLINES LOCATED ON THE TOP OF THE MOUNTAIN

Dolines can appear singly, as was the case on the littoral slope, but they usually appear at the top parts of the mountain as doline fields, where the density highly increases and reaches till 121 dolines per km^2. Two major locations have been chosen: the polje of Baške Oštarije and the uvala of Bilensko Mirevo (Figs. 5 & 6). The Baške Oštarije polje is an area of contact karst developed on the boundary between more and less permeable rocks; accordingly, considered as marginal karst polje (Gams 1978; Perica *et al.* 2002b). The second location at Bilensko Mirevo is an ancient terminal basin with numerous small dolines.

A) Baške Oštarije

The Baške Oštarije pass (at 928 m altitude), situated on the main road which crosses Velebit Mt., corresponds to the most narrow part of the mountain. Along the transversal fault of Brušane, the Triasic dolomites are in contact with Permian – Werfenian sediments. The small Baške-Oštarije polje has developed along this contact zone (Perica & Buzjak 2001). The polje stretches out in an E–W direction; it is 3.75 km long and its width varies from 0.25 to 2.0 km. Together with the Suvaja Valley, it divides the central from the southern part of Velebit Mt. Besides karst and fluvio-karst, the derasion and periglacial processes have been mostly expressed in the relief formation of the area (Perica *et al.* 2002b).

Clastic-carbonate deposits of the Middle-Upper Triassic (Ladinian-Norian) period crop out in the area of Prpići at Baške Oštarije. The underlying deposits of Anisian age are palaeokarstified floatstones and rudstones, with interbeds of dark peloid–ooid packstone–wackestones with stromatolitic laminae (Sokač *et al.* 1974; Velić *et al.* 2006). In the area of microtectonically fractured carbonates, which are found between three major faults, numerous dolines and sinks (swallow holes) have been formed. Dolines are also sporadically formed in alluvial sediments of the lowest part of the polje at around 900 m altitude and are partly filled with periglacial slope deposits.

The central position of this natural pass has had very high importance throughout history (Perica 1998). In the dolines of the Oštarijsko polje, the autochthonous forests have been destroyed by fire in order to obtain agricultural areas during the 18th and 19th centuries. As a consequence of the forest devastation and usually short-lasting rainfalls, strong surface erosion of pedogenetic horizon occurs. Therefore, rocky karst predominates today. Strong outwash is also indicated by continuous occurrence of ash particles in pedohorizons up to 2.2 m and colluvial soils at swallow holes (Fürst-Bjeliš *et al.* 2001).

The doline density at Baške Oštarije varies around 15 doline per km^2 (source topographical map 1: 25 000). Seven cores have been done at the Baške Oštarije area (Fig. 5). One core has been done between the dolines (BO3) in the relatively lower part of the basin. It shows 40 cm of a brown (7.5YR4/4) and silty-clay soil. The others have been obtained from the dolines. The most representative ones have been chosen for physical and chemical analyses. Several differences have been observed. The soils can be distributed in two groups: the dolines in relatively upper (BO2 and BO5) and in relatively lower position (BO1 and BO7) in the basin.

In the upper position, BO2 is a little doline (5 m in diameter). The core was 40 cm deep. The sediment is brown (7.5YR4/4), silty-clay (clay: 37–57% and fine loam: 34–35%), with a polyhedral structure. At the surface, the granulometry tends to be finer, and the organic matter and the nutrient contents are higher (CEC, P, Mg, N). In depth, the content in $CaCO_3$ increase in feeble proportion. BO5 is somewhat higher in elevation with 7 m diameter and is enclosed with a dry stone wall. The sediment is still brown (7.5YR4/4), silty-clay (clay: 38–40% and fine loam: 40–43%) with a polyhedral structure. The granulometry is nearly homogeneous along the first 40 cm of depth. The sediment is

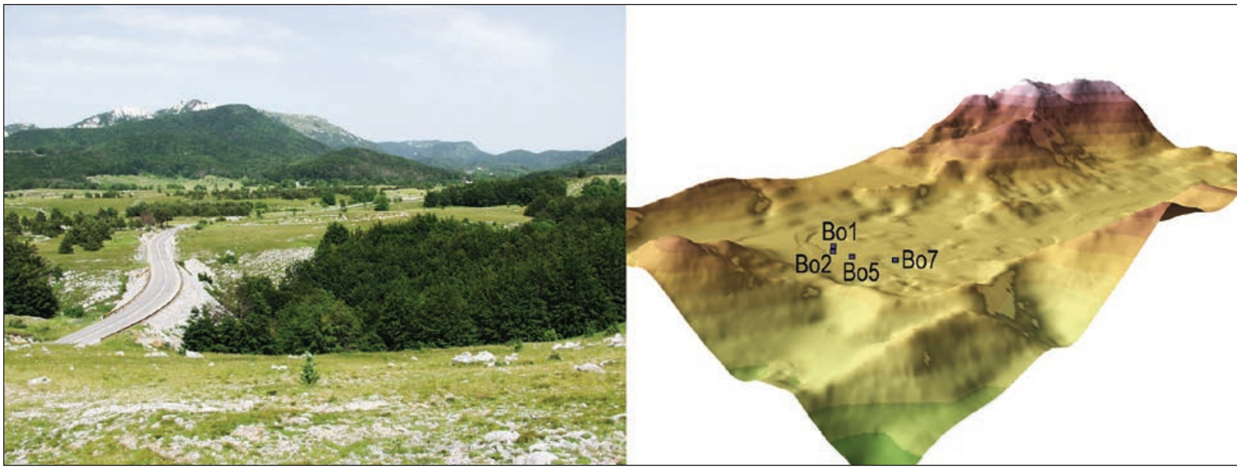

Fig. 5: Polje of Baške Oštarije with sampling locations (Photo: S. Faivre).

decalcified. The proportion of organic matter and soil nutrients is more important at the surface (CEC, P, K, Mg, N) as in BO2.

The dolines in relatively lower position present brown to brown-red soils (7.5YR4/4 to 7.5YR4/6 in particular in depth). The sediment is silty clay, always with a small quantity of sand (1.3 to 10,6%). It has a polyhedral structure. The pH is high and the $CaCO_3$ contents are higher than in BO2 and BO5. The BO1 (40 cm) core was made in a rectangular field not really in the lower part of Baške Oštarije, but just lower than BO2. In BO1, the sediment is small-sized (clay: 52–59% and fine loam: 29–34%) and richer in organic matter and nutrients in depth (CEC, K, Mg, N). The higher proportion of $CaCO_3$ at the surface could attest to colluvial contributions. In the BO7 (55 cm) core, the grain size (clay: 48–61% and fine loam: 27–35%) is finer and the nutrient content rises in depth. The finer grain size and the maximal cation exchange capacity - the organic matter, P, K, Mg, N, are in fact higher in the middle of the core (near 45–50 cm of depth). Up to this horizon, the soil shows impoverishment (as in BO1). We note that we have not sampled the surface of BO7, so the vertical evolution of the $CaCO_3$ content cannot be verified.

B) Bilensko Mirevo

During the Quaternary glacial phases, Velebit Mt. knows a cirque, plateaux and valley glaciers, which leave different types of moraines. Consequently, the glacio-karstic forms are beautifully developed all over the mountain. One particularly interesting site is the uvala of Bilensko Mirevo, which was a former terminal basin where the 4 km long Alan glacier melted. Relatively thick moraine material indicates several phases of Quaternary pulsations and the progressive retreat of the glacier tangs (Bognar *et al.* 1991). Such terminal moreinic volumes remodelled karstic heritage by the superpositioning of glacio-karstic and nivo-karstic morphologies as it is also the case e.g. in the Pyrenees (Auly 2007). Consequently, structural predisposition and karstic morphology and the extent of the thick cover of Pleistocene sediments here, together influenced pedogenetic phenomena.

Fig. 6: Dolines in glacial moraine deposits at Bilensko Mirevo (Photo: S. Faivre).

Middle Jurassic carbonate beds, mainly grey to dark grey thick layered and massive mudstones, with occasional scud of late digenetic coarse crystallised grey-brown dolomite (Sokač *et al.* 1974; Velić & Velić 2009), can be found below the moraine deposits.

Seepage through thick unconsolidated regolith or allogenic detritus over karst rocks generates suffusion depressions. Suffosion causes a dimpling of the surface with a multitude of small dolines at Milensko and

Tab. 1: Results of physical and chemical soil analyses.

Sample name	*Gauss–Krüger coordinates*	*Depth cm*	*< 2µm*	*2–20µm*	*20–50µm*	*50–200 µm*	*200–2000 µm*	*pH (water)*	*$CaCO_3$*	*CEC*	*P*	*Mg*	*K*	*C*	*Organic matter*	*N*	*C/N*
Kamenica	5493540 4969874	10–20	595	272	91	20	22	6,3	1	26.7	0.015	0.32	0.21	39.59	68.1	3.5	11.31
Stinica 1-1	5492145 4952617	10–20	736	170	60	25	9	7,5	2	28.6	0.008	0.27	0.27	33.29	57.3	2.96	11.25
Stinica 1-2		20–30	740	179	54	21	6	7,4	1	29.4	0.008	0.19	0.25	31.29	53.8	2.85	10.98
Baške Oštarije 1-1	5512191 4932066	15–20	522	295	105	66	12	8	101	21.6	0.016	1.42	0.21	35.76	61.5	2.56	13.97
Baške Oštarije 1-2		30–40	590	338	51	15	6	7,6	10	43.1	0.014	2.57	0.25	86.14	148.2	7.95	10.84
Baške Oštarije 2-1	5512147 4932028	10–20	570	342	65	16	7	7,7	10	34.4	0.008	2.18	0.17	65.25	112.2	6.01	10.86
Baške Oštarije 2-2		30–40	375	353	131	82	59	8	50	18.4	0.006	0.72	0.19	25.21	43.4	2.16	11.67
Baške Oštarije 5-1		10-–20	380	429	167	20	4	6,8	2	25.9	0.02	0.19	0.37	50.18	86.3	4.85	10.35
Baške Oštarije 5-2	5512139 4931852	30–40	397	406	174	17	6	7,1	2	25.5	0.015	0.1	0.16	42.63	73.3	4.2	10.15
Baške Oštarije 7-1	5512302 4931673	30–40	478	275	141	66	40	7,9	42	23.5	0.004	0.91	0.19	22.9	39.4	2.1	10.9
Baške Oštarije 7-2		45–50	606	338	43	12	1	8	80	25.7	0.012	2.16	0.41	26.51	45.6	2.38	11.14
Baške Oštarije 7-3		50–55	563	348	62	27	0	8,1	123	23.6	0.009	1.36	0.35	21.59	37.1	1.85	11.67
Bilensko Mirevo 1-1	5498418 4952237	10–20	393	418	164	20	5	7,3	2	22.1	0.008	0.18	0.12	31.56	54.3	3.19	9.89
Bilensko Mirevo 1-2		30–40	301	478	204	16	1	7,6	2	15.1	0.005	0.17	0.15	9.76	16.8	1.04	9.38
Bilensko Mirevo 1-3		45–50	305	453	219	22	1	7,6	1	15.7	0.007	0.15	0.15	12.5	21.5	1.28	9.77
Bilensko Mirevo 1-4		50–55	470	461	66	2	1	5,3	1	23.4	0.027	0.25	0.15	40.79	70.2	4.13	9.88
Bilensko Mirevo 1-5		60–70	491	438	66	4	1	5,7	1	24.3	0.024	0.18	0.14	40.12	69	4.08	9.83
Bilensko Mirevo 3-1	5498415 4952122	10–20	519	283	105	71	22	7,9	85	26.5	0.031	1.69	0.24	46.57	80.1	3.76	12.39
Bilensko Mirevo 3-2		30–40	505	284	102	60	49	8	21	20.6	0.003	0.76	0.16	18.54	31.9	1.69	10.97

* Grain size in ‰.
* $CaCO_3$, P, K, Mg, MOC, N, C/N in g/kg.
* CEC in cmol+/kg.

Dundović Mirevo (Fig. 6) as glacial till has been deposited into a well-developed karst floor, which sporadically outcrops in the upper parts of the uvalas.

The uvala of Bilensko Mirevo, situated at 1,350 m altitude, was intensively cultivated in the 19th century by seasonal inhabitants from the coast, who produced there almost all the needed food on the mountain during their stay. According to Faber (1984), the traces of small parcels from ancient times can be observed on the aerial pictures, testifying to the early anthropogenic impact on the area.

At Bilensko Mirevo, the doline density is around 11 dolines per km^2 (source topographical map 1: 25 000). The Bilensko Mirevo is a rather large uvala around 1.5 km long and 1 km wide. At Bilensko Mirevo, two suffosional dolines (BM1, BM3), and an inter-doline space (BM4) have been cored and sampled.

On the doline inter-space (BM4), the substratum has not outcropped. The space is used for agriculture and is included in a rectangular plot outlined by a dry stone wall. The soil is 20 cm deep (stopped by rock) (brown (7.5YR4/4), clayey and silty, with a polyhedral structure.

Physical and chemical analyses have been carried out at BM1 and BM3. BM1 is one of the biggest dolines of Bilensko Mirevo (25–30 m in diameter) and it is surrounded with a dry stone wall. The core obtained from BM1 is the longest one (stopped by rock; 70 cm deep). The sediment is brown (7.5YR4/4), silty clay loam (clay: 30–49%, fine loam, 42–48%, coarse silt 6–22%), with a polyhedral structure. Some calcareous fragments are characteristic all along the profile. $CaCO_3$ is nearly absent. Below 50 cm, the organic matter and the soil nutrients are higher (CEC, C, N, P, K, Mg), the grain size is finer, but the pH is lower (50–55 cm) (Tab. 1). We noticed that the surface (10–20 cm) became clayey and was also rich in nutrients. Between 50 and 20 cm of depth, the nutrients contents decrease. Two micro-charcoals have been observed near 15 cm and 48 cm of depth. They look like very small needles (less than 2 mm). They were probably brought about by colluviation and consequently have not been used for radiocarbon dating.

Fig. 7: Doline MB3 at the Milensko Mirevo (Photo: S. Faivre).

The BM3 doline is 6 m deep and 27 m in diameter (Fig. 7). The core was stopped at 40 cm by rock. The results of physical and chemical analyses differed from BM1. The sediment is more clayey (clay: 51%, fine loam, 28%). It also contains more sand, especially at depth. The sediment is not decalcified and shows an increase of $CaCO_3$ content on the surface. Over the 40 cm observed, the grain size was finer, the organic matter and the nutrient content were more important near the top of the soil (CEC, P, K, Mg), but the observed rates were higher than in BM1.

DISCUSSION

THE CLOSE CORRELATION BETWEEN GEOLOGICAL/GEOMORPHOLOGICAL STRUCTURE AND LAND OCCUPATION

Exposed geomorphological, geologic and geoecological properties, mutually interconnected, determine in a particular way the evolution of land occupation. As has been explained, dolines and uvalas have been particularly important location factors on Velebit Mt. from ancient times, that is, the spatial distribution of dolines directly influenced spatial distribution of settlements. The second important factor influencing settlement location is fresh water sources, defined by local geological properties, which can be found right along the first levelled surface (100–300 m) where the primary settlements are. But dry summer months, lack of water, thin soils in a small number of dolines, modest pastures and, therefore, scarcity of food, compel people to make use of the natural (geomorphologic) properties of the mountain, that is, to start the vertical control of the space. So people from the coast searched for additional land and found it on the next structural line (the second levelled surface at 700–900 m altitude), where uvalas are aligned. During summer, the same people occupied high mountain uvalas (which represent the third altitudinal level at around 1,300 m) with a great number of dolines due to the "accelerated corrosion" in central parts of the depressions and of structural blocks (Gams 2000; Faivre & Pahernik – 2007). These numerous dolines were particularly appropriate for agriculture and cattle breeding. The adaptation and exploitation of those natural properties of the area provided the predisposition for survival in the environment where living was always hard and where, according to a Croatian saying, "stones grow in the fields".

Velebit Mt. presents the types of land-use typical to Mediterranean countries that produce changes in the surface, e.g. deforestation and adaptation of karst surfaces for agriculture (Nicod 2003a; Gams 1991). Therefore, the doline also becomes an anthropogenic karstic form, because those anthropogenic impacts can be found in their soils such as are found in the case of Bilensko Mirevo and Baške Oštarije. The increased solution in the epikarst zone (Pahernik 1998; White 1988; Gams 2000; Ford & Williams 2007), together with appropriate climatologic properties in the upper parts of the Mountain, largely contribute to the accelerated corrosion that is also reflected in the length of the doline soil profiles of the area.

THE SEDIMENTARY ARCHIVES SIGNIFICANCE

Due to the bad conditions for coring and the absence of datable material, most of the results incline to be rather indicative. Nevertheless, answers to several questions have been documented. The most important one is the thickness of soil in the dolines and sometimes also in the doline interspace. Water content is more important when the soil is deep. Moreover, there is a domination of loamy clay texture classes, a high pH and good organic matter and nutrient content. So the dolines surely correspond to the best agricultural areas on this rocky mountain (the rock appear in surface outside the dolines). But many differences between the studied areas, and even between nearby dolines from the same doline field have been observed.

Furthermore, on the littoral side, the soils have a finer grain size and are decalcified, while the $CaCO_3$ content increases in several dolines on the upper part of Velebit Mountain. The soils are brown everywhere, except in Stinica. They are reddish (*terra rossa*) in this doline located just beside the sea.

The observations made in the same doline fields at Baške Oštarije and Bilensko Mirevo are particularly interesting; we noticed differences from one doline to another. The main differences concern the grain size, the $CaCO_3$ content, the organic matter and the nutrient content. The analyses show that the best nutrient contents are associated to the finer granulometry, sometimes in depth (BO1, BO7, BM1) and sometimes on the surface (BO2, BM1, BM3). Occasionally, the differences between the depth and the surface are not significant (Stinica1, BO5). These differences can be partly explained by the exposure of the doline and by changes in vegetation cover (Barany 1993; Aniko 1999). However, the differences concerning the grain size and the $CaCO_3$ content seem to depend on their position in the basin at Baške Oštarije, since the dolines located in the relatively lower parts have a finer granulometry and are not decalcified. At Bilensko Mirevo, differences between the dolines can also depend on the type of doline and their morphology. The BM3 doline is in both a lower position in the basin and morphologically deeper than BM1. The higher proportion of $CaCO_3$ attests to colluvial contributions (BO1, BO7, BM3). In other dolines, like BM1 and Stinica, the colluvial contributions are also attested to, but only by the presence of more or less rounded calcareous fragments.

Nevertheless, most of the cores are not long and there is no clear stage in the sedimentary sequences. The processes are homogeneous. This homogeneity has been also observed elsewhere. For example, the samples of the doline fill on the Gaverghera plateau (Venetian pre-Alps, Italy) show a very homogeneous overall trend in their cumulative particle size curves and in the percentage content of sand, silt and clay (Sauro *et al*. 2009). Only the more complete bore profiles, BO7 and especially BM1, allow proposing a hypothesis for future research. They have shown an impoverishment in the more recent part of the soil that could perhaps correspond to a period of intense land use between the 17^{th} and 19^{th} century. This evolution becomes inverse in the surface horizon (only observed in BM1), perhaps because of the rural depopulation observed since the last century. Unfortunately, the rare micro-charcoals observed have not allowed the datation of the observed processes.

CONCLUSION

The study on dolines and soils reveals the close links existing between local lithological and structural situations, neotectonic activity, and geomorphic and pedogenetic processes. However, their evolution is also sensitive to climatic and environmental changes, as well as to land use impacts. So, the current aspect of the Velebit Mt. dolines is the result of phases of intense karstic morphogenesis, accompanied by obvious pedogenetic processes, the velocity of which was related to climatic conditions but also to human impacts.

The relatively large but shallow dolines at the littoral side of Velebit Mt., which appear singularly, are older forms. At the Stinica doline, below the thin horizon of brown soil, *terra rossa* formation has been found. On the other hand, the dolines situated on the karst polje and karstic uvalas up to 900 m altitude are characterised by small and relatively young dolines, most probably formed after LGM. They form doline fields in moraine material so their morphogenesis is associated with glacial at Bilensko Mirevo and periglacial origin (morphogenetic processes) at Baške Oštarije.

In this study we have also found that the soil depth in the dolines is differently distributed. They are mainly shallow in the littoral zone, up to 30 cm, while in the upper part the dolines have deeper soils up to 70 cm. Consequently, the ecological conditions seem much more appropriate for soil formation in those upper zones. The relatively thin soil cover in the Stinica area may also be related to its open-sided morphology. It is opened toward the Velika Draga gully and this may be related to the erosion periods in the past.

These analyses reveal that the soils in the dolines were the best for agricultural activities in the past, as well as also being so today. So, the found impoverishment of the soil horizon could be correlated with the increased environmental impact in the period between the 17th and first half of the 20th century (dated by: Rogić 1958; Fürst-Bjeliš *et al*. 2001; Nicod 2003a; Fürst-Bjeliš & Lozić – 2006), as a consequence of the increasing population density and increased land use.

To conclude, the studied dolines of Velebit Mt. do not present very good data for environmental history reconstruction for two reasons. The first reason is the lack of datable material and the second the important differences observed between nearby dolines in the same area, linked to the topography or to their genesis, which constitute another difficulty to assure the representatives of the sedimentary archives.

ACKNOWLEDGEMENT

This research was supported by the Ministry of Science, Education and Sport of Republic of Croatia (Project 119-1191306-1305 *Geomorphological and geoecological research of Karst areas in Croatia*) and by GEOLAB, UMR 6042-CNRS, France, which is warmly acknowledged. We remain indebted to Ivica Rendulić and Mladen Pahernik for the drawing of the figures.

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