WP3

Platy limestone – geologic definition and its use as a mineral commodity

Appendix 2.4

Final report for the project area in Bosnia and Herzegovina

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CONTENT

Abstract

The HERAG external expert team worked on the project RoofOfRock and prepared the outputs for the Bosnia & Herzegovina project area (Western Herzegovina County and Herzegovina-Neretva County). Outputs consist of all of the geological aspects of the RoofOfRock project that have been defined and supervised by the leading partner – Geological Survey of Slovenia (GeoZS).

A database and geological overview map of the RoofOfRock project area for Bosnia & Herzegovina at scale 1:250,000 were compiled and used as the basis for an overview on building limestone in general (Chapter 2). Regarding their potential as building limestones, the geological units presented on the overview map (1:250,000) are classified according to three categories: low potential, potential and high potential (Appendix 1). More than 20 of the most important types of building limestones cropping out in the project area are listed, along with 27 typical quarries (Appendix 2).

HERAG's experts worked in close collaboration with other project partners and their external experts in the process of setting up a common definition of platy limestone (PL) as well as with compiling data for the database and the geological maps. On the basis of an extensive geological survey, spatial occurrence and general characteristics of selected types of PL were outlined, the results of which appear in Chapter 3. Identified PL types were classified according to their occurrence (thickness of PL sequences within other bedded limestones and spatial extent) and to quality, in three categories: low potential, potential and high potential types. Potential and high potential PL types were mapped (21 polygons, Appendix 3) at scale 1:50,000.

After reporting on the general occurrence of platy limestone in the project area in Bosnia & Herzegovina, we focussed on PL as a mineral commodity (Chapter 4) and on the general spatial limitations of its use and its natural heritage. The aim of this report is to identify possible sources of the most promising types of platy limestone (high potential PL units and localities) within the investigated parts of the Adriatic karst region in Bosnia & Herzegovina.

Show-case objects are described in Chapter 5. The aim of this part of the RoofOfRock project was to identify different types of building limestones (including platy limestone) used on the

selected show-case objects, and to relate the limestone types used with the geological units defined on the geological maps at 1:250,000 and/or 1:50,000.

All of the results are summarized in Chapter 6, along with some recommendations and guidelines for all of the geological as well as some natural and cultural aspects of platy limestone in the investigated area of Bosnia & Herzegovina.

Complete materials (Excel tables, analytical results, photographs, a GIS database as .shp files) were sent to the GIS database hosted by the lead beneficiary – GeoZS – and are included on an updated CD, along with the Final Report.

1 INTRODUCTION

The HERAG external expert team prepared the project outputs for the Bosnia & Herzegovina project area (West Herzegovina County and Herzegovina-Neretva County).

After preparing an overview of building limestone in the B&H part of the project area (Act. 3.1), we focused on the main subject of the RoofOfRock project – platy limestone (Act. 3.3), with the aim of identifying different possible types of platy limestone (PL) within the investigated regions of the Adriatic karst. To this end, major sedimentological and paleontological characteristics, stratigraphic position and the age of various platy limestone horizons were studied.

According to certain recognized characteristics, the spatial occurrence of all types of PL were defined on maps at a general scale of 1:50,000, along with an assessment of their general potential as PLs, which served as the basis for an evaluation of the listed types of platy limestone as mineral commodity and for the identification of potential quarrying areas. WP3 also included the selection, together with geological expertise, of certain show-case objects. Natural heritage of platy limestone was also studied in the framework of geological actions. Geological data collected within the scope of the survey was incorporated into Excel tables, as the basis for the GIS database (WP7).

The requirements of the RoofOfRock project are specified as follows:

- review of existing relevant documents and data with a view to the preparation of a detailed overview (list) of all types of limestone from the Adriatic region of Bosnia & Herzegovina that were used as building stone.
- fieldwork, with the goal of defining all types of building limestone in the project area in Bosnia & Herzegovina, and to present them on a geological map at scale 1:250,000.
- cooperation with the leaders of WP3 (LB GeoZS) and WP5 (FB5 DMG UniTS) in the process of setting up a common definition of platy limestone;
- collecting and editing of available archive material (spatial occurrence, all available lithological and paleontological data, quarry areas etc.) of types of platy limestone for West Herzegovina and Herzegovina-Neretva Counties;

- fieldwork: lithostratigraphic (formational) geological mapping of the selected areas required for a relevant spatial identification of platy limestone according to established written geological standards;
- conducting detailed sedimentological and paleontological laboratory analyses of samples from localities where platy limestone was recognized as not sufficiently determined for use in the project (i.e. owing to age, paleontological and lithological characteristics);
- preparation of a geological dataset for formational geological maps on the platy limestone (scale 1:50.000) of selected areas;
- review and evaluation of all paleontological historical data on platy limestone as regards natural heritage;
- active cooperation with leaders of WP3 (LB GeoZS), WP4 (FB6 UP ZRS), WP5 (FB5 DMG UniTS) and WP6 (FB7 JZ PŠJ) in the analysis and synthesis of the limitations for use of platy limestone
- active cooperation with leaders of WP3 (LB GeoZS) in order to prepare estimates on the quality and quantity of reserves of platy limestone in order to select locations of potential quarrying areas and to set guidelines for its sustainable exploitation;
- review of existing relevant documents and data with the goal of selecting typical and autochthonous houses in Herzegovina;
- review of existing relevant documents and data, fieldwork in the Project Area, and petrological and paleontological analyses with the aim of identifying the source areas of building limestone from 5 selected houses in Herzegovina;
- detailed lithostratigraphical mapping of selected parts of Herzegovina to define the origin of building limestone used in selected houses;
- gather and unify material from selected parts of the B&H project area and prepare detailed geological maps (provisional scale 1:50,000) of the origin of building limestone used in 5 selected houses;
- collect and unify all geological data and maps on platy limestone (scale 1:50,000) from the B&H part of the karstified project area and continued feeding of the GIS

database. Data is in ESRI .shp file format and prepared according to the specific requirements of the WP3 leader (LB GeoZS).

Following the preparation of the overview of building limestone in general in the project area of Bosnia & Herzegovina, we focused on the geological definition of platy limestone as the main task-subject of the RoofOfRock project. As part of regional building limestone heritage in general, platy limestone is recognized as genuine regional natural heritage linking many common cultural and traditional practices.

During the preparation work, we gathered all of the archive data and used it for the project RoofOfRock. We also recognized many areas characterized by the local occurrence of platy limestone. The HERAG expert team has been working in close collaboration with the Lead Beneficiary in the process determining a common definition for platy limestone and in the gathering of data for the database and the geological maps. HERAG experts attended a number of formal meetings (Matavun, Split, Trieste, Pula, Vodnjan, Međugorje, Piran), as well as many interviews with representatives of the Contracting Authorities and their external experts integral to the successful implementation of the project. We selected, in close cooperation with the Contracting Authorities, the most promising areas of platy limestone occurrence in nature, which were then geologically investigated in detail during the fieldwork.

According to the recognized potential and spatial occurrence of all types of PL previously defined on maps at a general scale of 1:50,000, we evaluate selected types of platy limestone as a mineral commodity with the ultimate goal of identifying potential quarrying areas. In the selected and most promising sites, detailed sedimentological and paleontological data was compiled for the purpose of natural protection proposals (according to age, paleontological and lithological characteristics, genesis, etc.). Three important sites within the scope of natural heritage were proposed as geo-sites: Raška gora, Kolojanj and Grabova draga. In addition, we propose general guidelines for the sustainable exploitation of platy limestone.

Following the fieldwork, the most interesting and relevant data was collected and incorporated into Excel tables and the GIS database.

1.1 OVERVIEW OF THE PROJECT AREA – GEOGRAPHIC DESCRIPTION

The RoofOfRock project area in Bosnia & Herzegovina includes West Herzegovina and Herzegovina-Neretva Counties, situated along the southern border between Bosnia & Herzegovina and Croatia (Fig. 1.1). Detailed investigations of platy limestone were planned within selected areas. West Herzegovina County comprises the northern part of project area, while Herzegovina-Neretva County comprises the southern part of the project area.

The area investigated within this project includes the karstic parts of these two counties (i.e. carbonate platform deposits of Outer Dinarides within Federation B&H entity). The area under consideration belongs to the central part of the High Karst Dinarides, including some of the most prominent mountain peaks in Bosnia and Herzegovina, such as Čvrsnica (2228m asl), Prenj (2155m asl), Raven (2074m asl), etc. In the south and southwest, the project area borders on the Dalmatian area of Croatia, while in the west, north and east the project area borders, respectively, on Livno County, Central Bosnian County (both in Federation B-H entity) and on the entity Republika Srpska (Fig. 1.2).

Along with the mountains, one of the most visually striking geographic features in the project area is the Neretva River, which runs through most of the project area, and opens into the Adriatic Sea in Croatia, near Opuzen. Alongside the Neretva, another important river in the project area is Trebižat, the right[eastern?] tributary of the Neretva River. Other significant rivers in the project area are the Bregava and the Buna, which are the left [western?] tributaries of the Neretva River.

Together with the rivers and mountains, the essential geomorphological-relief features in the project area consist of numerous karst fields (poljes), among which the most significant are: Popovo Polje, Mostarsko blato, Bekijsko polje, Brotnjo polje, and Posuško polje, along with many other, smaller karst fields. Above these karst fields and above the Neretva River valley as well are several vast karst plateaus, the most significant of which are Raška gora, Brotnjo, Dubrave and Podveležje.

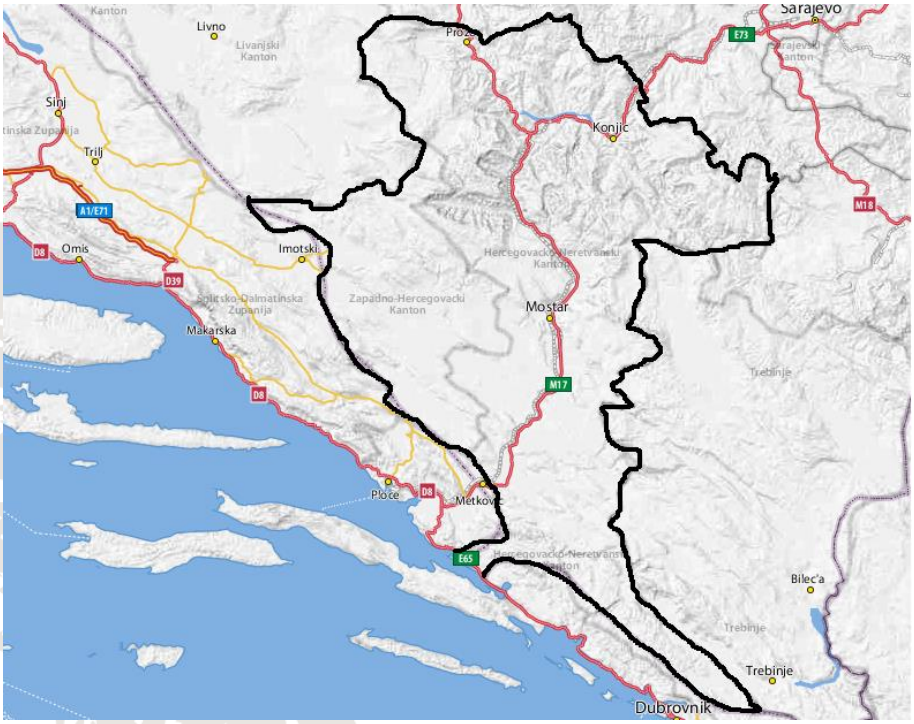

Fig. 1.1. Map of the project area in Bosnia and Herzegovina.

Fig. 1.2. Map of the southern part of Bosnia and Herzegovina.

2 GEOLOGICAL DEFINITION OF (PLATY) LIMESTONE IN THE PROJECT AREA

2.1 DEFINITION, OCCURRENCE AND DEPOSITIONAL ENVIRONMENTS OF LIMESTONE

According to some of the most widely cited geological classifications (TREFETHEN, 1950) limestone is a carbonate sedimentary rock that is characterized by more than 90% calcium carbonate ($CaCO_3$) content, while platy limestone is a very thin-bedded limestone that is characterized by a bed thickness of 1-10 cm (cf. McKEE & WEIR, 1953; CAMPBELL, 1967; combined in KORBAR et al., 2012). According to such classification, we further consider laminated rock (<1 cm in thickness), thin-bedded (10-30 cm), medium thick-bedded (30-60 cm), thick-bedded (60-120 cm), very thick-bedded (>120 cm), and massive rocks.

Limestones (all types) were largely formed the during Jurassic, Cretaceous and Lower Paleogene ages. On the northernmost parts of the Herzegovina project area (Inner Dinarids) older types of limestone also appear, which were formed during the Upper Paleozoic and Triassic, when the area belonged to the Paleo-Tethys Ocean. The karstified part of the project area in Herzegovina belongs to the External Dinarides, which includes all Jurassic to Cretaceous megasequences formed on the Adriatic carbonate platform. Today carbonates of former extensive carbonate platforms also comprise the coastal Adriatic parts of Italy, Slovenia, Croatia, Herzegovina and Montenegro.

Platy limestones in the project area are mainly light to dark grey in colour, and of mudstone to packstone textural types. They often also contain distinctive stromatolitic and horizontal lamination. Cretaceous platy limestones consist mainly (almost 99 percent of internal components) of calcium carbonate, while in the Eocene limestones – and particularly in Miocene limestones – a higher proportion of clay is also present. This is also reflected as increased lenses of marls and sandstones within platy limestone sequences, and even the domination of marly sequences.

Platy limestones of Cretaceous age are the most widespread among the Mesozoic geological formations in the project area. They are deposited in the shallow-sea and lagoonal environments of the former carbonate platform. Carbonates of Paleogene age were also deposited on the platform, while the youngest, Miocene carbonates (including platy

limestones), were deposited in the lake environments of the newly-formed inlands during intensive tectonic processes.

Depositional environments of different investigated types of platy limestone vary substantially. While sedimentation of Cretaceous platy limestones occurred mostly in marine environments, mainly in shallow lagoons (Fig. 2.1.), the somewhat younger Paleocene platy limestones were deposited in freshwater basins, lakes and lagoons with predominantly brackish (mixed fresh and sea) water. Eocene platy limestones were deposited in marine environments and occasionally in shallow-water environments, lagoons and estuaries. On the other hand, the youngest (Miocene) platy limestones in the project area were deposited in freshwater environments, within intracontinental lakes and fresh-water basins (Fig. 2.1b).

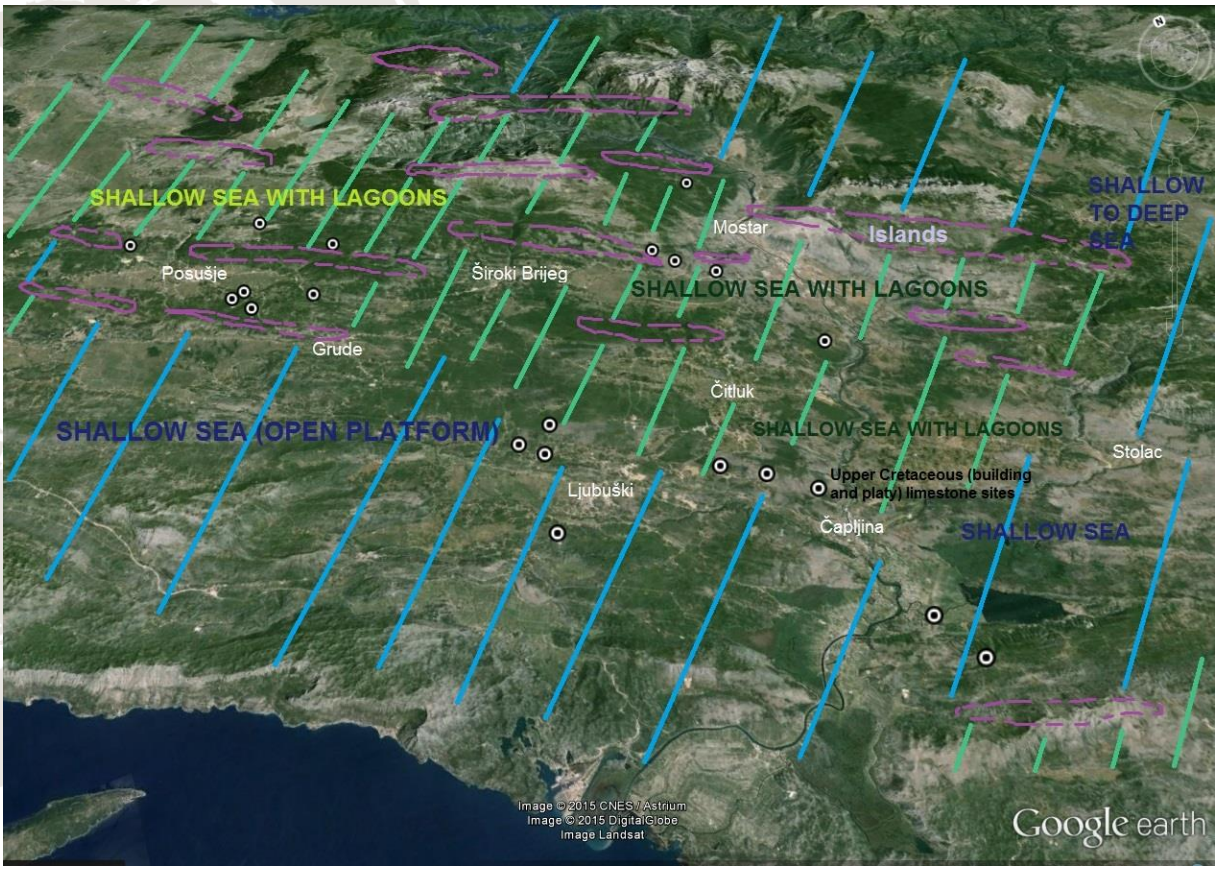

Fig. 2.1. Simplified sketch of former Middle and Upper Cretaceous (~ 100 to 65 million years BP) depositional environments marked as present-day (GoogleEarth) topography.

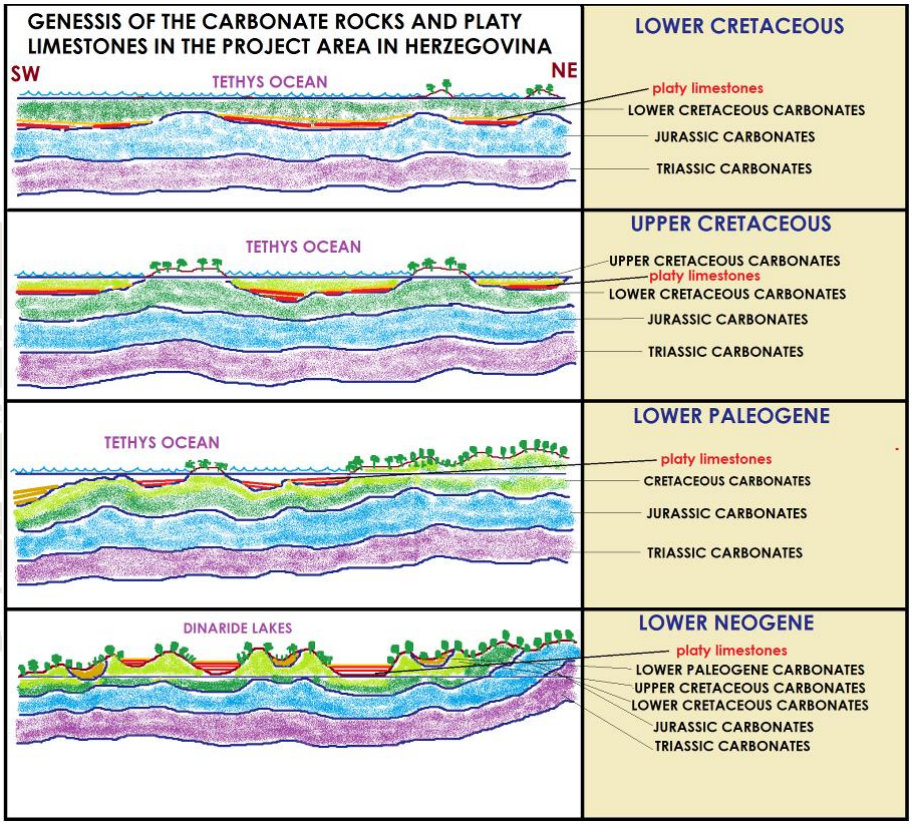

Fig. 2.2. Illustration of the genesis of different types of platy limestone in the project area; platy limestone depositional environments are marked in red.

2.2 GEOLOGICAL SETTING

In the geological sense the main part of the project area in B&H belongs to the External Dinarides, while the smaller northern part belongs to the Internal Dinarides. Carbonate rocks of the External Dinarides were mainly deposited on the Adriatic carbonate platform. Lithofacies associations of the External Dinarides were mainly related to the Tethys sea and Alpine orogenic cycle, while lithofacies from the Internal Dinarides were genetically related to the Variscan orogenic cycle during the Paleozoic age (HRVATOVIĆ, 2005). So, as can be seen on Fig.2.4. (in green), the major part of the project area consists of Cretaceous carbonate sediments represented by shallow water limestones and dolomites, or sporadically with carbonate breccias. The northern parts of the project area consist mainly of Triassic carbonate and clastic rocks, where smaller parts of this area contain Paleozoic and Triassic volcanic, metamorphic and sedimentary rocks. Within the Upper Cretaceous carbonate rocks in the northern and middle parts of the project area specific fossiliferous lithofacies particularly rich in molluscs (rudists, shells, gastropods, bryozoans) occur, which fully correspond to the depositional facies of ''saccharoidal limestone'' recognized earlier in

Italy (CARBONE et CATENACCI, 1978). These specific lithofacies are important, because in many cases they represent upper deposits above the older Cretaceous thin-bedded and platy limestone.

Unlike the other project areas (Croatia, Slovenia, Italy) where mostly Middle Paleogene deeper sea and/or deltaic lithofacies types appear, very shallow sea (coral reef) lithofacies types which consisted of highly fossiliferous limestones and sporadically of carbonate clastics appear here, especially in the western Herzegovina dominate. Lower Paleogene lithofacies types here are almost the same as in the Dalmatian area, and are represented by Lower Eocene foraminiferal limestones. Also here, mostly in north-western Herzegovina, Upper Paleogene clastics consisting mainly of conglomerates, marlstones and sandstones appear, which fully correspond to the well-known north-Dalmatian Paleogene lithofacies called Promina beds. The youngest carbonate sediments in the Herzegovinian project area were formed during the Lower Neogene (Miocene) age, at the bottom of freshwater intracontinental lakes. Sometimes occurred as real limestone with an oolithic structure, but they were most often developed as well-bedded and thin-layered (platy) marlstone and carbonate marls. The largest outcrops of thin-layered and platy carbonate sediments of the Miocene age are present in the middle, northern and western parts of the project area, around the cities of Mostar, Široki Brijeg, Prozor-Rama and Posušje.

Platy limestone outcrops in the project area are exclusively present within Mesozoic and Paleogene-Neogene sedimentary formations. Most of the outcrops are of Cretaceous age, while outcrops of Paleogene-Neogene age are subordinate.

The majority of platy limestone sites within the project area belong to the central zone of the External Dinarides, which is characterized by intensive folding, faulting and overthrusting. An identical structural-tectonic profile extends regionally, from the western parts of the Dinarides in Croatia, through the Dinarides in Bosnia and Herzegovina, down to the eastern borders of Montenegro. High elevation mountain ranges consist predominantly of Jurassic and Cretaceous carbonate rocks (limestones and dolomites). The described tectonic units are often referred as High Karst Overthrusts. They comprise some of the highest peaks in Bosnia and Herzegovina (i.e. Prenj = 2155m asl and Čvrsnica = 2228m asl), which are located in the northern part of the project area. The entire project area is composed of the following six structural-tectonic units, starting from the south (Fig. 2.3.): 1)

Ljubuški-Svitava tectonic unit, 2) Čitluk-Stolac tectonic unit, 3) Blagaj tectonic unit, 4) Velež tectonic unit, 5) Čabulja tectonic unit and 6) Imotski tectonic unit.

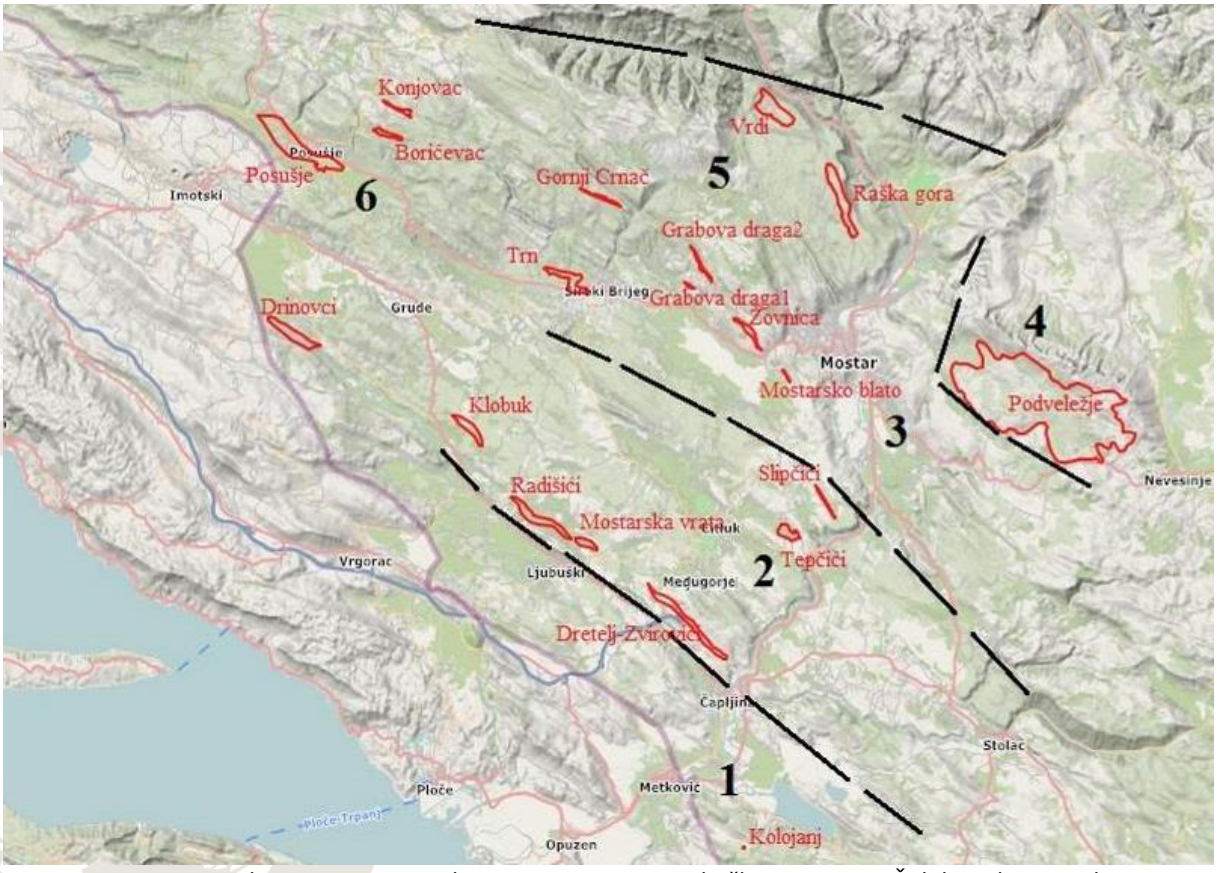

Figure 2.3. Structural-tectonic units in the project area: 1 – Ljubuški-svitava, 2 – Čitluk-Stolac, 3 – Blagaj, 4 – Velež, 5 – Čabulja and 6 – Imotski tectonic unit.

2.3. GEOLOGICAL OVERVIEW OF BUILDING LIMESTONE IN THE REGION OF HERZEGOVINA

The database and overview map of the Bosnia & Herzegovina project area at scale 1:250,000 (Fig. 2.4., b) are based on the formal data listed on related sheets of the Basic geological map 1:100,000; on sheet Metković (RAIĆ & PAPEŠ, 1977), sheet Mostar (MOJIČEVIĆ & LAUŠEVIĆ, 1973), sheet Imotski (RAIĆ et al., 1967), sheet Ploče (MARINČIĆ et al., 1971), sheet Prozor (SOFILJ & ŽIVANOVIĆ, 1971), sheet Trebinje (NATEVIĆ & PETROVIĆ, 1967) and sheet Kalinovik (MOJIČEVIĆ & TOMIĆ, 1982). In the analysis of existing building limestone horizons and their spatial distributions we used several particularly important papers dealing with building limestones, the so-called architectural-building (AG) stone in Herzegovina (PUDELKO et al., 2000, ŠARAVANJA & MARIJANOVIĆ, 2004, ŠARAVANJA et al., 2013). These studies largely consist of geotechnical and engineering-geological data on mineral deposits of AG

stone in the project area. However, a basic unification and harmonization of geological units and data was carried out for the purposes of the project. The overview map at scale 1:250,000 has been finally harmonized in cooperation with the Lead Beneficiary GeoZS and the Croatian Geologic Survey (HGI-CGS).

Fig. 2.4. Geological overview map of the B&H part of the RoofOfRock project area (for details see project Web application).

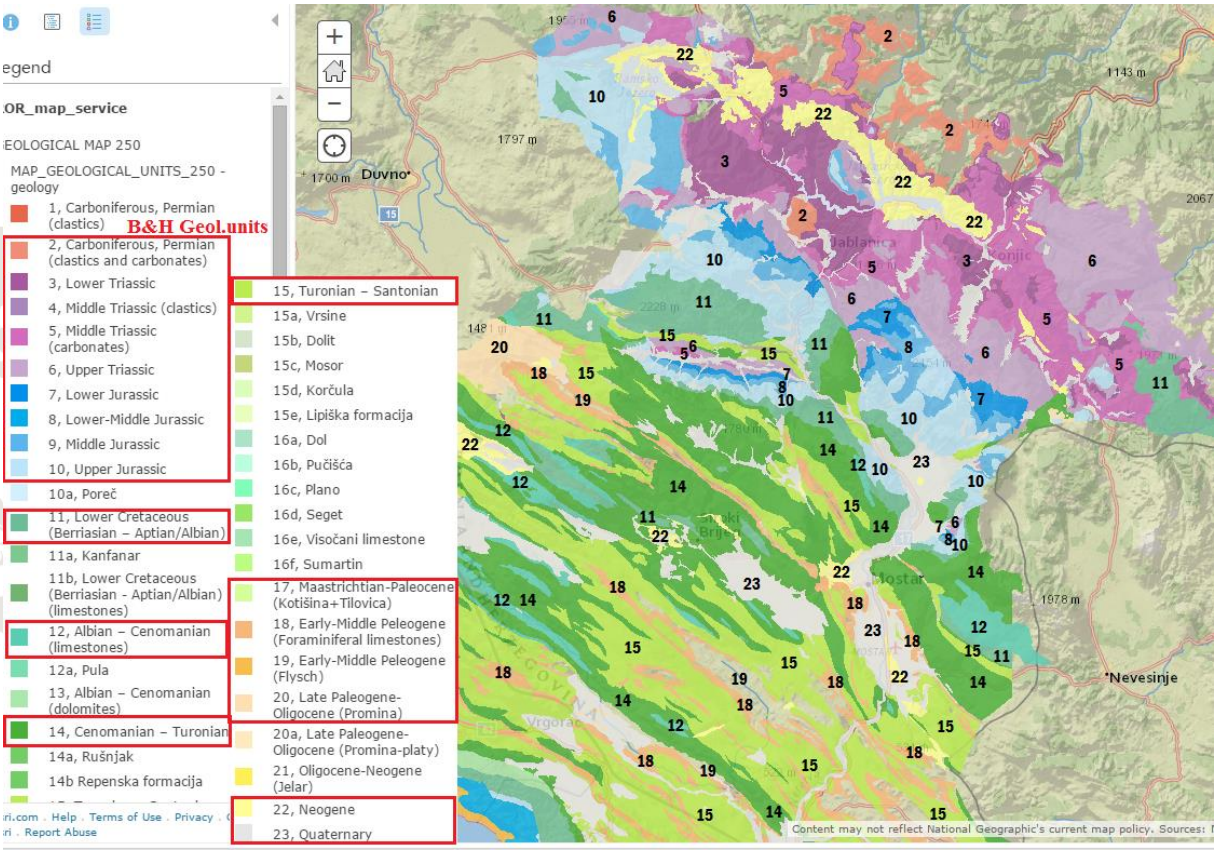

Fig. 2.5. List of geological units and legend of the geological overview map (1:250,000) of the B&H part of the RoofOfRock project area.

According to their potential value as building limestones, geological units are classified into three categories: low potential, potential and high potential. Low potential types include poorer quality limestone, used not for commercial purposes but only locally. Potential types include relatively quality building limestone that could also be commercially used where abandoned quarries exist. High potential types include types that are/were widely commercially used in a number of active quarries; the occurrence of high potential types is usually indicated on more detailed lithostratigraphic maps (subunits a, b, c... in Fig. 1.2b and on the list of geological units in Appendix 1). On the basis of classification, the map of potential geological units as building limestone was elaborated for Herzegovina (Fig. 2.6.). Geological units with “no potential” (e.g. flysch, igneous rocks, Quaternary etc.) are not indicated on the overview potentiality map.

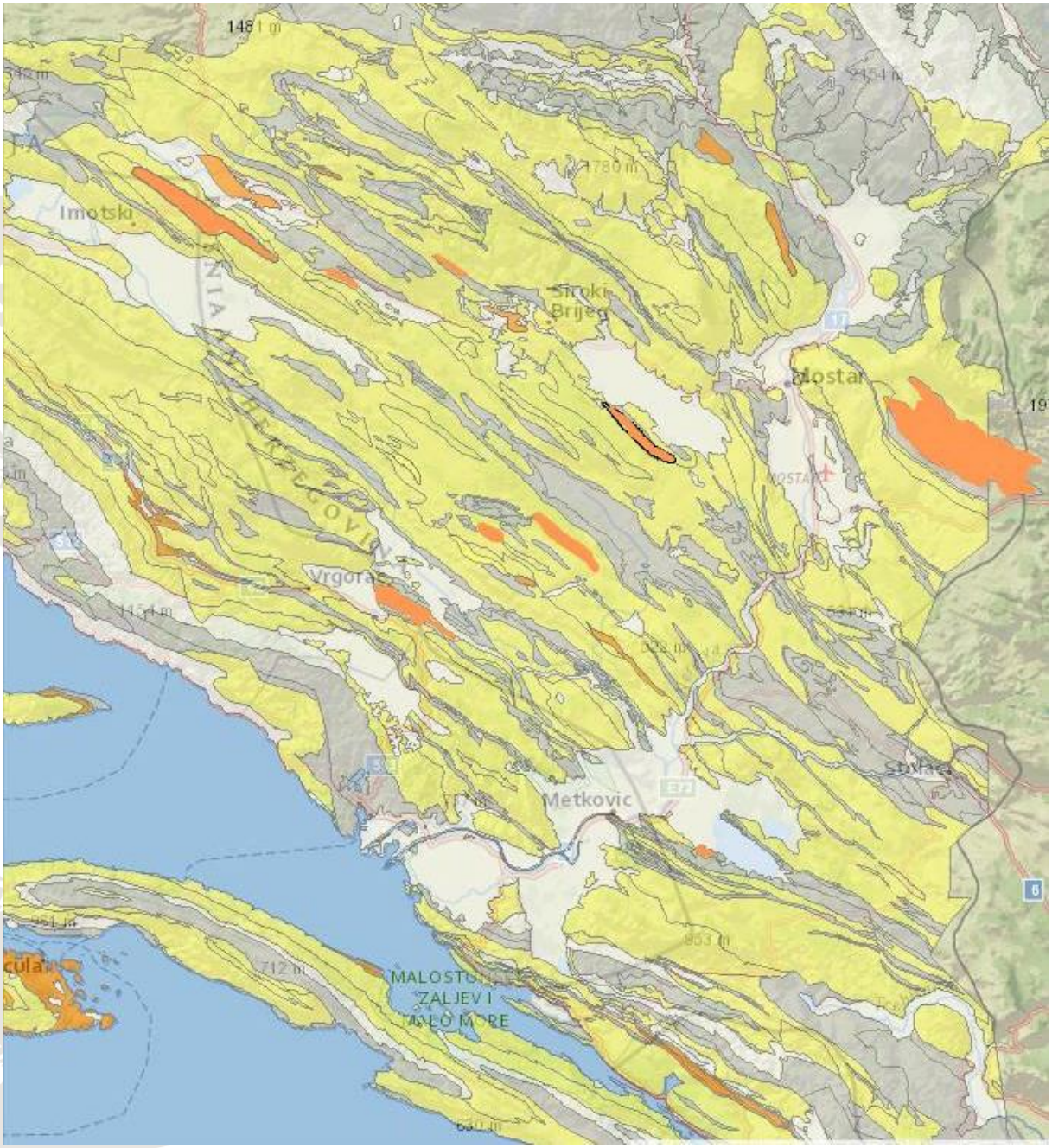

Fig. 2.6. Overview map of general building limestone potential in the B&H part of the RoofOfRock project area (grey – low potential, yellow – potential, orange – high potential).

The most important types of building limestone appear in the north-western part of the project area in B&H, due to specific depositional environments that existed in the region through geological history (see Chapter 2.1). The majority of building limestones are massive limestones and limestone-dolomitic breccias suitable for exploitation as limestone blocks (Figs 2.7., 2.8., 2.9.). Also noteworthy is the fact that a very large area with massive and thick-layered, largely Cretaceous limestones, holds particular potential for the exploitation

of irregular blocks of so-called 'tombolons'. Many building limestone quarries in the project area have been exploiting such irregular blocks, which have been processed after quarrying. More than 20 of the most important types of building limestones in the project area have been selected in the list (Appendix 1), along with 27 typical building limestone quarries (Appendix 2). However, as special building limestone types, widely used platy limestones, too are investigated in detail within the RoofOfRock project.

Fig. 2.7. Active quarry of Upper Cretaceous building limestone 'In-Ka-Hercit' in the village of Crveni Grm, near Ljubuški.

Fig. 2.8. Active quarry of Upper Cretaceous 'Kušanovac' building limestone, in the village of Crno Lokve, near Široki Brijeg.

Fig. 2.9. Active quarry of Upper Cretaceous 'Osoje' building limestone near Posušje.

3 GEOLOGICAL RESEARCH ON PLATY LIMESTONE

3.1 METHODOLOGY OF DETAILED GEOLOGICAL INVESTIGATION AND MAPPING

As the first step in the research methodology, WP3 experts undertook a detailed review of numerous existing studies related to the limestone of Western Herzegovina County and Herzegovina-Neretva County. Many such studies containing information about platy limestones were undertaken in the framework of geological mapping for maps at scale 1:100,000 and 1:25,000, and in the framework of investigations of bauxite ore deposits.

A significant number of recent investigations have been conducted in order to estimate the potential of quarrying areas for architectural and building limestone, for which sustainable use is one of the primary goals of this project.

Fieldwork at all significant platy limestone sites was performed for the detailed investigations and geological mapping of the project area. Geological archive material was reviewed in detail before carrying out the fieldwork. Fieldwork included photo-documentation of the platy limestone outcrops and documenting lateral and vertical lithological changes along the outcrops. Numerous samples containing petrological and paleontological data were collected. Micropetrographical analyses were performed on selected samples. Paleoenvironmental and sedimentological interpretations were made based on the data collected. Structural elements were also measured in the outcrops and interpreted. All collected data was used for the preparation of geological project outputs, databases and all geological maps and reports. The work benefitted from the good cooperation with researchers from HGI – Croatian Geological Survey (external geological experts covering the Croatian part of the project area) and with the lead beneficiary – GeoZS – Geological Survey of Slovenia.

3.2 GENERAL CHARACTERISTICS AND SPATIAL OCCURRENCE OF PLATY LIMESTONE IN HERZEGOVINA

Platy limestone in the project area occurs mainly in Mesozoic lithostratigraphic formations and also in some of Tertiary sedimentary formations. Platy limestone from the Cretaceous age is the most widely used as building material. Most of the sites with Cretaceous platy

limestone occurrences are located in the central and in south-western parts of the project area, while most of those with platy limestone from the Paleocene, Eocene and Miocene age occur in the western part of the project area. Sites with Paleozoic (Devonian) platy limestone occurrences are located in the northern and north-eastern part of investigated area. These are not discussed in detail in this study, because they are located in the Middle Bosnian Schist Mountains, which are not included in our project investigation because they do not belong to the karstified coastal Adriatic region.

In the Herzegovinian part of the project area, platy limestone (PL) appears within sequences that could be range from a few tens of meters up to hundreds of meters thick, as is the case of the PL megasequence at the Podveležje site. But it is important to emphasize that the superficial spatial occurrence of PL depends significantly on the relation of the geological (bed dip angles) and morphological (flat or steep relief) features. In the areas where the dip of the limestone beds is gentler and the surface relatively flat, platy limestone can be exposed over particularly wide areas.

The majority of PL sequences occur within other bedded, largely shallow-water carbonate deposits of the Early Cretaceous (Albian), Middle-Late Cretaceous (Albian-Cenomanian, Cenomanian, and sporadically Campanian and Maastrichtian), Early Paleogene (Paleocene), and Middle Paleogene (Early Middle Eocene) ages, respectively.

Most of the **Lower Cretaceous and Upper Cretaceous sites** (Vrdi, Podveležje, Drinovci, Mostarska vrata, Grabova draga1, Dretelj, Radišići, Zvirovići, Mostarsko blato, Žovnica, Gornji Crnač and Slipčići) contain thin-bedded (up to 10 cm) platy limestones. They are light-yellow to light-grey in colour, frequently contain stromatolitic laminae, and are largely of mudstone to wackestone textural types (after DUNHAM, 1962). Skeletal grains are mostly represented by benthic foraminifers, rudist and other skeletal debris, while peloids are the most common non-skeletal grains. Sometimes synsedimentary folds are clearly visible within the beds. At some of the Cretaceous sites (Mostarska vrata, Drinovci) thin layers of chert are present, while at others (e.g. at the Kolojanj site) fine-grained platy limestone (mudstone type), containing chert nodules with bituminous coatings is found.

Lower Paleocene (possibly even Maastrichtian) platy limestone at the Borićevac site is light-grey in colour, fine-grained (mudstone to wackestone textural types), with pronounced horizontal lamination. It is also locally synsedimentary folded, with the limestone composed

of skeletal debris (algae, molluscs, echinoderms etc.).

Eocene (probably Lower to Middle Eocene) platy limestones are present at the Grabova draga2 site. They are light-grey to light-brown in colour, with the beds averaging between 2 and 6 cm thick. Platy limestone horizons appear in the form of laterally discontinuous lenses and laterally alternate with marly limestone and even with marlstones with conglomerate lenses. Eocene platy limestones are also present at the Tepčići site, while thin-bedded Middle Eocene limestones, so-called "slates", are specifically defined at the Konjovac site. Only at this site, within the entire project area, are these "slate" limestone plates present. Distinctive fossil assemblages with numerous, diverse and well-preserved marine fauna is also characteristic at this site.

Miocene platy limestones and locally marly limestones are present at the Trn and Posušje sites (Fig. 3.1.). The main lithological characteristic of these types is a well-bedded carbonate sequence across the entire project area. In Trn and Posušje, the limestones are extremely thin-bedded or platy. They are often called '**Miljevina**' stone. Lithologically, Miocene platy limestones are biocalcarenites to biocalcisiltites with up to 30% non-carbonate grains.

In the Herzegovina project area spatial occurrences of platy limestone polygons on the surface are parallel to Dinaric, NW-SE-oriented structural-tectonic units and mountain ranges (Fig. 3.2.). Platy limestone of Cretaceous age predominates in both Counties studied. The largest spatial extent of platy limestones is found at the Podveležje site, where nearly the entire southern part of the Velež mountain consists of well-bedded and platy limestones, ranging stratigraphically from Aptian to Turonian (Fig. 3.1.). All of the other platy limestone sites are of far smaller spatial extent. However, there are several prominent sites; among them the most significant localities are Raška gora Vrdi, Dretelj-Miletina, Radišić-Proboj and Drinovci.

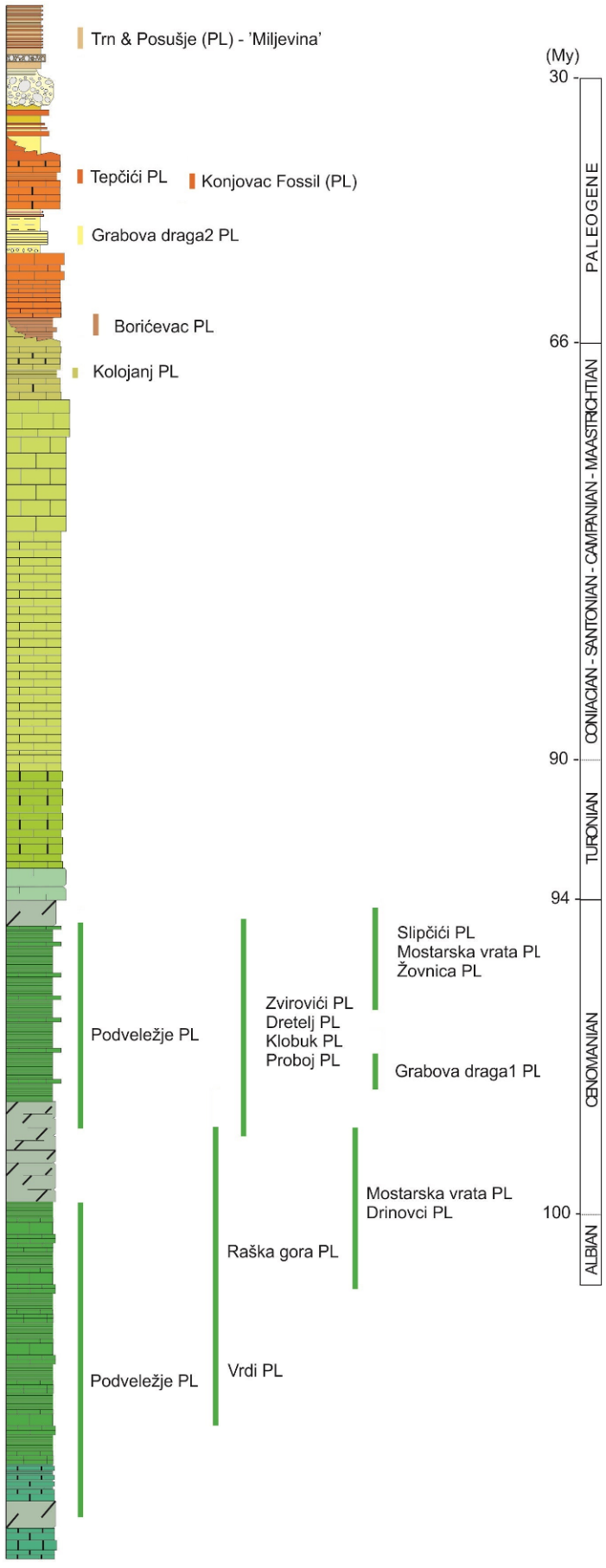
Trn & Posušje (PL) - 'Miljevina'
Tepčići PL
Konjovac Fossil (PL)
Grabova draga2 PL
Borićevac PL
Kolojanj PL
Podveležje PL
Zvirovići PL
Dretelj PL
Klobuk PL
Proboj PL
Slipčići PL
Mostarska vrata PL
Žovnica PL
Grabova draga1 PL
Raška gora PL
Mostarska vrata PL
Drinovci PL
Podveležje PL
Vrdi PL
(My)
30
66
90
94
100
PALEOGENE
CONIACIAN - SANTONIAN - CAMPANIAN - MAASTRICHTIAN
TURONIAN
CENOMANIAN
ALBIAN

Fig. 3.1. Schematic correlation of sedimentary successions that include major PL sequences in the project area of Bosnia and Herzegovina (the upper part of a thick (some km) Mesozoic and Cenozoic "layer-cake" of sedimentary rocks). Cretaceous carbonate units in the lower part (Albian to Maastrichtian age; in green, shallow-water limestone; in blue, deeper-water limestone, in grey, dolomite). Paleogene carbonate and siliciclastic units in the uppermost part (orange to brown: shallow- to deep-water units). Occurrences of platy limestone are marked by closely spaced lines, while the units shown on the detailed maps as polygons are marked by vertical bars and names (not in scale). My-million years (age of rocks), PL-platy limestone.

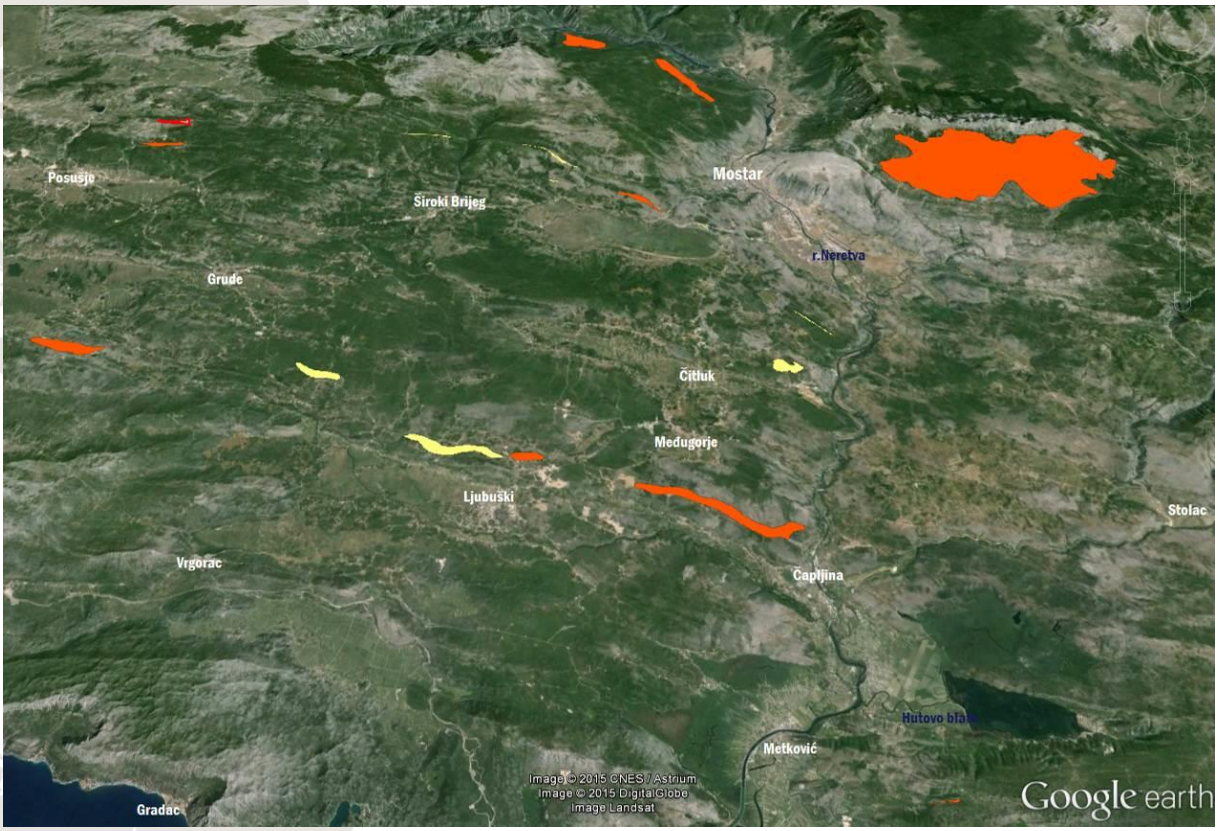

Fig 3.2. Map of platy limestone occurrences in the Herzegovina (orange – high potential, yellow – potential) platy limestone sites.

3.2.1 Podveležje area

The most significant site in the entire project area containing platy limestone outcrops suitable for quarrying for building and architectural purposes is the **Podveležje area**. The Podveležje locality is a large, broad and elongated area at the southern foot of the Velež Mountain east of the city of Mostar (Fig. 3.2.b), built mainly of Cretaceous (Albian-Cenomanian) platy limestone.

Fig 3.3. Outcrops of Lower Cretaceous platy limestone in the southern part of the Podveležje site.

Even today, platy limestones exposed in this area are quarried in a few local quarries, and numerous abandoned quarries can be found in the area. The most significant reason behind the investigation of this locality is the fact that platy limestones are historically used for roofing of almost all of the houses in the Old City of Mostar, as well as on the famous Old Bridge in the immediate vicinity. Additionally, the selected in Mostar show-case object in the scope of the RoofOfRock project, "Bišćevića kuća" house, is also roofed with platy limestone from the Podveležje area. Spatial occurrence (a broad and elongated area covered with platy limestones), accessibility and ease of excavation were the main reasons for their historical use for the roofing of houses in the Old City of Blagaj (show-case object nr.2), in the "Velagića mlinica" water mill (show-case object nr.3; see chapter 5) and in the "Čaršijska džamija" mosque in the city of Stolac (show-case object nr.5) as well as in other objects in Blagaj and Stolac.

In this area that features numerous abandoned quarries, the layers of Podveležje platy limestone dip slightly toward the southwest, with plates averaging in thickness from 5 to 20 cm (Fig. 3.3.). Paleontological evidence shows that platy limestones from the Podveležje area are mainly of Albian and Cenomanian age. Fossil fish findings are already well known in this area. Most of the findings are undetermined, but *Coelodus* genus (Fig. 3.5.), which is also described in the platy limestones of Croatia (island of Hvar, Dalmatian hinterland) and in

Slovenia as well, is also common in the Podveležje area. Alongside the fossil fish, the most common biota are specific ostracods and algae, suggesting sedimentation in brackish-water environments. Cretaceous fossil macro- and microbiota were already determined as far back as the 1960s (Slišković, 1963): foraminifers and algae in Neocomian limestones (*Cuneolina* sp.*; Salpingoporela annulata*); foraminifers (*Cuneolina, Orbitolina*) in Barremian-Aptian limestones; Chondrodontae, rudists (*Ichthyosarcolites, Neocaprina*); and gastropods (*Nerinea schionensis*) in Cenomanian succession. In the upper parts of Upper Cretaceous formations (younger than Cenomanian) rudist bivalves predominate exclusively.

Figure 3.4. One of the numerous active platy limestone quarries at the Podveležje locality, at the southern foot of the Velež Mt. (top left of photo).

Figure 3.5. Fossil[ized?] fish in platy limestone at Podveležje site – Coelodus sp.

The main lithological characteristics of platy limestones at the Podveležje site are a light grey to a yellowish-brown colour (depending on the clay content within the carbonates), bed thickness ranging from 5 to 20 cm, and no visible synsedimentary folds. Limestones are generally inclined toward the north, with an angle of inclination between 20 and 40 degrees. Mudstone to wackestone textular types of limestones are present.

3.2.2 Vrdi area

Another important site with Cretaceous platy limestones is at the Vrdi plateau and in the **Vrdi village area** next to **Čabulja mountain** (1780m), where a similar type of Cretaceous platy limestone as is found in the Podveležje area, is present. There platy limestones are exploited to a far lesser extent than in the Podveležje area. Sequence is also very well paleontologically and stratigraphically defined (SLIŠKOVIĆ et al., 1962; BEHLILOVIĆ, 1964).

According to paleontological studies, series of thin-layered and platy limestones are of Neocomian and younger Cretaceous ages. Fossil biota consist of shells (*Veniella* sp.), algae (*Salpingoporella* sp., *Bacinella irregularis*), and foraminifers (*Orbitolina discoidea,* Nummuloculinae, Cuneolinae, Miliolidae).

Figure 3.6. Outcrops of Lower Cretaceous platy limestones on the northernmost part of the Vrdi site.

According to previous paleogeographic studies (together with data for underlying Jurassic strata and overlying Upper Cretaceous strata) (Fig. 3.7.) limestones from the Vrdi area were deposited mainly in warm and shallow marine environments. Occasional, extremely shallow-water episodes occurred in the Early Jurassic, Early Cretaceous and Cenomanian periods, which resulted in marine fauna and fossil terrestrial flora, accompanied by bitumen and bauxite deposits.

The main feature of platy limestone at this site is its uniform lithological composition. Light-grey to yellowish-brown thin-bedded limestone of mudstones to wackestone textural types prevail. Beds are generally inclined towards the south to southwest, with an angle of inclination ranging from 30 to 60 degrees. Layers thicknesses range between 5 and 12 cm, with no evidence of synsedimentary folds.

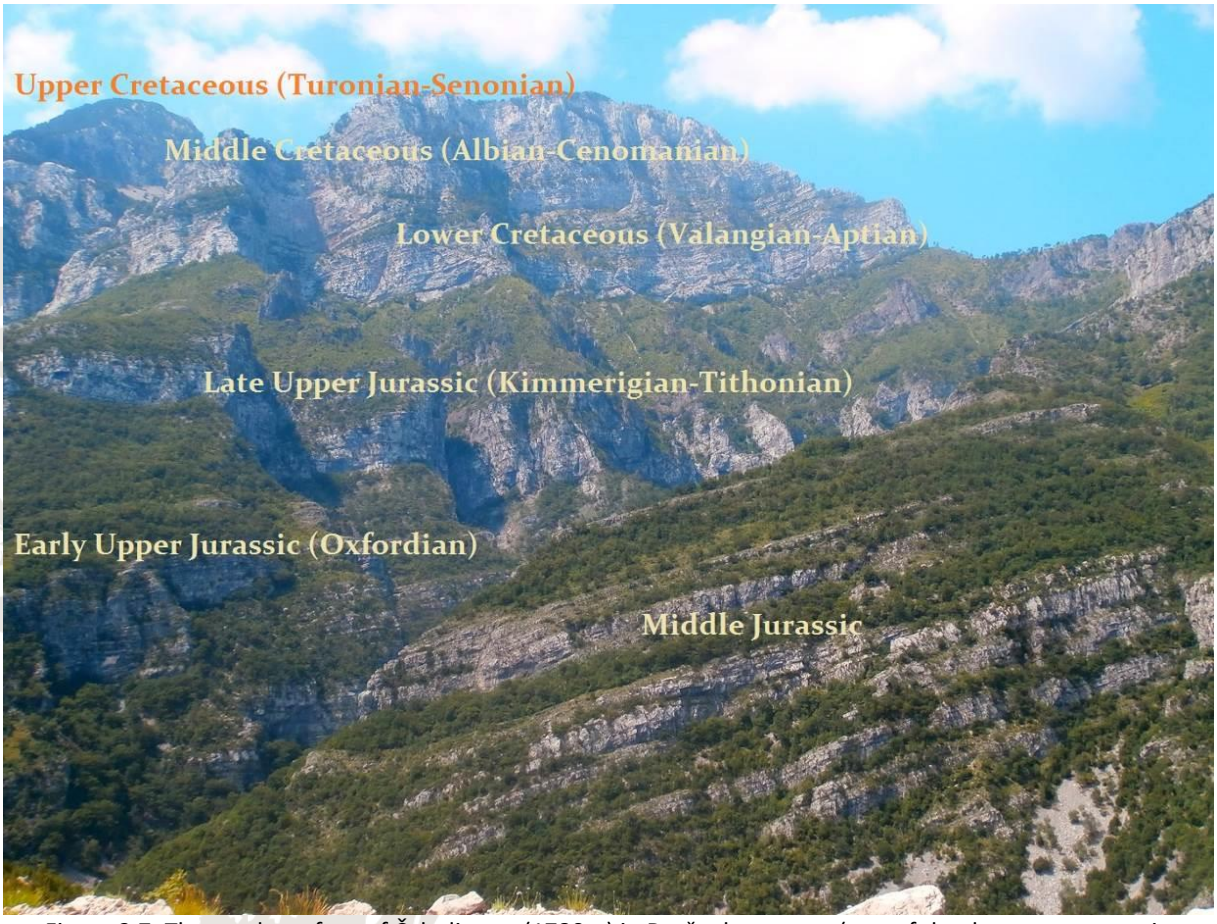

Figure 3.7. The northern face of Čabulja mt. (1780m) in Dreżanka canyon (one of the deepest canyons in Europe, with side-depths of up to 1500m) represents a unique open museum of Mesozoic carbonate megasequences from the ancient Tethys ocean, with all stratigraphical layers from the Middle Triassic to Upper Cretaceous clearly visible.

3.2.3 Drinovci site

At the **Drinovci site**, on the south side of Grude, lies a significant zone of platy limestones. This zone stretches in the Dinaric direction (NW-SE) and contains, like in the Podveležje area, Aptian to Cenomanian stratigraphic horizons with platy limestone. Platy limestones are frequently synsedimentary folded. They often show stromatolitic lamination and contain lenses of cherts and dolomite. At some of the transitional levels between dolomite and limestone sequences real lumachellas of primitive rudists forms (Requienidae) were found (Fig. 3.8.). All of these characteristics suggest largely shallow-marine, protected, even lagoonal environments, in the stratigraphic range from Lower Cretaceous to Upper Cretaceous.

The main lithological characteristics of platy limestones from the Drinovci site are light grey to dark grey colouring, mudstone to wackestone textural types (Fig. 3.9.), distinctive laminations (stromatolites) and synsedimentary folds. Lenses of dark grey platy dolomitized limestone appear locally within the platy limestone sequences. Beds are not uniformly inclined due to the faults and folds. Angles of inclination range between 20 and 70 degrees toward the north and northeast. The average thickness of beds ranges from 3 to 12 cm. PL horizons are usually up to 15 m thick.

Limestone is being excavated in an active quarry (Fig. 3.10.).

Figure 3.8. Shells of primitive rudists forms (Requienidae) in limestone at Drinovci site.

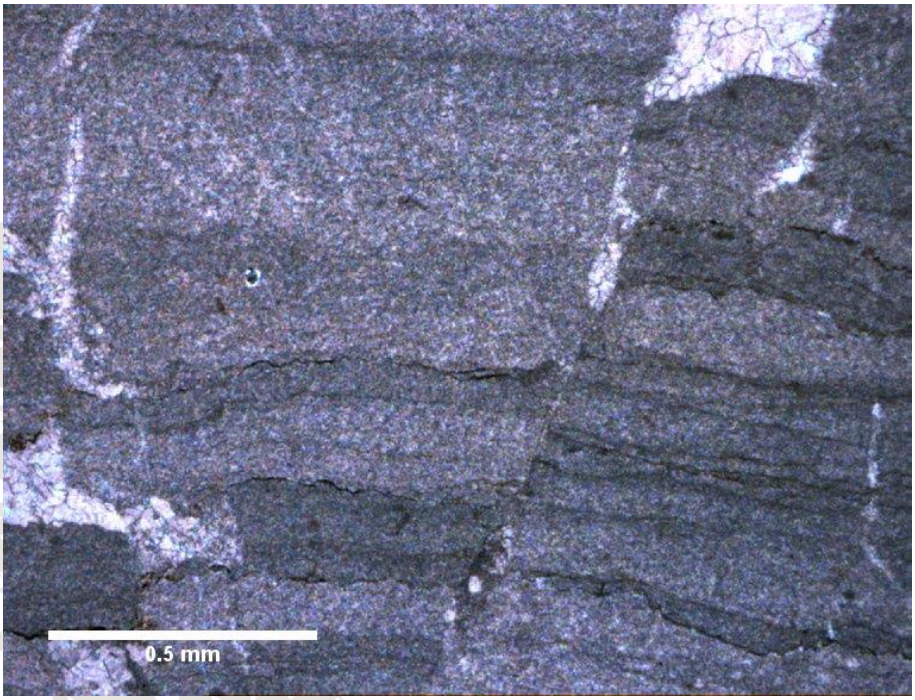

Figure 3.9. Microphotograph of laminated mudstone and stromatolitic wackestone-packstone from Lower Cretaceous platy limestone at Drinovci locality.

Figure 3.10. Active quarry of Lower-Middle Cretaceous bedded and platy limestone at the Drinovci site.

3.2.4 Zvirovići-1, Zvirovići-2, Dretelj and Miletina sites

Localities **Zvirovići-1, Zvirovići-2, Dretelj and Miletina**, together with related quarries (Fig. 3.11.), are also significant sites from the Cenomanian age. This narrow zone, stretching out

in the Dinaric direction (NW-SE) within a squeezed and inclined syncline, is mainly formed of thin-layered limestone and subordinately, of dolomitic limestone. Paleontologically, the most significant fossil taxon is the bivalve *Chondrodonta* (Fig. 3.13.). Together with Chondrodontae, better preserved fauna of rudist bivalves (*Caprinula, Ichthyosarcolites, Schiosia, Praeradiolites, Radiolites*) appear sporadically. Typical Cenomanian microfossil communities also appear at these localities. These platy limestones were deposited, as they were over the entire study area, mostly in very shallow lagoons and in vast shoals as well.

The main lithological features of platy limestone in this elongated zone are mudstones to packstone textural types (Fig. 3.11.), light grey to yellow in colour, and platy limestone layers without synsedimentary folds, but with very frequent lenses of dark grey dolomitic limestones. Beds are generally inclined toward the north, with a dip angle ranging from 30 to 50 degrees.

Figure 3.11. One of the largest quarries of platy limestone in the project area, at Zvirovići1 locality (Upper Cenomanian platy limestone).

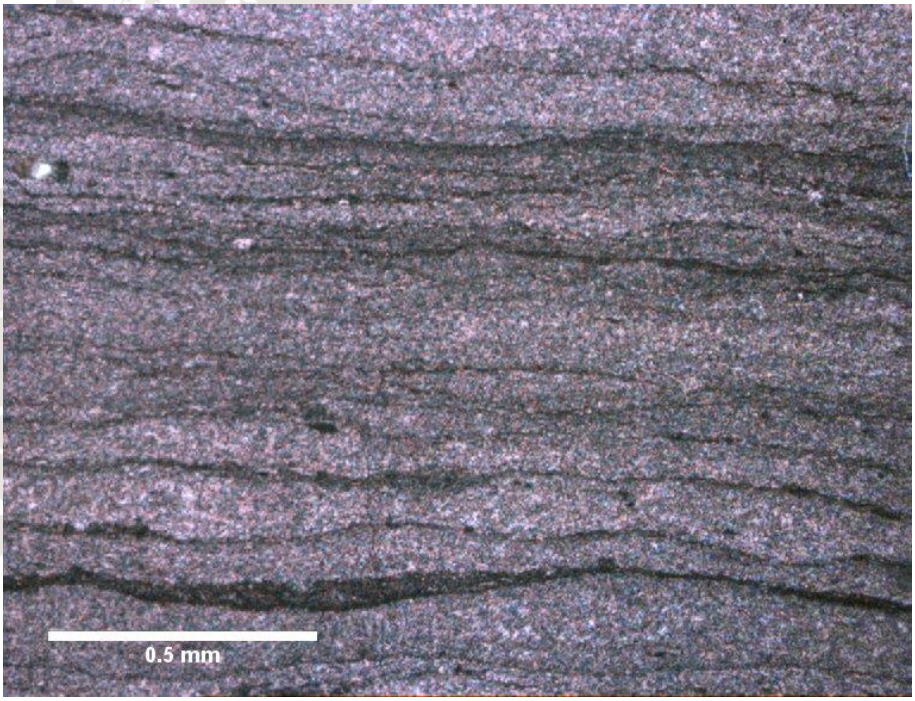

Figure 3.12. Microphotograph of laminated mudstone and stromatolitic wackestone-packstone from the Lower Cretaceous platy limestone locality of Zvirovići.

Figure 3.13. Typical and the most widespread macrofossil in the elongated zone of Cenomanian platy limestones, between Dretelj and Miletina – *Chondrodonta joannae* shells.

Figure 3.14. Numerous rudists of genera *Caprinula, Caprina, Ichthyosarcolites, Schiosia* etc. in Cenomanian limestones at Crnopod locality.

3.2.5 Gornji Crnač site

Within the Upper Turonian and Senonian formations platy limestones rarely appear in the project area. Localities with platy limestone were recorded in only one stratigraphic level between the Cenomanian and Turonian, and in one stratigraphic level within the youngest Senonian carbonates. Platy (dolomitic) limestone in the Late Cenomanian to Turonian

stratigraphic level is present in the wider area of the village of **Gornji Crnač**. Beds are sporadically very synsedimentary folded (Fig. 3.15.).

Figure 3.15. Platy limestones of the Cenomanian-Turonian age showing prominent synsedimentary folds at the Gornji Crnač site.

3.2.6 Kolojanj site

At the **Kolojanj site**, in the Neum municipality, Upper Senonian platy limestones of very high quality appear. Significant fossil fish fauna is found at this site. Very well-preserved specimens of dark fish skeletons, embedded within the light-yellow micritic matrix, are the distinguishing marks for this site. Together with fossil fish, carbonized leaf fossil are found in the same strata at this locality, most likely representing remnants of historic coastal plants. Large irregular, spherical and ellipsoidal siliceous nodules are found within platy limestones as well, which may represent episodes of deep-water incursions in the shallow-water environments and blooming of Si-planktonic organisms (radiolarians, diatoms). They may also represent the introduction of volcanic material originating from submarine or subaerial eruption(s), possibly even from great distances, into the carbonate-platform environments (DURN et al., 2003; BARUDŽIJA, 2008).

Figure 3.16. Highly restricted site with high quality platy bituminous limestones, containing well-preserved fossilized fish, coastal plants and siliceous nodules at the Kolojanj site.

Rudist limestones (*Radiolitides* fauna) appear as thinner lenticular layers within these limestone sequences. It can be assumed, for Upper Senonian platy bituminous limestones with abundant fish fauna, coastal flora and siliceous nodules found at the Kolojanj site, that deposition occurred in a partially-closed anoxic lagoon with occasional deep-water incursions and the development of siliceous nodules.

Figure 3.17. Well-preserved fossil fish, about 17 cm long, possibly of genus *Scombroclupea*, from Upper Cretaceous platy limestone at the Kolojanj site.

The main lithological characteristics of platy limestone from the Kolojanj site are fine-grained mudstone textural types, horizontal lamination, bed thicknesses between 3 cm and 15 cm and light grey to white colouring. Dark bituminous and siliceous lenses appear locally within the beds. Beds are generally inclined toward the northwest and dip angles range from 25 to 40 degrees.

3.2.7 Boricevac (Cerov dolac) site

The significant site for Paleogene (probably Paleocene) platy limestone is located in the wider area of the village of **Cerov dolac**, east of Posušje. In these platy limestones typical freshwater-brackish fauna with small gastropods (*Stomatopsis, Cosinia*) is found. These limestones are highly bituminous, which indicates that they originated in semi-closed and closed freshwater-brackish lagoons and lakes. This formation has been characterized as the so-called Liburnian layers. Several studies examined the micro- and macrofossil assemblages of these layers in the project area. Sedimentary environments and conditions were also interpreted within these studies in the past (Slišković et al., 1962, 1968, 1978, 1989).

Figure 3.18. One of the large abandoned quarries of Lower Paleogene platy limestone at the Borićevac site.

These earliest Paleogene sediments are lithologically characterized by light grey to brown platy limestone lithofacies, containing horizontal and stromatolitic laminations, and with layers averaging in thickness from 8 to 20 cm. Beds are generally inclined toward the northwest, with dip angles varying due to synsedimentary folds. This lithofacies is a base-member of the succession of rocks that cover well-known bauxite deposits in the project area.

3.2.8 Tepčići site

Platy limestones of Late Paleogene age were not, until now, described in the project area. However, Eocene platy limestones at the **Tepčići site** east of Čitluk, are explored within this project and in several previous studies (Glamuzina, 2012) as well. At the Tepčići site there is a restricted zone with platy limestones, which contain abundant macrofauna (*Lucina*, *Corbula*, *Trapezium*, *Cardium*, *Cerithium*) and less frequently terrestrial fossil flora (*Nypa*, *Eucalyptus*). These limestones were deposited in a brackish lagoon and/or in estuary environments. Occasionally they contain lenses or thin sequences of marly limestone and clayey-sandy limestone.

Figure 3.19. Paleogene (Eocene) platy limestones in an old drywall at the Tepčići site.

This lithofacies is characterized by a limited and confined zone of irregular shape within the end portion of the Paleogene syncline structure. The main lithological characteristics are grey colours, wackestone to grainstone textural types, horizontal lamination, bed thicknesses between 2 cm and 12 cm, strongly expressed synsedimentary folds, and locally increased marly (clay) content.

3.2.9 Grabova draga2 and Konjovac site

The **Grabova draga2 site** is an elongated zone (stretched in the Dinaric direction, NW-SE) with platy limestones containing macro- and microfauna of Early- to Middle-Eocene (Ypresian to Early Lutetian) age. These limestones are deposited in marine environments. A particularly representative site with thin-layered limestone “slates” in alternation with marly limestones of Paleogene age is located northeast of the village of **Konjovac**. A well-preserved coral reef (entire ecosystem consisting of corals, bryozoans, worms, algae, forams, gastropods, bivalves and echinoids) (Fig. 3.20.) is particularly significant for this site. As a result, the Konjovac site will be protected as a natural geoheritage site, but not in the frame of this project.

Figure 3.20. A part of the lithified coral reef at the Konjovac site from the Eocene age.

Figure 3.21. Old dry-walls made of Middle Eocene platy, shaly and fractured (cleavage) fossiliferous limestone near the site of Konjovac.

Figure 3.22. Outcrops of Paleogene platy limestones on the easternmost part of the Grabova draga2 site.

At the Grabova draga2 site, the main lithological features are characterized by the presence of thin-bedded to platy, grey to yellow-brown limestones of mudstone to packstone textural types, with average layer thickness ranging from between 3 cm and 8 cm (Fig. 3.22.) and with frequent marine trace fossils and clusters of benthic foraminifera. Beds are generally inclined toward the southwest, with a dip angle ranging from 40 to 70 degrees.

The main lithological features of the Konjovac site are thin-layered and foliated grey to yellow limestones of packstone to grainstone textural types, containing abundant skeletal parts of fossils (predominantly bivalves and gastropods). These slaty limestones present immediate overlay of bauxite deposits in the project area. Bed inclinations vary, depending on local or basic paleoreliefs, with dip angle ranging from 5 to 30 degrees.

3.2.10 Trn (Široki Brijeg) and Posušje site – Miljevina Neogene platy limestones

The youngest significant formation in the project area is a platy limestone formation from the Miocene age. These sediments were deposited, as discussed for some previously described sites (the Trn site, near Široki Brijeg, and the Posušje site as well), in continental lakes and in freshwater basins. Marly limestone lithofacies prevail.

Figure 3.23. Platy limestones from the Miocene age in a dry riverbed of the Ugrovača River, at Trn locality.

Limestones are characterized by thin-layered platy limestones of mudstone to grainstone textural types. Occasionally, increased marly (clay) appears. Individual lenses of marls and sandstones within limestone sequences also occur. On some of the upper bedding planes wave ripples are clearly visible. Beds are gently inclined.

3.3 STRATIGRAPHY AND AGE

Almost all of the Cretaceous platy limestone sites lie in the Aptian to Turonian stratigraphic range. The majority of Cretaceous platy limestones are from the Cenomanian age. This is well correlated with the platy limestone stratigraphic position in Croatia (Dalmatia – Milna formation), as well as with the coastal region of Slovenia (Kras – Povir formation). Upper Senonian (Maastrichtian and possibly even Paleocene) carbonate successions in the project area also see significant occurrences of platy limestones, which are exploited by local residents in the village of Kolojanj, south of Čapljina. Furthermore, a significant Paleocene

platy limestone site is located northeast of Posušje (Boraćevac locality). There are also a number of smaller Eocene platy limestone sites considered within the project (Grabova draga2, Tepčići and Konjovac). Miocene thin-layered limestone at the Trn and Posušje sites represents the youngest platy limestone considered within the project.

In the Herzegovina-Neretva County, Cretaceous platy limestones predominate in most of the sites. The Vrdi, Raška Gora and Podveležje sites are of Early Cretaceous to Cenomanian age; while the Dretelj, Mostarsko Blato, Žovnica, Slipčići and Kolojanj sites are of Late Cretaceous age. Only at the Tepčići site does Middle Eocene platy limestone appear. In the West Herzegovina County, most sites are also of Cretaceous age. The Drinovci and Mostarska vrata sites are of Early Cretaceous age and the Gabrova draga1, Zvirovići, Miletina-Crnopod, Radišić-Proboj and Gornji Crnač sites are of Early Cretaceous to Cenomanian age. The Boraćevac site is of Paleocene age; the Grabova draga2 and Konjovac sites are of Eocene age; and the Trn and Posušje sites are of Miocene age.

3.4 HISTORICAL USE OF PLATY LIMESTONE

The most widely used type of platy limestone in the past is the stone from the Podveležje site, which was used intensively during the time of Ottoman rule in Herzegovina. At that time, platy limestones used for the roofs of houses in the Old City of Mostar (around the Old Bridge) (Fig. 3.25.) was intensively quarried from the Podveležje area. Various buildings in Blagaj, near the Buna river spring, and the City of Stolac were also roofed with platy limestones from the Podveležje area. It is estimated that the earliest use of platy limestones in the project area probably dates back to the Bronze Age. A complex of masonry city walls and tumulus, constructed entirely of Upper Cenomanian platy limestone (Fig. 3.24.), has been revealed west of the village of Dretelj (Čapljina Municipality).

Figure 3.24. Prehistoric (Bronze Age or Illyrian) rampart of Cenomanian limestones at the Dretelj site.

Tombs from the Bronze- and Illyrian Ages within the tumulus have been discovered at several sites in the project area, and been found to be constructed of several (usually 4 or 5) layers of side- and cover- pieces of platy limestone.

Figure 3.25. Roofs of platy limestone from the Podveležje site, near the Old Bridge in Mostar.

Highly important archeologically remains of an Early Christian basilica (Fig. 3.26.) at the Tepčići site were built almost entirely of Eocene platy limestone from the same Tepčići location, which was simply harvested from the ground surface.

Figure 3.26. Remains of an early Christian basilica at the Tepčići site; Eocene platy limestone was used for some elements.

According to results from the field investigations of the project, most of the roofs of houses and buildings in the old Ottoman town of Počitelj were constructed of platy limestone from the (previously mentioned) locality of Dretelj near Čapljina. Another example of the historical use of platy limestone is the archaeological complex of Roman villas in Mogorjelo, near Čapljina. There, platy limestones (probably also from Dretelj) were used for the construction of staircases and parts around the windows (Fig. 3.27.).

Apart from the Mostar, Počitelj and Blagaj sites, Cretaceous platy limestones were used for roofing on other objects and buildings from the Ottoman period. The most significant among these objects are: (1) a mosque ("Čaršijska džamija") in the City of Stolac, with supporting facilities covered with platy limestones from Podveležje; (2) Lalića kula (Lalić tower) near Ljubuški, which is roofed with platy limestones from the Mostarska vrata site (see ID_5007); and (3) Majića kula (Majić tower) near Drinovci, which is roofed with platy limestones from the Drinovci site (Fig. 3.28.).

Figure 3.27. The ancient (Roman) archaeological complex 'Mogorjelo' near Čapljina.

Fig 3.28. Boundary building from the Ottoman period, the 'Majić tower' in the village of Drinovci, near Grude.

Apart from the Middle Ages and the time of Ottoman rule in Herzegovina, platy limestones were also intensively used for roofing of houses by local residents in the periods between the two World Wars and immediately after the Second World War. Most of these houses have been ruined and/or demolished. Some rare but valuable examples of such houses, however, remain within the project area, including one that was discovered in the village of Dretelj during the field investigations of the project (Fig. 3.29.).

More recent evidence of platy limestone usage is found in many dry walls, chapels and mills. Among them, prominent examples include dry walls in Zvirovići, in Borićevac (Fig. 3.30.) and

in Tepčići, in a chapel in Hutovo, and at the mill in Zagorje (in the Posušje municipality).

The youngest objects in the project area built of platy limestones are a number of houses in the villages southwest of Široki Brijeg (Fig. 3.31.). Most of these houses have their walls and exterior stairways made entirely of thin-layered and platy, often marly limestones from the Miocene age, and which are locally known as “miljevina”.

Figure 3.29. Old house with a roof made of platy limestone from the Cenomanian age, in the village of Dretelj.

Figure 3.30. Impressive old dry wall, made entirely of platy limestone from the Paleocene age, on the Borićevac site.

Figure 3.31. One of many older houses with walls made of platy limestone from the Miocene age, at Široki Brijeg.

3.5 SUMMARY OF GEOLOGICAL RESEARCH ON PLATY LIMESTONE

The HERAG team worked in close collaboration with the project partners and other external experts in the process of determining a common definition of platy limestone as well as on the compiling of data for the database and geological maps. After an extensive geological survey and according to the recognized characteristics, spatial occurrence of all types of PL were mapped at a general scale of 1:50,000, along with an assessment of their general potential as PL. Platy limestone occurrences of recognized value for the project are shown in Chapter 3, while more detailed descriptions of PL as mineral commodity, which includes natural protection and other spatial restrictions, are shown in Chapter 4. All data on PL occurrence is included in the database and on the enclosed CD (Excel tables, analytical and photo material, .shp files).

The project area is characterized by a succession of carbonate platform carbonates (80%), along with various overlying carbonate-siliciclastic sedimentary rocks (20%). However, the

most interesting PL horizons were recognized within Cretaceous lagoonal and shallow-marine deposits.

In accordance with the 1:50,000 map of PL occurrence and POLYGON attribute tables, we reviewed the importance of low potential, potential and high potential types, as indicated on the maps. Low potential types are distributed sparsely in thin horizons within the region, as parts of the units that are shown on the general geological map at 1:250,000 (Chapter 2), but without significant platy limestone content.

Potential and high potential PL types were mapped at scale 1:50,000 (**Appendix 3**). **POTENTIAL** polygons are marked **yellow**, while **HIGH POTENTIAL** types are shown in **orange** on the multicolour topographic base map. The data served as a basis for the evaluation of listed types of platy limestone as a mineral commodity and for the identification of potential quarrying areas. In the Herzegovinian part of the project area most of the PL sequences are only a few meters thick, in places less than a meter, but the spatial occurrence of PL depends significantly on the relation of the geological (bed dip angle) and morphological (slope angle) features. Detailed lithological and paleontological characteristics of studied PL types are presented in chapter 3.2.

4 PLATY LIMESTONE AS A MINERAL COMMODITY AND ITS NATURAL HERITAGE

4.1 INTRODUCTION

After reporting on the general occurrence of platy limestone (PL) in the project area covered by B&H partners, we focus on PL as a mineral commodity with respect to general spatial limitations of usage and its natural protection. The aim of this project action is to identify possible sources of the most promising types of platy limestone (high potential PL units and localities) within the investigated regions of the Adriatic karst. For this purpose, the stratigraphic position, age, and the major sedimentological and paleontological characteristics of various platy limestone units were studied, both in situ and in the subsequent laboratory analyses. According to the recognized potential and spatial occurrence of all types of PL previously defined on maps at a general scale of 1:50,000, we evaluated selected types of platy limestone as a mineral commodity in order to identify potential quarrying areas. The quality of selected samples has been assessed on the basis of field observations combined with geomechanical laboratory analyses of flexural strength. In the selected and most promising sites, detailed sedimentological and paleontological investigations were conducted (their age, paleontological and lithological characteristics, genesis, etc.) for the purpose of proposing them for natural protection.

The study of platy limestone as mineral commodity and the identification of potential quarrying areas requires the gathering of data from WP3 (Act. 3.3) and correlation with WP4, WP5 and WP6 data, with the aim of analyzing and synthesizing the limitations of the use of platy limestone, such as land use, natural, physical, social and legislative limitations that should be included in the work of action 3.4. In this report, we use all of the data on PL occurrence and working materials from WP4 and WP5 to propose potential quarrying areas. However, all data should be unified and incorporated into a joint GIS database (work of WP7), where it will be overlaid with geological maps indicating the spatial occurrence of platy limestone. Following the coordination established at the meetings in Trieste (February, 2014), Split (April, 2014), Međugorje (June, 2014), Matavun (October, 2014), and Piran (December, 2014), we evaluated spatial limitations of PL usage, proposed the most interesting natural heritage sites, and estimated the quality and quantity of PL reserves,

either as selected high-potential polygons, or selected locations proposed as potential quarrying areas. In addition, we proposed some general guidelines for the sustainable exploitation of platy limestone.

4.1.1 ASSESSMENT OF PL AS A MINERAL COMMODITY IN GENERAL

Different types of platy limestone (PL) are shown and described in the chapter on PL in general. The quality and quantity of each type of PL has been evaluated during the fieldwork. The most representative samples were collected from both the outcrops and the buildings. Furthermore, estimations as a basis for the evaluation of PL as a mineral commodity and for the identification of potential quarrying areas were discussed among the members of the team, as well as with the local inhabitants. After all the data was collected and unified and the maps of platy limestones prepared, office work continued and GIS-based databases were prepared. The GIS data was used to assess the quantity of each high-potential type of PL. Finally, we used both the database and the maps to prepare the report.

For the purposes of assessing PL as mineral commodity with a view to possible future sustainable exploitation we focused only on high potential units and localities. In addition, possible impacts on the natural environment were also taken into account.

4.2 HIGH-POTENTIAL PLATY LIMESTONE OCCURRENCE, LIMITATIONS AND GEOLOGICAL ASSESSMENT OF IT AS A MINERAL COMMODITY

In Chapter 3 all major occurrences of platy limestone in the karstified part of the project area are defined and described in detail. Zones with platy limestone are presented as polygons on the map (at 1:50,000). Through the fieldwork (including geological mapping and collecting of data from local inhabitants and platy limestone users) and through the analyses of the collected material and documentation, several characteristics of platy limestones are identified for the most important sites. These characteristics refer to the quality of platy limestones as a mineral resource and identify certain potential areas for exploitation.

Considering the average thickness of platy limestone within the geological unit, which is defined and accepted within in the RoofofRock project as the main criterion for the potential of platy limestone, several potential areas with platy limestone can be clearly singled out on the maps:

1. The area around the Podveležje site
2. The area around the Zvirovići site
3. The area around the Drinovci site

4 The area around the Raška Gora and Vrdi sites

5. The area around the Borićevac site

After the evaluation of all platy limestone sites within the entire project area in Bosnia and Herzegovina, the Podveležje site with Cretaceous platy limestone was identified as the largest and highest potential site. Potential platy limestone sites of considerable thickness and significant rock quality, as e.g. at the Raška gora site, were also discovered. According to the platy limestone thickness within the whole sequence thickness criterion, all identified sites are classified into three categories and represented by coloured polygons on the GIS map:

1. LOW POTENTIAL (< 10 % of PL, no colour)
2. POTENTIAL (10 – 30 % of PL, yellow colour)
3. HIGH POTENTIAL (> 30 % of PL, orange colour)

Below, we present six of the most important platy limestone localities where the material has potential as mineral commodity.

PODVELEŽJE SITE – EAST OF MOSTAR, VELEŽ MT.

According to the collected data and the results of the fieldwork within the RoofOfRock project, a broad area around the Podveležje site, composed predominantly of thin-bedded and platy limestones, can be clearly identified. Almost the entire southern side of the Velež Mountain consists of limestone from the Early and Late Cretaceous age. This zone of platy limestone probably represents the largest zone of platy limestone across the entire RoofOfRock project area. Extending 16 km long and some 6 km wide (Fig. 4.1.), and stretched in the Dinaric direction (NW-SE), the entire zone is characterized by layers uniformly inclined toward the north and northeast, with a dip angle of between 10° and 30°. These are predominantly fine-grained, light-grey to yellowish, thin-bedded limestones, with layers of between 3 cm and 20 cm. As a rule they contain a very small percentage of dolomite.

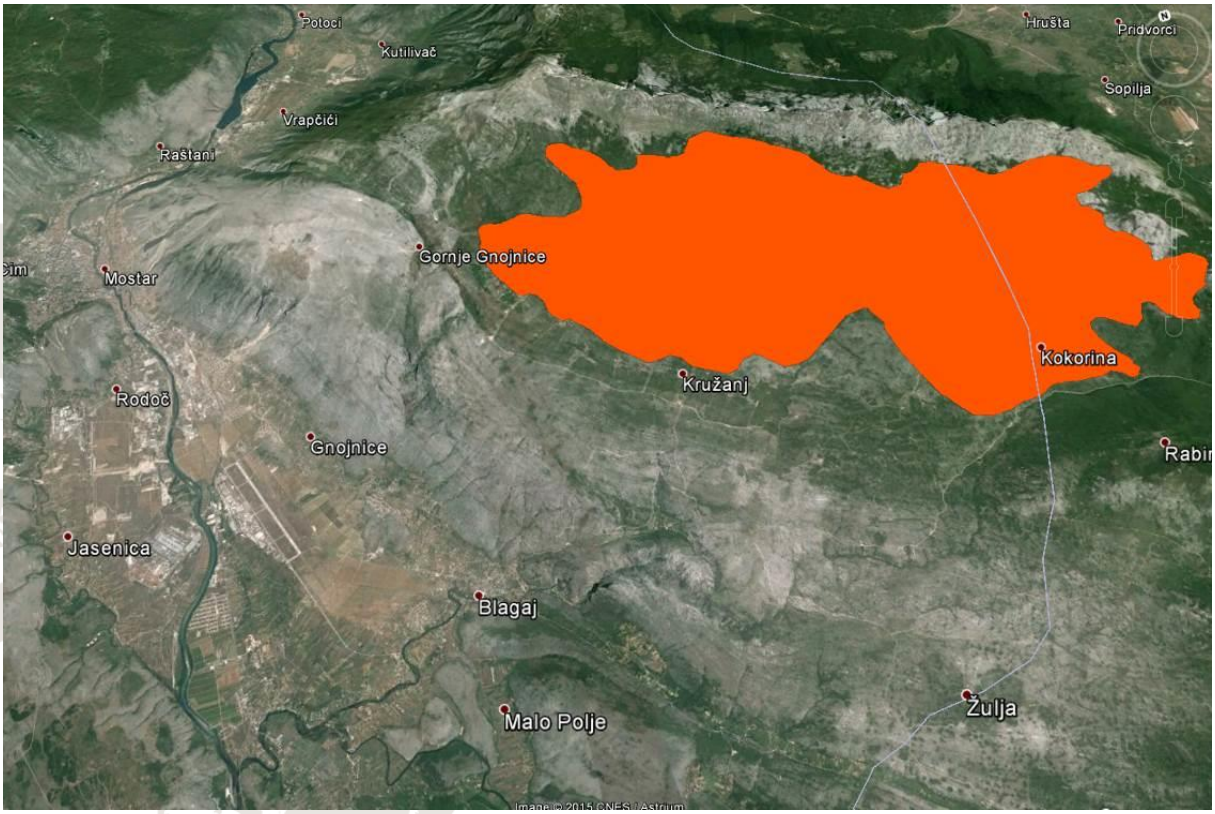

Figure 4.1. Map of the Podveležje PL site.

A large zone of platy limestone on the Podveležje site extends through several Cretaceous stratigraphic units, with the largest area occupied by limestones from the Albian-Cenomanian age. Platy limestone (with a thickness of more than 30% within a single unit) extends across the entire southern slope of the Velež Mountain, east of the city of Mostar and the village of Dobrić, all the way to Nevesinjsko polje and the village of Bojišta. A large number of active and inactive quarries are present in the area, especially in the eastern part. It is worth mentioning that these platy limestones have been excavated and used for building and construction since Prehistoric times. Numerous remains, "gradinas" and tumuls, are evidence of their usage in the Bronze and Iron Ages. They were most widely used for construction purposes in the Middle Ages, during the reign of the Ottoman Empire, when these platy limestones were extensively used to cover the roofs of hundreds of houses in the Old Town of Mostar (around the famous Old Bridge), as well as in the Old Towns of Blagaj, Stolac and Počitelj. More recently, these limestones have been exploited and used for roofing on many buildings, especially those built for touristic purposes. A good example of such (recent) usage for touristic purposes is the Herceg Ethno Village in Medjugorje, where all of the houses and the paths between them are fashioned from Cenomanian platy

limestones from Podveležje site (Fig. 4.2.).

Figure 4.2. 'Herceg Ethno Village' tourist complex near Medjugorje, with roofs of stone from the Podveležje PL site.

Previous lithofacies studies determined limestones of almost the entire Cretaceous range of stratigraphic units outcropping on the southern slope of Velež Mountain. The boundaries between some of the stratigraphic units are only tentatively determined. On the other hand, boundaries between some of the other units are unconformable and therefore clearly visible in the field. Almost all units are stretched in the Dinaric direction (NW-SE) and alongside the Velež Mountain as well. From the profile in Fig. 4.5 (in SW-NE direction) the youngest Cretaceous units can be seen at the SW part of the profile, followed by the oldest Cretaceous units in the longest (middle) part of the profile, and by the Cenomanian units in the uppermost part of the profile.

Previous studies (particularly Slišković, 1963), determined numerous fossils of micro- and macrofauna in the observed units of Cretaceous age. Some of these fossils are very good stratigraphic markers. The youngest Cretaceous units (ranging from Turonian to Maastrichtian) in the lower part of the profile, are enriched in rudists, including several forms of less frequent or rare species, including *Pseudopolyconites giganteus*, *Katzeria hercegovinensis, Vaccinites ultimus, Petkovicia verajana* and *Sphaerulites boreaui*. Additionaly, *Cuneolina, Dicyclina* and *Keramosphaerina tergestina* microfossils are also found in these units. Lithologically, these are thick-layered and massive, white to light-grey micritic limestones, often recrystallized and containing networks of thin calcite veins. These units are

in tectonic contact with Lower Cretaceous units (forming an overturned anticline). A very narrow zone of Albian-Cenomanian sediments, predominantly dolomites, and Lower Cretaceous thin-bedded limestones, ranging from 'Neocomian' to Albian, follow. The platy limestones at the end of the profile, and at the higher altitudes of the slope sections, are from the younger Cenomanian age, and contain chondrodonts and radiolitid rudists.

Figure 4.3. Small fish fossil discovered during WP3 expert fieldwork on the Podveležje platy limestone slab.

An additional paleontological element at this site is the fossil fish (special specimens of *Coelodus* sp.), found in the Albian-Cenomanian platy limestones. Furthermore, some other forms of fossilized fish and their traces were discovered more recently, i.e. small curved needlefish and an interesting shark's tooth (Fig 4.4.).

Figure 4.4. Fossilized shark's tooth, also discovered during WP3 expert field work.

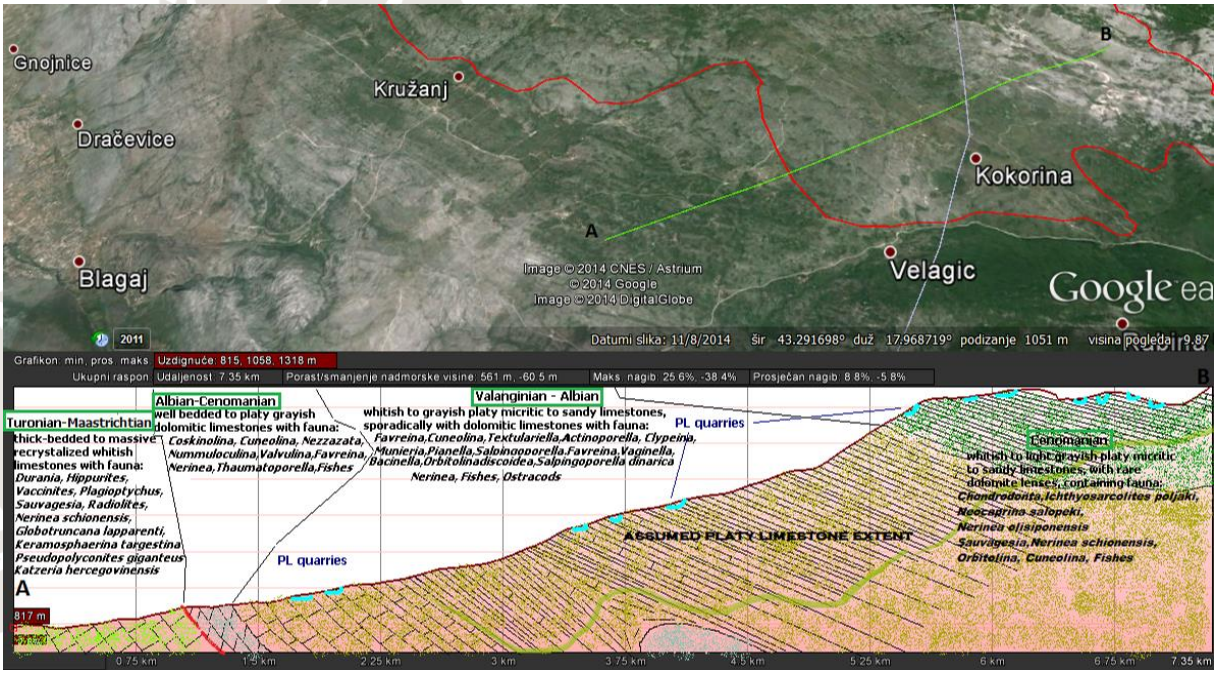

Figure 4.5. Geological profile (green line) through Cretaceous limestones on the eastern part of the Podveležje PL site/polygon (red). PL localities and quarries within the carbonate succession are marked in light blue.

Compactness, uniform thickness (ranging from 3 up to about 15 cm), an almost uniform dip direction, and no visible synsedimentary folding or delamination, are strong indicators that raise the potential of this platy limestone zone considerably. Limestones are mostly of mudstone to packstone texture types, and are compact and colourful (variable colours depend on the position of the layer within the quarry). Especially interesting and decorative

lithotypes are the red and reddish-brown layers, intercalated with a mesh of yellow veinlets, which are quarried in the middle part of this zone (Fig.4.6.). These colours also enhance their potential for usage as architectural natural stone, for both external and particularly internal applications.

Figure 4.6. Red, decorative type of Podveležje platy limestone.

Figure 4.7. Numerous small ancient (medieval) PL quarries at the Podveležje site, among which are several newly reopened and activated quarries.

Lithofacies and biofacies characteristics of the Lower- and Middle Cretaceous sequences with platy limestone indicate deposition in shallow, muddy to sandy marine lagoons. Occasional episodes of shallowing and intrusion of meteoric waters into lagoons were recorded. Thin-layered limestones are mainly deposited in the central parts of these lagoons. Changes in the sedimentary environments of the Early Cretaceous and Paleogene ages are well documented in the sedimentary sequence in the western part of the Podveležje site. Considering a very thick succession of thin-bedded and platy limestones formed in shallow sea environments, there is no doubt that these layers (most probably those of Albian age) contain other Cretaceous vertebrate fossils such as reptiles, fish and especially dinosaurs in the form of fossilized tracks or footprints.

Based on recent satellite image overviews and fieldwork on the sites, at least 50 quarries of platy limestone have been recorded within the boundaries of the Podveležje site polygon (Fig. 4.9.). These are not, as a rule, large quarries, because these platy limestones are only quarried by local residents. Large quarries for commercial purposes are rare. Most of the quarries are actually abandoned surface excavation pits. It should be noted that there are a large number of these small quarries/pits in the area that have existed since Medieval times. Today these quarries are heavily indurated and vegetated, and therefore hard to recognize in the field, but expert geologists have found some parts in the area with numerous small Medieval-age quarries, among which some have been newly reactivated (Fig. 4.7.). Considering the spatial distribution of these quarries in relation to the geological and relief characteristics, it is evident that a number of quarries, especially the most recent of them (Fig. 4.8.), are located in the highest elevations in the area (1300–1400 m above sea level), within the sequence of Cenomanian platy limestone. Another zone of quarries is located in the lower parts of the area, which are built of Lower- to Middle Cretaceous ("Neocomian" to Albian) platy limestones. Therefore, it can be concluded that the entire area inside the Podveležje site polygon has a high platy limestone potential, while surrounding areas probably have moderate to high potential as well.

Fig 4.8. Interesting and picturesque old dry walls made of Podveležje platy limestone north of the village of Podveležje.

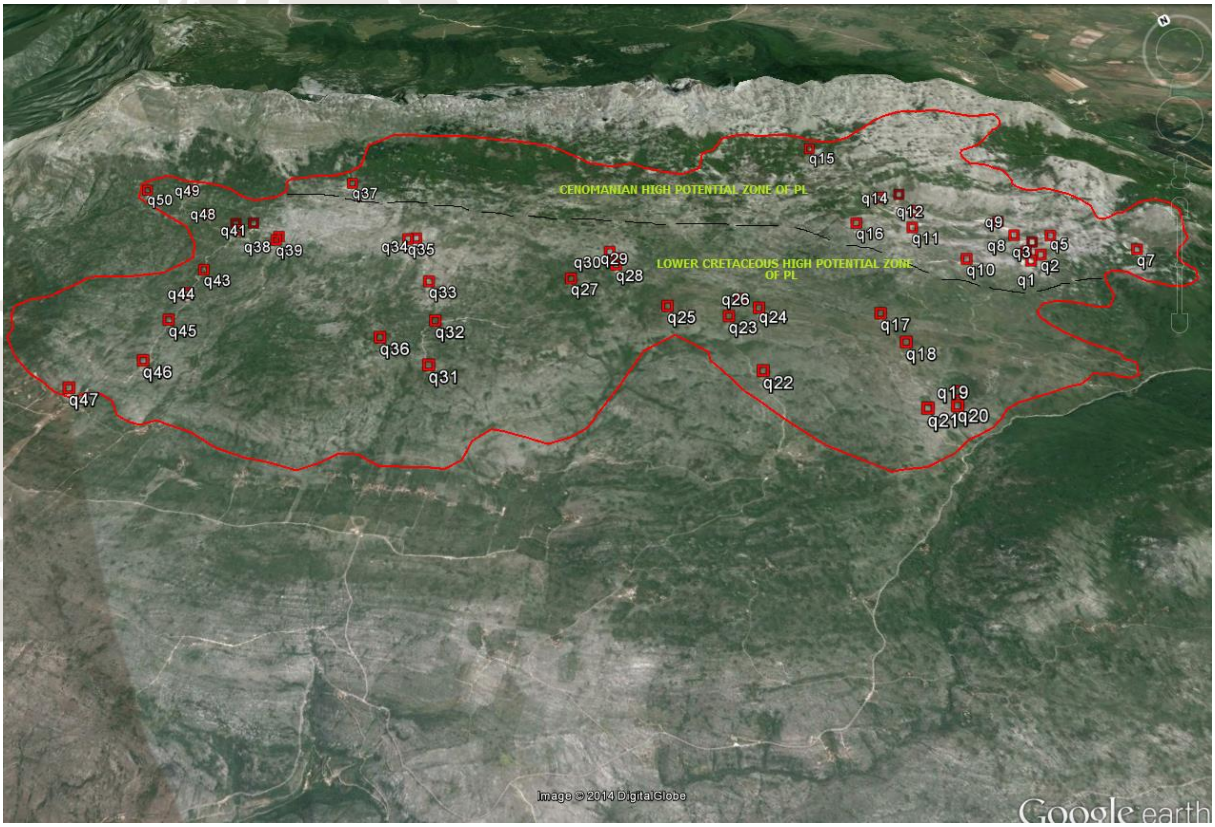

Figure 4.9. Recognized quarries (active and inactive) of platy limestone in the Podveležje PL polygon.

ZVIROVIĆI SITE – NORTH OF ČAPLJINA

In the area north of Čapljina the long (9.5 km) and narrow zone of platy and well-bedded limestones from the Cenomanian age is determined (Fig. 4.10.). One of the largest quarries within the entire project area in Herzegovina is located in this area, more precisely at the Zvirovići-1 site. This quarry has terraced floors excavated over 200 m along the main strike-axis of platy limestone layers (Fig. 4.11.). The site is about 140 m wide, and the trend is to develop quarrying toward the north in the future. Several smaller quarries are located southeast of the Zvirovići-1 quarry described above,. Approximately 2.5 km toward northwest is the Zvirovići-2 site, another large quarry located within the same zone of Cenomanian platy limestones (Fig. 4.12.). These limestones are characterized by their particular quality, compactness and uniformly thick (4–10 cm) layers. Lithologically, these are mudstone to wackestone limestones and laminated stromatolitic limestones. They are also characterized by their attractive orange and yellow colours. Additionally, these platy limestones show only minor delamination or cleaving in very thin layers. Moreover, they exhibit almost uniform inclination within the Cenomanian platy limestone zone, together with a pronounced lack of synsedimentary folding. All these features are additional indicators contributing to the high potential evaluation for this site, especially in the area between the Dretelj and Zvirovići-1 sites (Fig. 4.13.).

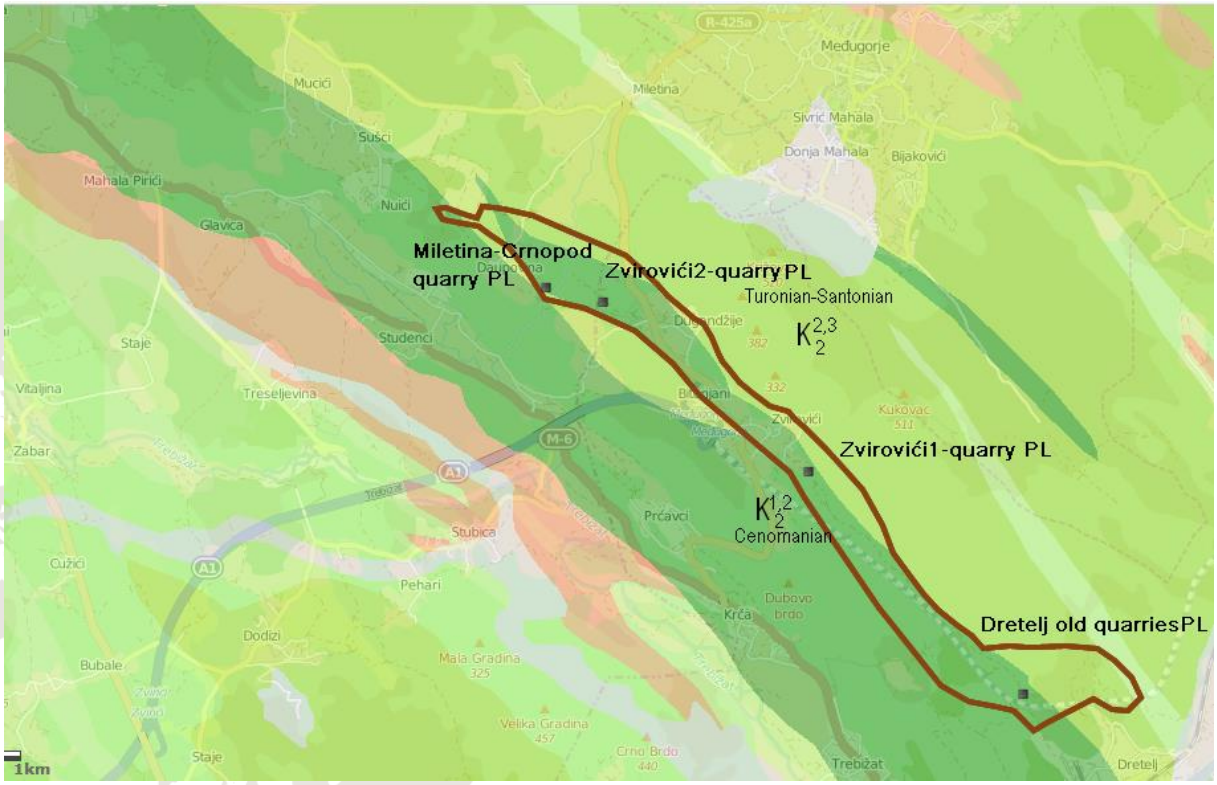

Fig 4.10. Zvirovići PL site/polygon, including several of the most important quarries.

Figure 4.11. Zvirovići 1 quarry, one of the largest PL quarries in the entire BiH project area.

Figure 4.12. Zvirovići 2 quarry, the second largest active quarry in this long Cenomanian PL zone.

Figure 4.13. The highest potential area (orange circle) with PL in the frame of the Dretelj-Zvirovići PL polygon.

The Dretelj site is located at the south-eastern part of this zone. This site was found during the fieldwork related to the RoofOfRock project, with the usage of these high-quality platy limestones for roofing in the old medieval City of Počitelj determined. These two sites (Dretelj and Počitelj) are closely related, across the Neretva river. Prehistoric objects such as tumuls and "gradinas" (most probably from the Bronze Age), are made almost entirely of

these platy laminated limestones, and are also found at the Dretelj site and surroundings. Dating these limestones to the Cenomanian age is corroborated by numerous *Chondrodontae* shells and Radiolitidae rudists (*Praeradiolites, Radiolites*). Additionaly, in the north-western part of this zone, at the Miletina locality, attractive rudist macrofauna (Caprinidae, Caprinulidae, Caprinuloideidae, Ichthyosarcolitidae, Monopleuridae and Radiolitidae) has been discovered. Non-rudist fauna of bivalves (*Neithea, Cardium, Chondrodonta*) and nerineid snails are found together with the above-mentioned rudists. On the geological profile across this zone of platy limestones rhythmic stratification representing shallowing upward cycles are visible. It has been determined that the zone extends toward the northwest of the village of Miletina and crops out near the village of Crnopod.

Further toward the northwest, Albian-Cenomanian dolomitic limestones continue, forming the core of an overturned anticline structure. Bellow this overturned anticline, with the core made of Albian-Cenomanian dolomitic limestones and with the limbs made of Cenomanian thin-bedded limestones, abandoned quarries of platy limestones at several sites along this zone (Mostarska vrata, Radišići-Proboj and Klobuk – Fig 4.14.) have been determined. Unlike limestones from the previously-described eastern Cenomanian platy limestone zone (Dretelj – Zvirovići), platy limestones in these western sites are intensively synsedimentary folded (Fig. 4.15), and easily break down into smaller pieces. Locally they also contain higher a proportion of the dolomitic component, due to which fact they have lower compressive strength characteristics. Therefore, they were not classified as high-potential platy limestone sites. Although considered as potential to low potential, it should be noted that these platy limestones were used for roofing in the late Middle Ages. The most prominent example is the show-case house nr. 5 - Lalić tower, in the village of Mostarska vrata (Fig. 4.16).

Figure 4.14. PL sites/polygons along Cenomanian zone.

Figure 4.15. Synsedimentary folded platy dolomitic limestones near Radišići site.

Figure 4.16. Selected show-case house – the medieval 'Lalića tower' near Ljubuški, with roof of PL from the Mostarska vrata site.

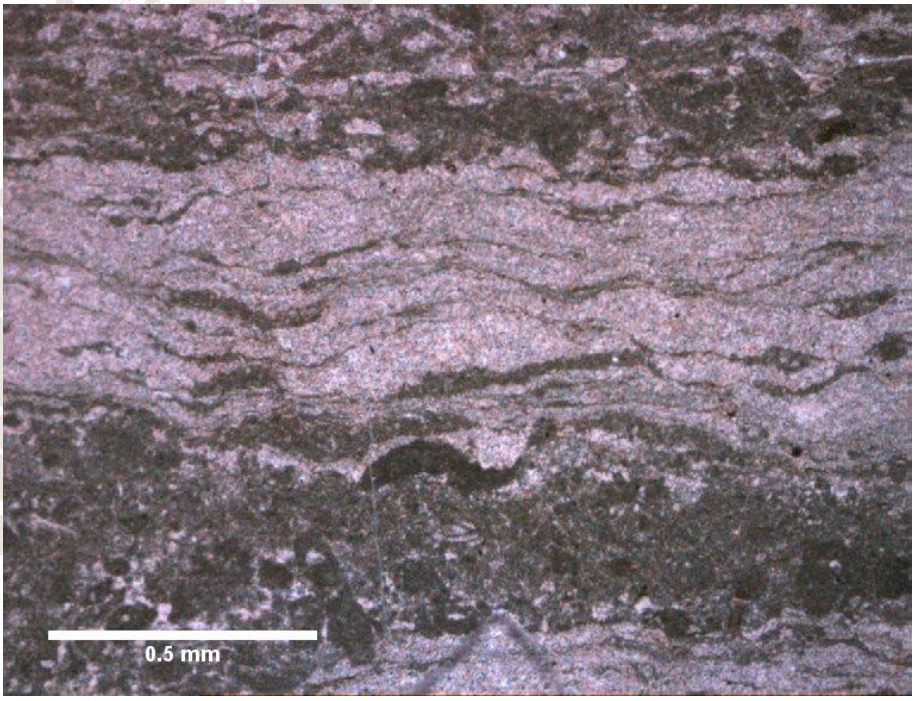

Figure 4.17. Microphotograph of laminated mudstone and stromatolitic packstone from Lower Cretaceous platy limestone locality of Mostarska vrata.

DRINOVCI SITE – SOUTH OF GRUDE

At the Drinovci site (south of Grude), Albian-Cenomanian platy limestones are determined in a zone 4.5 km long and 0.7 km wide (Fig. 4.18.). This zone extends in the Dinaric direction

(NW-SE), from the village of Peć-Mlini south-east, all the way to the border with the Republic of Croatia. Two quarries are identified in this zone: a smaller, inactive quarry in the eastern part (Fig. 4.19.), and a larger, active quarry in the western part of the zone. In the eastern quarry, layers are inclined mainly towards the north, and in the western quarry layers are inclined towards the south-west. Thin-bedded and platy limestones, occasionally dolomitized and synsedimentary folded, are the main lithofacies. They are underlain by limestone breccia with a red matrix, which is widely observed at the Aptian-Albian boundary in Dinaric Karst and which is interpreted as regressive emersion breccia (JURKOVŠEK et al., 2013). Platy limestone sequences are overlain by Cenomanian, massive and thick-bedded, dolomitic limestones and dolomites. An interesting site with Albian-Cenomanian grey dolomitic limestones containing abundant fossils of primitive rudists (Requieniidae family - *Toucasia, Requienia* sp., etc.), was identified north of the main zone with platy limestones, on the asphalt road-cut south of the Nuga lake (Fig. 4.21.).

Like in the previously-described site, alternating layers of fine-grained platy limestones, well-bedded limestones, dolomitized stromatolitic limestones and limestone-dolomite layers showing emersion features indicate cyclic sedimentation of shallowing-upward cycles as recorded and well described throughout the Dinaric Karst (TIŠLJAR, 2001). Although platy limestones at this site are synsedimentary folded, due to the relatively large extension of this platy limestone zone and due to their historical usage for local building and construction purposes as well, this zone is evaluated as a high potential zone for further exploitation. A representative example of the historical usage of this platy limestone is the medieval Ottoman (Turkish) border tower (at the medieval Ottoman-Venice borderline) – Majića kula in the village of Sebišina, near Drinovci. It is still preserved in its original form, with the roof made of platy limestones (Fig. 4.20.).

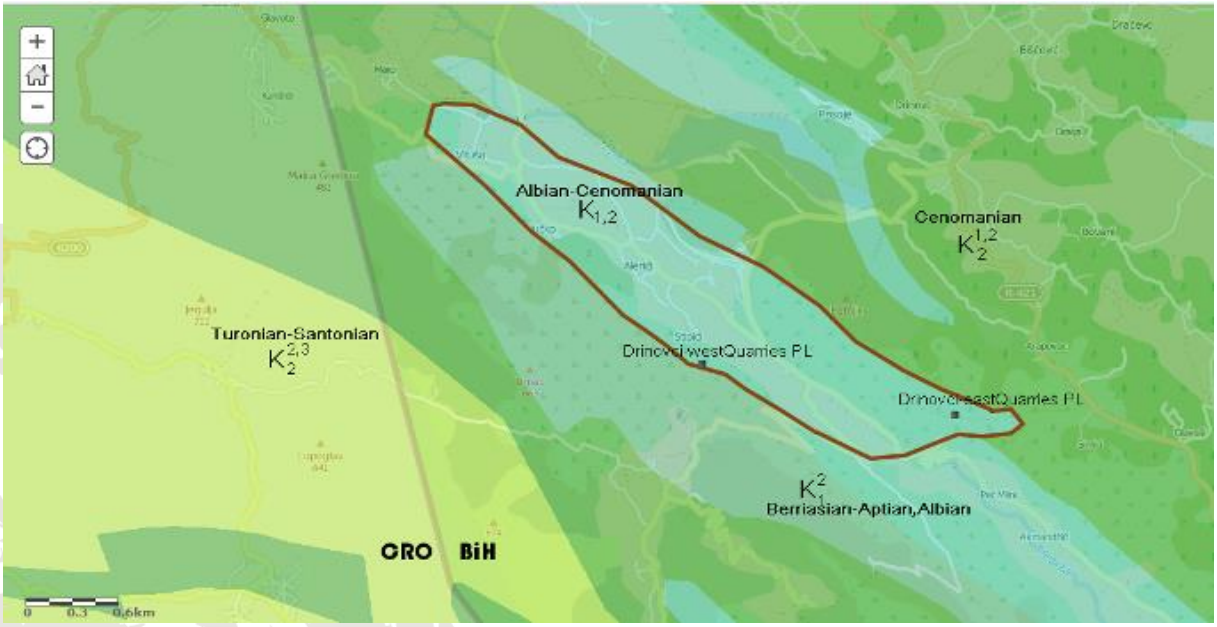

Figure 4.18. Drinovci PL polygon with incorporated quarries.

Figure 4.19. One of the smaller abandoned quarries of Drinovci platy limestone in the eastern part.

Figure 4.20. 'Majića kula', medieval Ottoman-era building south of Grude, covered by PL from the Drinovci site.

Figure 4.21. Limestone layer with numerous primitive rudist (Requienidae) sections.

RAŠKA GORA AND VRDI SITES – NORTH OF MOSTAR

Two large Cretaceous platy limestone sites, Vrdi and Raška gora (Fig. 4.22.), are located on the high karst plateau north of Mostar, on the right side of the Neretva River. In the Vrdi village area, Lower Cretaceous platy limestones are determined in a zone 3 km long and 1 km wide, extending in the Dinaric direction (NW-SE). These are fine-grained, yellow-grey to

red platy limestones of very good quality. They have been quarried and used locally for architectural and building purposes (Fig. 4.23.). Platy and well-bedded limestones are determined in the Vrdi area, starting already at the Jurassic-Cretaceous boundary. However, the Lower Cretaceous sequences contain generally thicker beds, of between 20 and 50 cm, while the Upper Cretaceous sequences are more platy and thin-bedded (max. 15 cm-thick beds). These sequences are very well lithostratigraphically and biostratigraphically described at Čabulja Mt. (BEHLILOVIĆ, 1964). The same paper also contains description of the micropaleontological and lithological characteristics of Neretva River-Vrdi plateau profile/column, which appears (slightly modified) in Fig. 4.25. Within these sequences of thin-bedded Lower Cretaceous limestones, preserved bivalve *Veniella weberi* and snail *Natica karakaschi* were found, indicating their Early Cretaceous (Valanginian) age.

Thin-bedded and platy limestones also appear continuously in an elongated zone in the northern part of the Raška gora area, southeast of the Vrdi site (Fig.4.24.). These limestones belong to the stratigraphic range from the Aptian-Albian to the Early Cenomanian. Despite the very large area of high-quality platy limestones at this site, they were not quarried in the past at all, due to the inaccessibility of the area. Discovery of this site during the fieldwork within this project constitutes a valuable contribution, because this zone is evaluated as a high potential zone for further exploitation. According to the abovementioned paper (BEHLILOVIĆ, 1964) describing the identical lithofacies sequence northwest of this site, these thin-bedded limestones are concordantly overlain by the limestones with *Salpingoporella dinarica* and underlain by the limestones with chondrodonts and neocaprinids. These Middle Cretaceous limestones are determined in the zone 6 km long and 0.5 to 0.6 km wide, stretching in the Dinaric direction (NW-SE). Additionally, a particularly valuable site with abundant fossil rudists and other molluscs has been discovered within the sequence of overlying Cenomanian limestones. Therefore, due to its natural heritage this site will be proposed as a geo-site (see chapter 4.5)

Figure 4.22. Spatial extent of Raška gora and Vrdi PL sites/polygons.

Figure 4.23. Local house built from Vrdi platy limestone.

Figure 4.24. Platy limestone at the Raška gora site showing desiccation cracks on the upper bedding plane, indicating a shallow-marine (intertidal) environment.

Figure 4.25. Geological profile of the Neretva-Vrdi plateau (modif. after Behlilović, 1964 & Mojičević et al., 1973).

POLOG (ŽOVNICA) SITE – WEST OF MOSTAR

Just a few kilometres to the west of the city of Mostar, at the foot of the Mikuljača hill, lies a recently discovered, relatively large geological unit composed of genuine platy limestone of Cenomanian age (Fig. 4.26.). This high potential platy limestone zone has only one relatively small and abandoned quarry on the easternmost part near the Žovnica hill (Fig. 4.28.). With prospecting of the limestone layers during the fieldwork in this quarry, rich chondrodont-rudist fossil association with excellent preservation of chondrodont shells was also discovered. Unlike the easternmost part of this zone, the other major western part of the zone contains high quality platy limestone, which until now was not known. This PL zone is characterized by alteration of thin-layered and platy limestones of fine-grained (mudstone to wackestone type) texture, with slightly thicker yet well-layered dolomitic limestone to stromatolitic limestone sequences. This lithological characteristic, together with paleontological content, clearly shows shallowing-upward cycles. Here it is important to mention that layers of genuine platy and thin-bedded limestone dominate through the entire sequence (Fig. 4.29.).

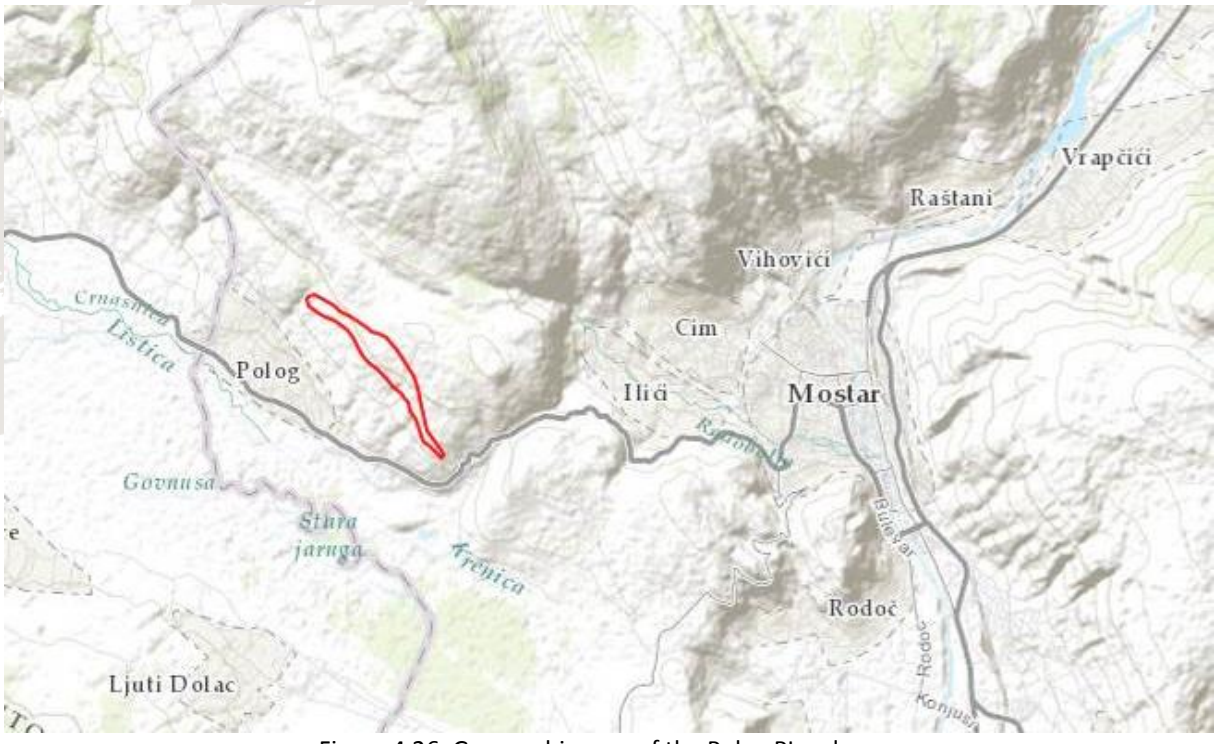

Figure 4.26. Geographic map of the Polog PL polygon.

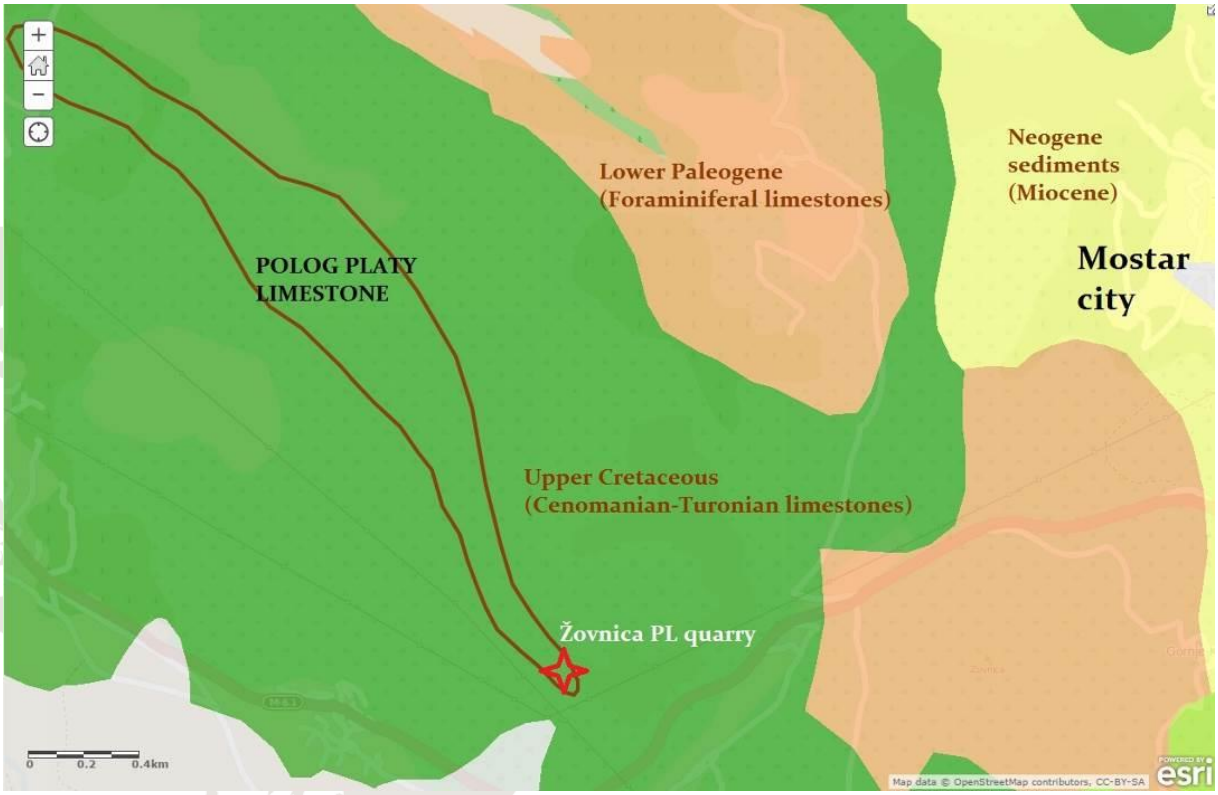

Figure 4.27. Geologic map of the surrounding area of the Pologe PL zone.

Figure 4.28. Žovnica platy limestone quarry in the easternmost part of the PL zone.

Figure 4.29. Outcrops of Polog platy limestone with slightly inclined layers toward the north.

BORIĆEVAC SITE – NORTH-EAST OF POSUŠJE

In the area northeast of Posušje, a zone with predominantly Lower Paleogene platy limestone, extending 2 km in the Dinaric direction, is determined. Here these limestones appear as genuine platy limestones, unlike their non-platy occurrence in other parts of the project area. Within these platy limestones, lenses with brackish and freshwater fauna (composed predominantly of *Melanopsis* and *Stomatopsis* gastropods) have been found. These gastropods, together with the accompanying microfauna, are indicative for calm, brackish and freshwater lagoons, or semi-closed lakes, existing through most of the Late Cretaceous and Early Paleogene eras.

In the southern and central parts of this zone, platy limestones are underlain by Upper Cretaceous rudist limestones, while in the northern parts they are underlain by bauxite deposits with a footwall of highly fossiliferous Middle Paleogene carbonate and clastic sediments (Fig.4.32.). These bauxite deposits were exploited in the past; more recently bauxite production has almost completely ceased. Until recently, however, platy limestones were exploited until only recently. Within this zone there are several abandoned quarries and one active quarry of platy limestone. Despite pronounced synsedimentary folding, this zone is evaluated as high potential zone for further exploitation, due to the large area of propagation, relatively uniform slope and azimuth of the layers and their uniform thickness

and compactness. Almost 90% of the area that are identified as Lower Paleogene geological units, and on the Basic Geological Maps marked as PcE_1 (Fig. 4.30.), are made up of platy limestones. In the remains of the old houses, especially on the old dry walls, the highly decorative and enduring features of platy limestones can be observed (Fig. 4.31.).

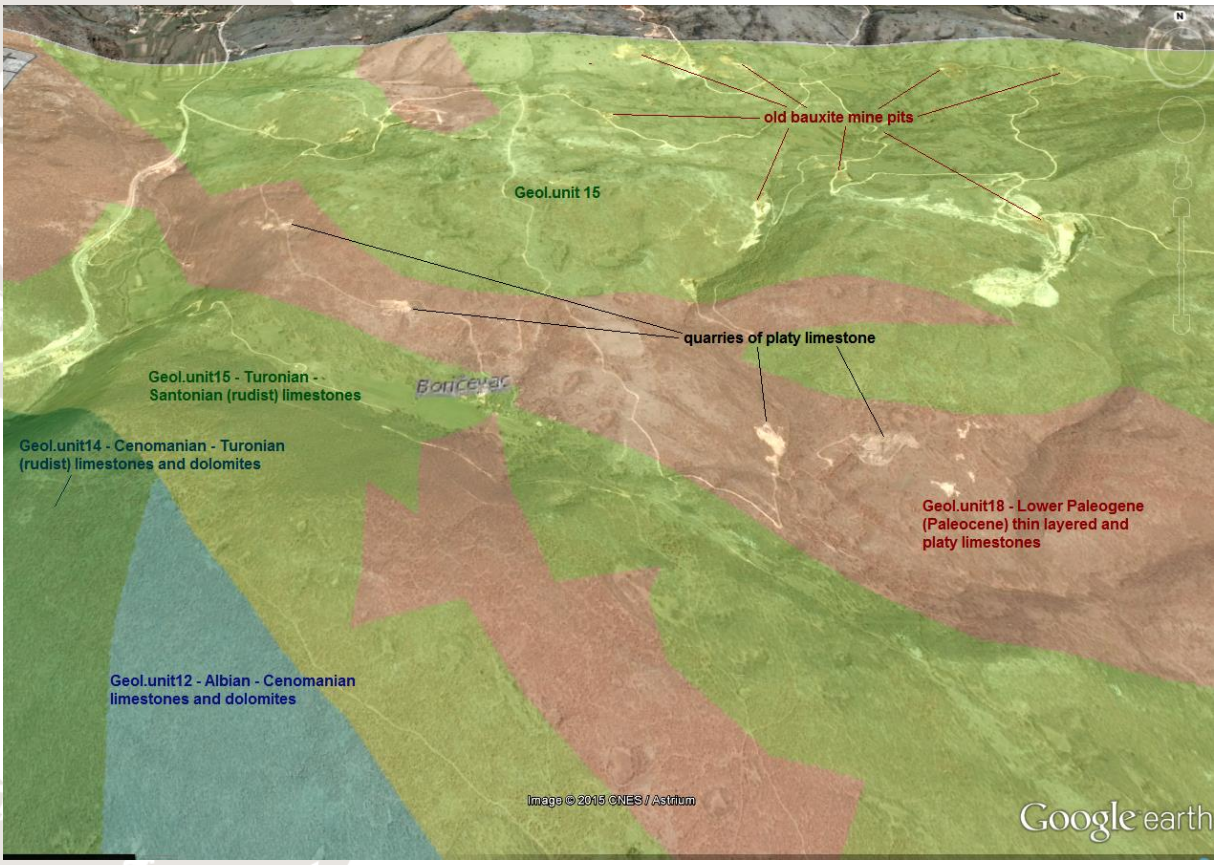

Figure 4.30. Boricevac platy limestone site with marked quarries (modified after Raić et al., 1967 and GoogleEarth, 2014).

Figure 4.31. Old dry-walls built of Boricevac Lower Paleogene platy limestones.

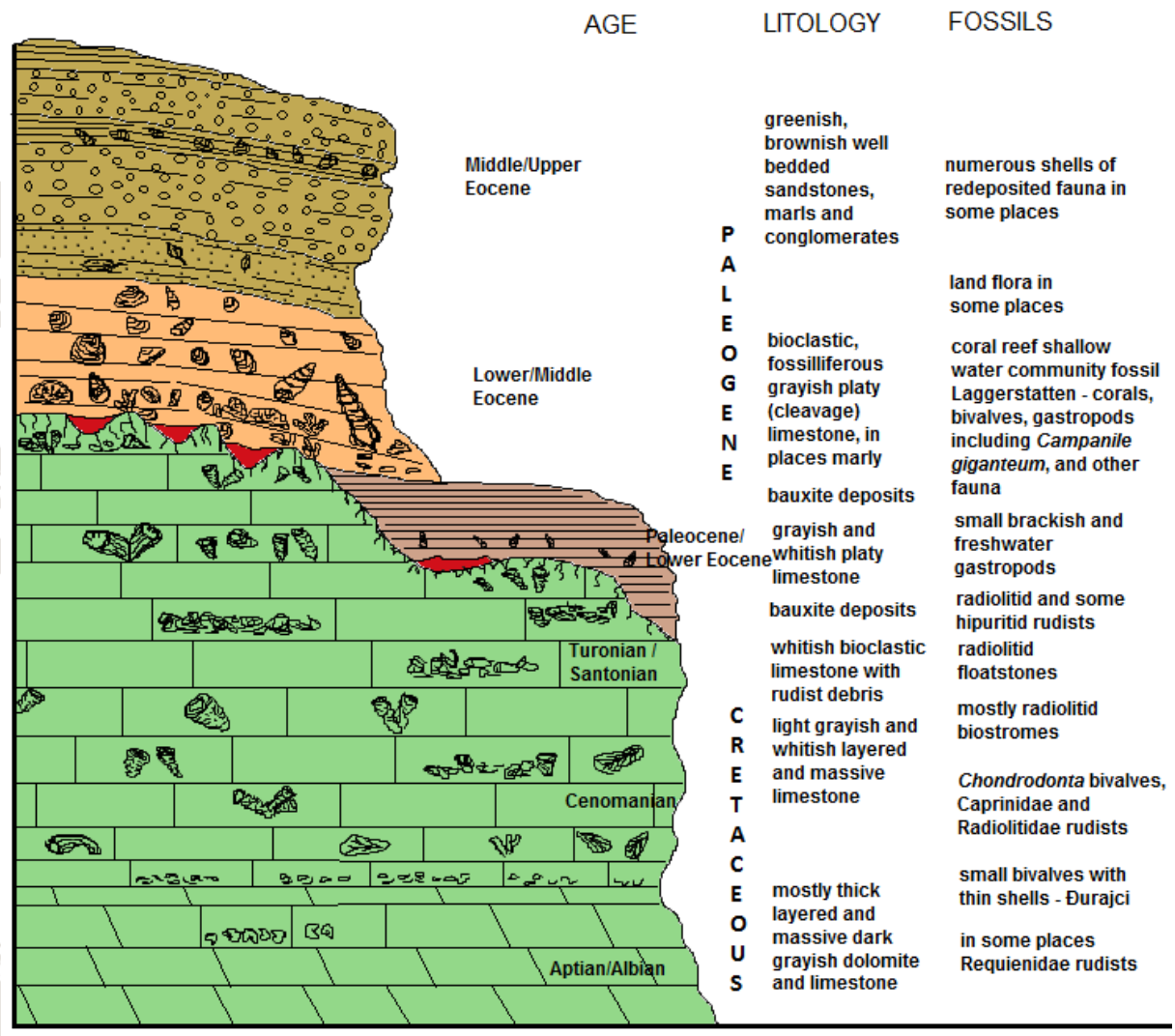

Figure 4.32. Schematic geological column for Boricevac and Konjovac Paleogene PL sites.

4.3 LABORATORY ANALYSES OF MECHANICAL CHARACTERISTICS OF PLATY LIMESTONE

Within the RoofOfRock project a set of selected PL samples (table 4.1.) was analysed in a geomechanical laboratory with the aim of numerically assessing the quality of the samples as expressed by flexural strength (see Table 4.1.).

General information on the laboratory:

Task: PROJECT ROOFOFROCK, WP3 – MECHANICAL PROPERTIES OF PLATY LIMESTONE

Laboratory: METRIS – Materials Research Centre, Laboratory 4

Operators: mag. ing. Mech. Davor Mandić, dott.ssa mag. Tea Zubin Ferri

Equipment: Universal testing machine 250kN Messphysik Beta 250

Method: Flexural Strength.

Number of sample	Mark of sample	Flexural strength F max kN	Flexural strength σfM (MPa)	Location/Site
1	DR-GR	9,311	23,13	Dretelj - Zvirovići
2	KOL 1	5,501	22,14	Kolojanj
3	MAJ	8,263	10,06	Podveležje
4	MOS-BK	0,991	8,582	Mostar, Biščevića house
5	PODV 1	14,85	11,73	Podveležje
6	PODV 1A	10,89	23,58	Podveležje
7	PODV SJ	3,506	12,91	Podveležje
8	PODV VL	3,866	11,89	Podveležje
9	STOL	6,401	17,10	Stolac

Table 4.1. Results of laboratory analyses of some Herzegovina platy limestones.

To date, the mechanical properties of building limestones in the project area have largely been investigated for massive building limestone, and only occasionally for platy limestone. Therefore, only detailed studies of the physical and mechanical properties of platy limestones for the Boricevac site with platy limestones of Paleocene age, and for the Mukoša locality with layered Miocene limestones are available (ŠARAVANJA et al., 2013).

Platy limestone at the Boricevac site had a compressive strength of 120-125 MPa, which puts it in the category of medium to high-strength rocks.

Miocene limestones from the Mukoša site indicated compressive strength values ranging from 15.4 to 23.2 Mpa, putting them in the category of very low-strength rocks.

Estimated values for abrasion resistance of limestones from the Boricevac site are: 15.1 cm^3 / 50 $cm^{2,}$ placing them in the category of hard rocks. On the other side, estimated values for limestones from the Mukoša site are 48.0 cm^3 / 50 cm^2, making them extremely soft rocks.

In addition to these two sites, the characteristics of limestones from the Drinovac and Konjovac sites have been partially investigated. It is estimated that bedded limestones at the Drinovci sites have abrasion resistance values of 20.4 cm^3 / 50 cm^2 (moderately hard rocks category).

Eocene limestones from the Konjovac site have an estimated resistance to abrasion value for of 17.640 cm^3 / 50 cm^2, placing them in the category of hard rocks.

Water absorption tests showed values of: 15.2% for Miocene limestones from the Mukoša site; 0.54% for limestones from the Drinovci site; 0.23 % for limestones from the Podveležje site; and 0.198 % for limestones from the Konjovac site.

During the fieldwork within this project, samples for laboratory tests of mechanical characteristics were collected at the localities of Podveležje, Zvirovići 1, Zvirovići 2, Mostarska vrata, Radišić - Proboj and Drinovci (see Table 4.2).

ID_locality (consecutive numbers)	ID_SAMPLE	SAMPLER	DATE	SAMPLE FIELD NAME	FIELD QUALITY ASSESSMENT (descriptive)	FIELD Schmidt-hammer TEST Yes/No
5004	5080	Barudzija	14.12.2013	1_Drinovci_uros PET-1	too laminated	No
5004	5081	Barudzija	14.12.2013	1_Drinovci_uros		
5004	5082	Barudzija	14.12.2013	1_Drinovci_uros		
5004	5083	Barudzija	14.12.2013	1_Drinovci_uros		
5005	5084	Barudzija	19.3.2014	2_Podvelezje_uros PODV-1	good quality	No
5005	5085	Barudzija	19.3.2014	2_Podvelezje_uros PODV-1A		
5005	5086	Barudzija	19.3.2014	2_Podvelezje_uros PODV-SJ		
5005	5087	Barudzija	19.3.2014	2_Podvelezje_uros PODV-MAJ		
5005	5088	Barudzija	19.3.2014	2_Podvelezje_uros PODV-VL		
5007	5089	Barudzija	14.12.2013	3_Mo-vrata_uros	too laminated	No
5007	5090	Barudzija	14.12.2013	3_Mo-vrata_uros		
5007	5091	Barudzija	14.12.2013	3_Mo-vrata_uros		
5007	5092	Barudzija	14.12.2013	3_Mo-vrata_uros		
5011	5093	Barudzija	14.12.2013	4_Zvirovici_uros	good quality	No
5011	5094	Barudzija	14.12.2013	4_Zvirovici_uros		
5011	5095	Barudzija	14.12.2013	4_Zvirovici_uros		
5011	5096	Barudzija	14.12.2013	4_Zvirovici_uros		
5013	5097	Barudzija	14.12.2013	5_Proboj_uros	too laminated	No

5013	5098	Barudzija	14.12.2013	5_Proboj_uros		
5013	5099	Barudzija	14.12.2013	5_Proboj_uros		
5013	5100	Barudzija	14.12.2013	5_Proboj_uros		
5016	5101	Barudzija	18.3.2014	6_Dretelj_uros DR-GR	good quality	No
5016	5102	Barudzija	18.3.2014	6_Dretelj_uros		
5016	5103	Barudzija	18.3.2014	6_Dretelj_uros		
5016	5104	Barudzija	18.3.2014	6_Dretelj_uros		
5017	5105	Barudzija	2014	Mostar, Bišćevića house MOS-BK	good quality	No
5018	5106	Barudzija	2014	Stolac STOL	good quality	
5019	5107	Barudzija	2014	Kolojanj KOL-1	good quality	

Table 4.2. List of platy limestone samples taken for petrographic analyses and testing of mechanical characteristics.

According to the results of flexural strength in the geomechanical laboratory it can be concluded that the best quality (mechanical) platy limestones come from the two highest potential site-zones in the whole of the B&H project area: Podveležje and Zvirovići.

4.4 NATURAL HERITAGE OF PLATY LIMESTONE

In several investigated sites fossil macrofauna was found, which had already been documented for some of these sites. Due to the visual appeal, rarity and scientific value of these macrofossils, three sites are selected and proposed as geo-sites: Raška gora, Kolojanj, and Grabova draga. In addition to the valuable macrofossils, interesting sedimentological profiles are also present at these localities. The most valuable profile is at Grabova draga site. Raška gora and Kolojanj sites contain limestones of Cretaceous age, while Grabova draga represents Eocene platy limestone succession.

4.4.1 Geological-paleontological site Raška gora

Proposed name for the geo-site: Marbly limestone of Raška gora / Cro: Mramorni vapnenac Raške gore

Geographical position of the site: approx. 2 km south-southeast of the village of Sirge, at the Raška gora karst plateau

Surface area of the proposed site: < 1 ha, length approx. 0.7 km

Coordinates: A (south point of road): 43.404401,17.803978, B (north point of road): 43.410406,17.805260

The proposed geo-site Raška gora is located along the local gravel road, near the village of Sirge. The geological profile extends about 700 m, and lies entirely within the cadastral area of the road, not on private land. The proposed area is located just 1 kilometre south of the polygons with high potential platy limestones (Raška gora platy limestones) (Fig. 4.33.). Fossiliferous rocks, through which the road passes, directly overlay platy limestones of Albian-Cenomanian age.

The site is relatively accessible and can be reached from the city of Mostar in 20 minutes following the narrow asphalt road towards Raška gora. The largest part of the Raška gora karst plateau is located at altitudes of between 550 and 700 m a.s.l. Within the idyllic forest landscape numerous features of karst topography (including sinkholes and caves) can be observed. All of these features lend exceptional natural and geomorphological value to this area. The spatial position of this area alone is another important reason for its proposal as a geo-site. On the western side of the area Čabulja Mountain (1776 m) rises steeply, affording a fascinating view, to the north, of the highest mountains in Bosnia and Herzegovina – Čvrsnica (2225 m) and Prenj (2108 m). The canyons of the Neretva and Bijela rivers are carved through the central mountain ranges, which too are particularly impressive.

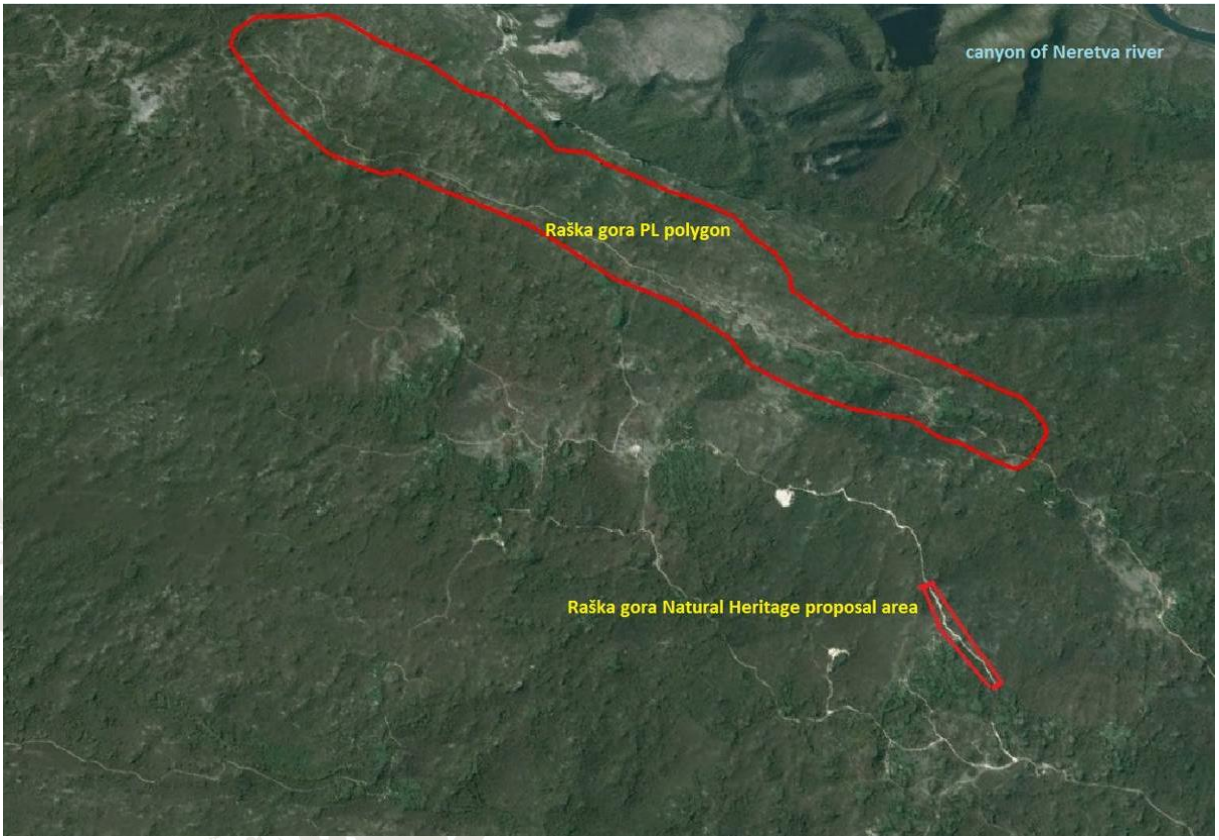

Figure 4.33. Location (smaller red polygon) of proposed geo-site 'Marbly limestones of Raška gora'.

Figure 4.34. View over the Raška gora karst plateau with PL and proposed geo-site to the north, toward the high karst mountain of Prenj with deep canyons.

Geological-paleontological value of "Marbly limestones of Raška gora"

The greatest value of the limestones at this site is their paleontological characteristics, especially the fossil assemblages. These rocks are almost pure (99% of $CaCO_3$) white

limestones. Due to recrystallization they are locally referred to as “marbles”. These characteristics have already been recognized as valuable and evaluated as limestones suitable for exploitation for industrial use; several quarries (now inactive) were active in the past. Previous investigations and fieldwork within the RoofOfRock project classified these limestones as dominantly bioclastic limestones, with abundant and diverse fossil macrofauna dominated by rudists. These limestones are only the upper part of a major megasequence containing rocks from the Late Jurassic to Cenomanian age. Previous studies (SLIŠKOVIĆ, 1962, 1968, 1971) described several new species of rudists (*Neocaprina extrema sirgensis, Distefanella raricostata, D. montagnei, Vaccinites narentanus*) in the Cenomanian-Turonian bioclastic limestone of Raška gora. In addition to these studies, BEHLILOVIĆ (1964) described the geological characteristics of the wider area of the Čabulja Mountain, and went on to describe several forms of rudists. The proposed geo-site is important, since these limestones directly overlay Albian-Cenomanian platy limestones discovered during the project fieldwork. The position of these platy limestones is indicated in Figs. 4.33. and 4.35., together with some areas with characteristic macrofaunal assemblages within Cenomanian deposits.

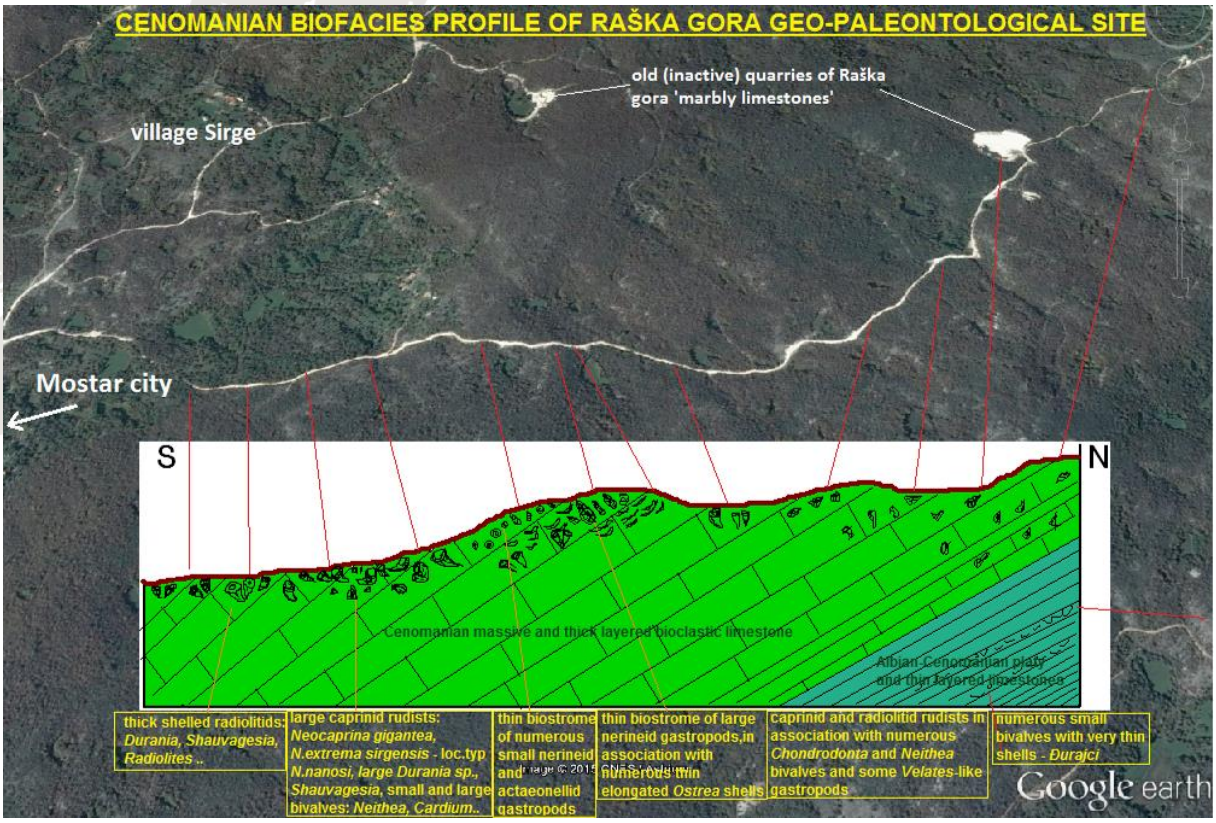

Figure 4.35. Illustrative geo-paleontological profile of Cenomanian ‘marbly’ limestones at the Raška gora site.

Rudists are the most dominant of fossil forms that can be found within the rocks along the section proposed as a geo-site. The Caprinidae family comprise the main form of rudists here. One particularly attractive species is the giant rudist *Neocaprina gigantea* (Fig. 4.36.), together with the taxons *Caprina, Caprinula, Ichthyosarcolites, Schiosia, Plagioptychus, Durania, Sauvagesia, Radiolites, Distefanella* and other forms. The preservation and diversity of fossil rudists suggests that one exuberant rudist "pseudoreef" stretched over the area during the Cenomanian and Turonian ages. This "pseudoreef" stretched southeast all the way to Velež Mountain, where a very similar Cenomanian rudist site has been investigated (SLIŠKOVIĆ 1963, 1968). In the fieldwork within the RoofOfRock project other macrofauna (especially chondrodonts) were also described in the area. With its well-known and ubiquitous *Chondrodonta joannae*, the Cenomanian rocks of the proposed site are characterized by numerous diverse forms of significantly less common types, such as *Ch. munsoni*, as well as numerous forms of *Neithea, Cardium* and *Arca* shells. The enigmatic forms of gastropods very similar to the Eocene genus *Velates* (Fig. 4.37.) and a very interesting shell similar to the genus *Tridacna* are also observed. However, the most significant paleontological findings consist in giant gastropods from the superfamily Nerineacea (Fig. 4.39.). These large gastropods occur within one very narrow limestone horizon (less than 3 m thick), associated with radiolitids *Durania* and *Sauvagesia*, and with numerous elongated oysters including numerous *Chondrodonta munsoni* and large *Neithea* shells as well. One lateral lens of limestone containing an abundance of small to medium-large gastropods from the Actaeonillidae and Nerineidae families (Fig. 4.39.) is also observed. Preliminary analysis of the newly-discovered gigantic nerineid gastropod (Fig. 4.40.), of which some specimens are larger than 30 cm, certainly represents a new species that is most similar to the genus *Cossmanea* from the Cenomanian rocks of Rocca di Cave in Italy (CARBONE ET AL., 1971.). Nevertheless, according to current discoveries of such large gastropods within the Mesozoic carbonate in the External Dinarides have not yet been registered, which only confirms the particular paleontological importance of this geo-site for geoconservation and protection.

Rudist biocenoses, as well as gastropod, chondrodont and ostreid communities, indicate specific Cenomanian facies developed in this area. Unlike the Cenomanian facies of southern Herzegovina and Dalmatia, where thick sequences of well-bedded limestones and dolomites

were deposited in intraplatform lagoons, “pseudoreef” or ‘’reefoidal’’ facies was developed in the area of Raška gora during the Middle and Late Cenomanian ages. The reef-like morphological body of organogenically-bounded limestone was formed in the tropical warm shallows of the Tethys.

Figure 4.36. Some of the large caprinid rudists (*Neocaprina gigantea*) at the proposed natural heritage site of Raška gora.

Figure 4.37. Interesting fossilized gastropod, similar to Eocene genus *Velates*.

Figure 4.38. Section of large, thick-shelled radiolitid rudist (*Sauvagesia*).

Figure 4.39. Numerous Actaeonellidae and Nerineidae gastropod sections on the whitish 'marbly' limestone of Raška gora.

Figure 4.40. Gigantic nerineid gastropod (new, recently discovered species) at the Raška gora geo-site.

4.4.2 Geo-site Kolojanj

Name of the proposed geo-site: Kolojanj platy limestones / Cro: Kolojanjski pločasti vapnenac

Geographical position of the proposed site: approx. 10 km south of Čapljina and 7 km east of Metković (Croatia)

Surface area of the proposed site: approx. 3460 m^2

Coordinates: Center point: 43.007946°, 17.717950°

In the southern part of B&H project area lies a valuable geo-paleontological site with platy limestones of Late Cretaceous to Early Paleogene age. These platy limestones contain exceptionally well-preserved fossilized fish, as well as terrestrial macroflora and rudists bivalves. This site was only discovered just a couple of years ago, while the paleontological and stratigraphical investigations were still in progress.

Preliminary paleontological observations have shown that most preserved fish specimens from this platy limestone could be representatives of the genus *Scombroclupea* (Fig. 4.41.), which are also found in the Upper Cretaceous platy limestones on the island of Hvar in Croatia. This beautifully preserved fish fossil is now located in the City Museum of Neum. In addition to the fossiliferous platy limestones at this site, the underlying Upper Creataceous rocks are represented by bioclastic limestones full of well-preserved rudists fauna (Figs. 4.42., 4.43.), among which some forms are very attractive and rare specimens among rudist fauna in External Dinarides (SLIŠKOVIĆ, 1968), including: *Vaccinites giganteus major*, locus typicus for *Gorjanovicia kolojani, G. acuticostata zidakensis*, genus *Pseudokuehnia* – with *Pseudokuehnia milovanovici*, *Petkovicia verajana*, *Vaccinites glusciensis*, *Bournonia dinarica*, *Distefanella raricostata*, *D. heraki* and *D. hrasnica*.

The site has additional value: in the immediate vicinity of the proposed geo-site stands one of the largest prehistoric hill forts (a so-called 'Gradina') in Bosnia and Herzegovina and beyond, with massive megalithic stone walls. As a result, highly valuable archaeological remains augment the already valuable paleontological content.

Figure 4.41. Fish fossil from Kolojanj platy limestone, now housed in the City Museum of Neum.

Figure 4.42. Some rudist specimens (*Gorjanovicia kolojani*), first described at this locality.

Figure 4.43. Some rudist specimens (Radiolitidae), first described at this locality.

Figure 4.44. Fossil terrestrial flora in platy limestone at the Kolojanj site.

4.4.3 Geo-site Grabova draga

Name of the proposed geo-site: Lower Eocene profile of Grabova draga / Cro: Donjoeocenski profil Grabove drage

Geographical position of the proposed site: approx. 8 km west of Mostar and 7 km east/northeast of Široki Brijeg

Surface area of the proposed site: approx. 2 ha

Coordinates: – point GB (Fig. 4.4.3.1.): 43.383154, 17.687924

The proposed geo-site includes a small area along the southern side of a small and narrow valley in the eastern part of the village of Grabova draga. Further, to the northwest, is a zone with Eocene platy limestones named Grabova draga2 PL polygon (Fig. 4.45.).

The significant paleontological and sedimentological characteristics of the proposed site can be observed in its excellent open profile, which stretches about 350 m long and 30-40 m wide. Paleogene sediments at this site also exhibit interesting tectonic characteristics, revealing an overturned syncline, over which Upper Cretaceous limestones are thrusted from the southwest. The Upper Cretaceous limestones and Paleocene rocks exist in unconformable contact in the northern part of the site. Furthermore, newly discovered Eocene platy limestones similar to those at the Raška gora site are exposed in the southern wing of the syncline. These limestones are paleontologically characterized by numerous large benthic foraminifera (*Discocyclina, Assilina, Assilina*). In the upper part of the profile,

closer to the core of the syncline containing clastic rocks, instances of a highly attractive and exceptionally large oyster, *Pycnodonta gigantica* (Fig. 4.46.), occur. Within the more clayey carbonates in the upper part of the profile, Terebratulidae brachiopods, decapod crab *Harpactoxanthopsis quadrilobata*, bivalves *Cardium*, *Pecten, Chlamys*, and other diverse forms of gastropods and bivalves are present. Terrestrial flora (Fig. 4.48.), recently discovered within the clayey-sandy platy limestone sequences, further contribute to the paleontological significance of the proposed geo-site. Giant Nautiloidea cephalopods are also found in the western part of the same formation (Fig. 4.49).

The present micro and macrofossil assemblages are indicative for conditions of deposition in a typical marine environment within the relatively shallow and semi-open part of the coastal zone in the middle and lower subtidal zone. The immediate surroundings of land overgrown with subtropical vegetation is indicated by findings of fossil flora. The succession of the western part of the geo-site was deposited in an even deeper, more open part of the subtidal zone, which is clearly indicated by the relatively numerous giant cephalopods.

Figure 4.45. Position of the proposed geo-site at Grabova draga on the geologic map.

Figure 4.46. Giant oysters (*Pycnodonte gigantica*) from the Grabova draga site.

Figure 4.47. Upper part of the naturally open profile of Lower Eocene rocks with platy limestones in the upper part and various carbonate-clayey clastics in the lower part.

Figure 4.48. Terrestrial fossilized flora in clayey-sandy platy rock.

Figure 4.49. Gigantic (35-45 cm) nautiloid cephalopods together with other Early Eocene macrofauna discovered at the Grabova draga locality.

4.5 OVERVIEW OF PLATY LIMESTONE AS A MINERAL COMMODITY

According to the descriptions of considered polygons with platy limestones (see previous section), basic qualitative characteristics and the potential for further exploitation, together

with quantities of platy limestones in the quarries, can be estimated. The general synthesis of the qualitative and quantitative characteristics for each polygon is shown in Fig. 4.50. The Podveležje area represents the highest potential for further exploitation of platy limestones. A large number of active and abandoned quarries of high-quality platy limestone mark the area. Another high potential polygon for further exploitation of platy limestone is the Raška gora site polygon, in which a thick sequence of high-quality platy limestone is determined. Furthermore, in the eastern part of the Zvirovići site polygon, high quality platy limestones exhibit a high potential for further exploitation and use in building and construction, especially for the roofing of houses. Platy limestones from the Zvirovići and Podveležje sites are also the most extensively and commercially used platy limestones in architecture and construction among all of the platy limestones from the area under consideration. The unmistakable quality of Cretaceous platy limestone from the Podveležje site is confirmed in the old houses and buildings (dating back to the Late Middle Ages), which are extensively roofed with these platy limestones. This is particularly the case in the Old Town of Mostar and in Blagaj, near the Buna River spring. Platy limestones from other potential sites (polygons) are far less used. The active quarries and the tendency to develop further excavation well indicate the high potential for these platy limestone sites. Additionally, the potential for further exploitation of platy limestones at the Vrdi, Drinovci and Borićevac sites and their use in architectural constructions is clearly observed in the many old and historic houses that are roofed with platy limestones from these sites.

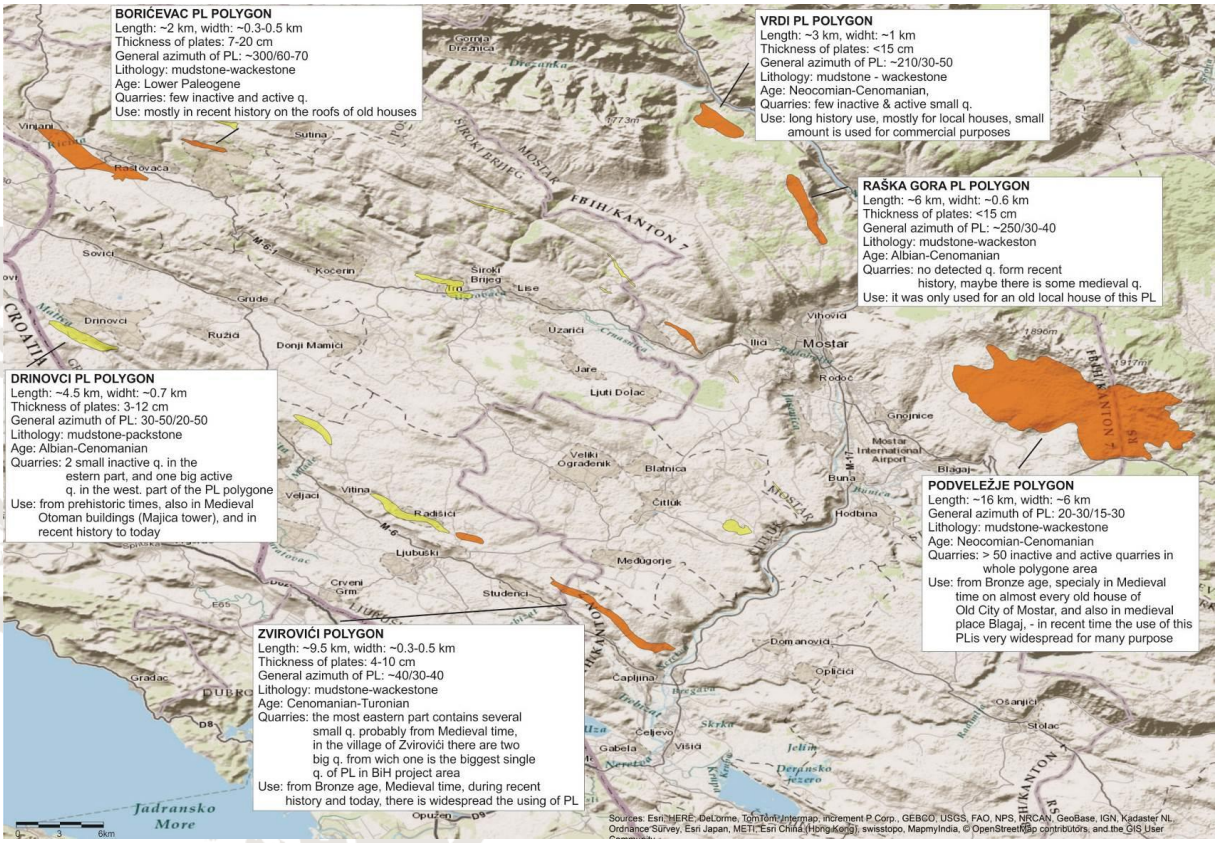

Figure 4.50. General synthesis of the qualitative and quantitative characteristics for the PL sites/polygons of highest potential.

The tables below indicate the basic characteristics and attributes of selected high potential platy limestone sites in the Bosnia and Herzegovina project area:

ID (polygon)	ID geol. unit	Name of platy limestone type	Basic lithology	Paleontological characteristics	Age
5001	11	Vrdi platy limestone	Greyish to brownish platy limestones of mudstone-wackestone structure	foraminifers, algae, Nerinea gastropods ..	Late lower Cretaceous
5002	12	Drinovci platy limestone	White and light grey platy limestone with stromatolites and chert intercalations	primitive rudists, small bivalves etc.	Late lower Cretaceous
5003	12	Podveležje platy limestone	Light grey to yellow thin-bedded mudstone-packstone outcrops over a very large area	fish fossils, caprinid rudists, Nerinea gastropods etc.	Albian - Cenomanian
5004	12	Raška gora platy limestone	Light grey to whitish platy limestone with sporadic or rare dolomitic platy limestone lenses	small bivalves with thin shells, foraminifers	Albian - Cenomanian

5008	14	Radišići platy limestone	Light grey to white platy and dolomitic limestone with stromatolitic lamination and slump structures	radiolitid rudists (Praeradiolites, Radiolites, Durania ..), Chondrodonta bivalves, Nerineid gastropods	Lower Cenomanian
5010	14	Zvirovići- platy limestone	Grayish to light grayish platy limestone with chert, horizontal and stromatolitic lamination, sporadicaly with reefoidal bioclastic limestone lenses	fish fossils, radiolitid rudists (Durania, Praeradiolites, Radiolites, Sauvagesia) caprinid rudists (Caprinula, Caprina, Ichthyosarcolites, Schiosia, Monopleura etc.), Chondrodonta and Neithea bivalves, Nerineid gastropods, corals, Cenomanian foraminifera etc.	Cenomanian
5012	14	Žovnica (Polog) platy limestone	Grey thin-bedded to platy fine grained limestones	Chondrodonta bivalves in general domination with radiolitid rudists	Cenomanian
5016	15	Kolojanj platy limestone	Light to dark greyish platy limestone with lamination, micritic structure and chert bituminous nodulas	fish fossils, radiolitid rudists, terrestrial flora remains etc.	Campanian-Maastrichtian
5017	18	Boricevac platy limestone	Dark to light grey thin-bedded, platy and laminated limestone	brackish gastropods (Melanopsidae etc.)	Paleocene
5033	18	Boricevac platy limestone	Dark to light grey thin-bedded, platy and laminated limestone	brackish gastropods (Melanopsidae etc.)	Paleocene
5022	22	Posušje miljevina - platy limestone	Dark grey to yellowish-brown thin layered and platy calcarenites and marly limestones	numerous fresh water (lake) molluscs - Congeria bivalves, gastropods, terrestrial flora, fish fossils etc.	Neogene

Platy limestone type	**Area of occurrence (descriptive)**	**Known commercial/potential quarries/delves**	**Quality assessment as building material**	**General use as building material**	**Platy limestone potential**
Vrdi platy limestone	Vrdi karst plateau	active and abandoned quarries – area of Vrdi village	very good quality	yes	3
Podveležje platy limestone	Mt. Velež, Podveležje karst plateau	active and abandoned quarries – N of Podveležje village and SW Velež mountain	very good quality	yes	3

Raška gora platy limestone	Raška gora karst plateau	No detected quarries (possibility of existence of some small, ancient quarries)	very good quality	yes	3
Drinovci platy limestone	Area of Drinovci and Peć-mlini villages	abandoned quarries – area of Drinovci and Peć-mlini villages	very good quality	yes	3
Zvirovići-1 platy limestone	E of Zvirovići village	active and abandoned quarries – E of Zvirovići village	very good quality	yes	3
Zvirovići-2 platy limestone	W of Zvirovići village	active and abandoned quarries - W of Zvirovići village	very good quality	yes	3
Miletina platy limestone	Area of Miletina and Crnopod villages	active and abandoned quarries - Miletina and Crnopod villages	good quality	yes	2
Dretelj platy limestone	NW of Dretelj village	abandoned quarries - area of Dretelj village	very good quality	yes	3
Polog platy limestone	W of Mostar city	abandoned quarries – foot of the Mikuljača hill	very good quality	yes	3
Kolojanj platy limestone	S of Čapljina,Kolojanj village	S of Čapljina, Kolojanj village	very good quality	yes	3
Boricevac platy limestone	NE of Posušje, Cerov dolac village	abandoned quarries - area of Cerov dolac village, NE of Posušje	very good quality	yes	3
Posušje platy limestone	Area of Posušje	Area of Posušje	good quality	yes	3

4.6 SUMMARY FOR PLATY LIMESTONE AS A MINERAL COMMODITY AND ITS NATURAL HERITAGE

Based on all presented information, figures and illustrations, it can be concluded that in the whole project area, Cretaceous platy limestones of Early Cretaceous (Neocomian) to Cenomanian age are the most suitable for further exploitation. These high potential Cretaceous limestones can be quarried at three sites: the Podveležje, Raška gora and Vrdi

sites. All belong to the same horizon (megasequence), located directly in front of the high karst overthrust, just below the highest mountains in Bosnia & Herzegovina: Velež, Čabulja, Prenj and Čvrsnica. Another high-potential site belongs to the long polygon of Cenomanian platy limestone north of Čapljina, with several active and very large quarries at the Zvirovići locality.

Owing to the visual appeal, rarity and scientific value of their sedimentological profiles, macro-structures and specially macrofossils as well as the natural heritage value, three sites are selected and proposed as geo-sites: Raška gora, Kolojanj, and Grabova draga sites.

5 SHOW-CASE OBJECTS

5.1 INTRODUCTION

In the framework of Action 3.2 of WP3 within the project area in West Herzegovina County and Neretva-Herzegovina County five show-case objects were selected with the aim of studying different types of building limestones and their sources of origin. The parameters for the selection of show-case objects were defined at several coordination meetings and in close cooperation with WP4 (cultural heritage) experts. The selection was made according to parameters such as:

- Houses built of types of limestone from typical formations
- Objects built of typical types of limestone from active and abandoned surrounding quarries
- Houses with roofs of platy limestone
- Limestone with characteristic macrofossils of karst formations
- Examples of good practice in reconstruction (if possible)
- Examples of poor practice (use of inappropriate types of stone, "geological contamination" etc.) (if possible)
- accessibility
- located in villages or smaller towns
- selections need not all lie within a single village
- active cooperation with WP4 (cultural heritage) local external experts and WP4 leader

5.1.1 OVERVIEW OF LOCALITIES - GEOGRAPHIC DESCRIPTION

As can be seen from the map (Fig. 5.1.), all selected objects are located in the southern part of Herzegovina. The northernmost show-case is located in the city of Mostar. Four of the selected objects (nr. 1, 2, 3 and 4) are located in the Herzegovina-Neretva County, while only one selected object (nr. 5) is located in the West Herzegovina County. All objects are related to the Ottoman architectural style of the late Middle Ages. The first object (Biščevića house) is located in the centre of Mostar, directly on the left bank of Neretva River. It is an integral part of the Old Town of Mostar and was built during the Ottoman period (late Middle Ages).

The second object (Gavrankapetanovića Tower) is an integral part of the Old Town of Počitelj and is also located along the left bank of the Neretva River. The third object (Velagića mills) also dates from the Ottoman period, and is located in Blagaj, near a spring of the Buna River. The fourth object is a mosque in the Old Town of Stolac. The fifth selected object, the Ottoman-era Lalića Tower, is located in the hamlet of Mostarska vrata, near Ljubuški (Fig. 5.1.).

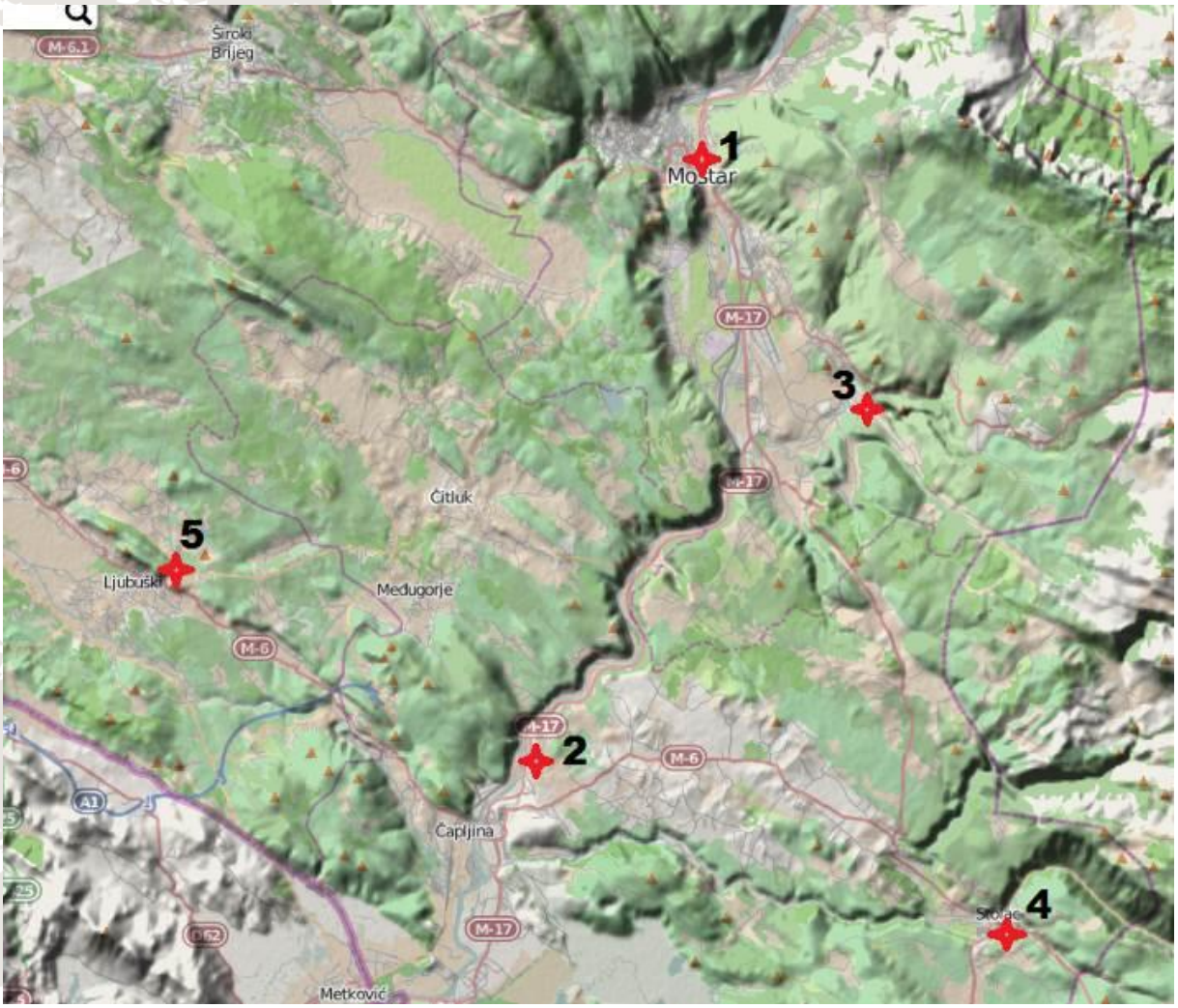

Figure 5.1. Topographic map of the selected show-case objects (houses).

5.2 METHODOLOGY OF DETAILED GEOLOGICAL INVESTIGATION

In collaboration with WP4 experts five characteristic show-case objects with roofs covered with platy limestone were selected in the project area in Herzegovina.

After examining the historical buildings in the project area, it is determined that the most prominent examples of buildings with platy limestones are parts of the old medieval Ottoman building complexes. All selected objects are historic buildings; today most are used

for touristic purposes as cultural and historical architectural heritage. Since most of the Old Town of Mostar (including the Old Bridge) is UNESCO cultural heritage and one of the most important touristic sites in this part of Europe, the logical choice for the first show-case object is a building in the Old Town of Mostar itself. Since the historic Ottoman buildings are built almost entirely of local limestones and their roofs are made of platy limestones, the other four show-case objects were also selected from among them.

It is very important to emphasize one particular characteristic for the B&H project area, unique among all of the other participant countries in this project: this is the widespread destruction of a large number of selected objects during the recent war (1992-1994). After the war, most of the objects (especially their roofs) were completely restored. A joint study by WP3 and WP4 experts determined that original platy limestone types were used for the restoration of roofs at selected objects nrs.1 and 3; and non-original (replacement) platy limestone types were used to restore the roofs at selected objects nrs.2, 4 and 5. Nevertheless, those cases in which non-original types of platy limestones were used are not seen as instances of poor practice, as replacement materials were actually of better quality than the original, and the restoration techniques employed actually produced more durable roofs. This curious relationship, *original roofs of poorer quality* vs. *newly-restored roofs of better quality*, requires a wider discussion, begging the question whether this is an instance of good practice or poor practice.

After selecting the show-case objects, analysis of the lithological and paleontological characteristics and the origin of stone materials used in the construction of these objects was carried out. All available information on the exact source of the original types of limestones that were used in the construction of roofs was collected. Investigation of the historical facts, sources and literature, accompanied by fieldwork and a comparison of platy limestones sites revealed that the platy limestones at show-case objects nrs.1, 3 and 4 originated from the Podveležje site. The platy limestones at show-case object nr.2 originated from the Dretelj site, and the platy limestones at show-case object nr.5 originated from the Mostarska vrata and Radišići sites.

Analysis of the origin of the stone used in selected architectural components at the show-case objects was based primarily on their petrological and paleontological features. Geographical distances between the sites and the selected objects were taken into

consideration together with transport scenarios as well. Interviews with the owners of the objects and with local residents were also conducted. The potential source rocks on their primary sites were analysed as well. In the overall analysis of the origin of building stone, geological maps, satellite images, orthophotos and geological literature were closely consulted.

5.3 GEOLOGICAL DESCRIPTION SHEETS OF SHOWCASE OBJECTS

5.3.1 GENERAL INFORMATION

Below, some general data on selected show-case objects:

1st SHOWCASE OBJECT – BIŠČEVIĆ HOUSE – OLD CITY OF MOSTAR

Name (official and common):	**"Bišćević House", Mostar**
Address (location):	**Bišćevića ulica 13**
Cadastral number, community:	**k. č. 3214-3215, k.o. Mostar**
Coordinates:	**y=6485241.62 x=4799564.75**
Owner / contact:	**Owner: Bišćević and Lakišić Families, +387 36 552 197**
Heritage status / protection:	**National monument**
Use (original):	**Dwelling house and tourist object**
Typology:	**Ottoman residential complex**
Short description (ground/floor plan, architectural elements, chronology):	**The complex has remained relatively unchanged from the 17th to 20th c., and consists of two parts: *selamluk* (men's yard, or part of the house for the reception of guests and business talks), and *haremluk* (women's or family courtyard, an intimate part of the building). The material used for building houses is a local quarry stone. Wood is used for the pillars, floor and roof construction, as well as for doors and windows.**

2nd SHOWCASE OBJECT – MAIN TOWER IN POČITELJ

Name (official and common):	**"Gavrankapetanović Tower", Glavna kula**
Address (location):	**Počitelj b.b., 88305 Počitelj, B&H**
Cadastral number, community:	**c. č. 2585 c.m. Počitelj**
Coordinates:	**y=6478573,06 x=4776802,36**
Owner / contact:	**Tourist board of Herzegovina-Nretva county, dr. Ante Starčevića b.b., Mostar, +387 36 355 090**
Heritage status / protection:	**National monument**
Use (original):	**Historical monument/Defence tower**
Typology:	**Ottoman fortification system**

Short description (ground plan, architectural elements, chronology):	**The fort of Počitelj was built in the 15th c. The central tower has an octagonal base with additions from the Ottoman period, 17-18th c.**

3rd SHOWCASE OBJECT – VELAGIĆ MILL IN BLAGAJ

Name (official and common):	**"Velagić Mill"/Velagića mlinica, Blagaj**
Address (location):	Velagićevina b.b., 88201 Blagaj
Cadastral number, community:	**c.č. 1447, c.m. Blagaj**
Coordinates:	**y=6492377,80 x=4790250.04**
Owner / contact:	**Owner: Velagić Family, 88201 Blagaj, +387 062 532 518**
Heritage status / protection:	**National monument**
Use (original):	**Ethnological monument/Mill**
Typology:	**Ottoman commercial complex**
Short description ground/floor plan, architectural elements, chronology):	**The facility's mills have an irregular rectangular shape: width on the north side is 6.83 m and 6.15 m on the south, with a length of 17.62 m. Under a first part of rammed earth. The walls are made of crushed stone 55-60 cm thick. Millers lived in the first part, while the second part consisted of five evenly distributed mills.**

4th SHOWCASE OBJECT – ČARŠIJSKA MOSQUE IN STOLAC

Name (official and common):	**"Čaršijska mosque"/Careva džamija**
Address (location):	**Ada b.b., 88360 Stolac**
Cadastral number, community:	**c. p. 2/219, c.m. Stolac**
Coordinates:	**y=6497068.38 x=4770950,40**
Owner / contact:	**Medžlis of Islamic community Stolac, Stolac +387 36 584 580**
Heritage status / protection:	**National monument**
Use (original):	**Religious / mosque**
Typology:	**Ottoman mosque with minaret**
Short description (ground/floor plan, architectural elements, chronology):	**The mosque complex consists of a mosque, cistern, the harem of the mosque, a fountain on the portal axis, gusulhana and harem walls. It is one of the largest B-H mosques built in the 16th c., measuring 18.30 x 15.30 m**

5th SHOWCASE OBJECT – LALIĆA TOWER HOUSE IN MOSTARSKA VRATA

Name (official and common):	**"Lalića tower house", Mostarska Vrata, Ljubuški/Lalića kula**
Address (location):	**Mostarska Vrata b.b., 88320 Ljubuški**
Cadastral number, community:	**c. p. 2718, c. m. Mostarska Vrata**

Coordinates:	**y=6464885,67 x=4784197.21**
Owner / contact:	**Ćerimović Family, M. Selimovića 12, Sarajevo, +387 62 346628**
Heritage status / protection:	**National monument**
Use (original):	**Housing and defence property**
Typology:	**Ottoman fortified residential tower**
Short description (ground plan, architectural elements, chronology):	**The tower is a tall building with a ground floor and two upper floors. The base is a rectangular 6:00 x 6.35m. The east wall is 8.50m high, the northwest 7.50m. The total height of the tower is 10.35m.**

5.3.2 SELECTED OBJECTS AND SELECTED ARHITECTURAL ELEMENTS

LIST OF SELECTED LIMESTONE ELEMENTS:

SHOWCASE OBJECT 1 – BIŠČEVIĆ HOUSE – OLD CITY OF MOSTAR

Selected limestone elements:	**0 walls:** **1 main roof:** **2 small roof:** **3 small roof** **4 entrance gate** **5 porch (doksat)** **6 courtyard floor**

SHOWCASE OBJECT 2 - MAIN TOWER IN POČITELJ

Selected limestone elements:	**0 walls:** **1 Roof of main tower** **2 Southeast entrance** **3 Western part of the tower** **4 Door belvedere** **5 Entrance to the tower** **6 Window on the south side**

SHOWCASE OBJECT 3 - VELAGIĆ MILL IN BLAGAJ

Selected limestone elements:	**0 walls:** **1 main roof (west)** **1 main roof (east)** **2 Path to the mill** **3 Mill entrance** **4 Hearth** **5 Millstone**

SHOWCASE OBJECT 4 - ČARŠIJSKA MOSQUE IN STOLAC

Selected elements: *limestone*	**0 walls:** **1 main roof of mosque:** **2 minaret** **3 main entrance of the mosque** **4 cistern** **5 fountain (shadrvan)** **6 muslim tombstone**

SHOWCASE OBJECT 5 - LALIĆA TOWER HOUSE IN MOSTARSKA VRATA

Selected elements: *limestone*	**0 walls:** **1 main roof:** **2 front door** **3 stairs** **4 cistern** **5 loophole** **6 wall shelf**

5.3.3 GEOLOGY OF TYPES OF BUILDING LIMESTONE USED

1st SHOWCASE OBJECT – (4001) "Bišćević House", Mostar

0 walls:

Foraminiferal limestones	Early-Middle Peleogene	Light grey massive micritic limestone with foraminifers (Alveolinae & Nummulites)
Tenelija and Miljevina	Miocene	Dark grey to yellowish-grey massive and thick layered oolitic limestone and calcarenites
Clastic-carbonate breccia	Quaternary	Dark brown to reddish breccia with fragments of cretaceous and paleogene carbonates

1 main roof:

Podveležje platy limestone	Albian - Cenomanian	Light grey to yellow thin-bedded mudstone-packstone; outcrops on the very large area

2 small roof:

Podveležje platy limestone	Albian - Cenomanian	Light grey to yellow thin-bedded mudstone-packstone; outcrops over a very large area

3 small roof

Podveležje platy limestone	Albian - Cenomanian	Light grey to yellow thin-bedded mudstone-packstone; outcrops over a very large area

4 entrance gate

Tenelija and Miljevina	Miocene	Dark grey to yellowish-grey massive and thick layered oolitic limestone and calcarenites

5 porch (doksat)

Foraminiferal limestones	Early-Middle Peleogene	Light grey massive micritic limestone with foraminifers (Alveolinae & Nummulites)
Tenelija and Miljevina	Miocene	Dark grey to yellowish-grey massive and thick layered oolitic limestone and calcarenites

6 courtyard floor

Podveležje platy limestone	Albian - Cenomanian	Light grey to yellow thin-bedded mudstone-packstone; outcrops over a very large area
Tenelija and Miljevina	Miocene	Dark grey to yellowish-grey massive and thick-layered oolitic limestone and calcarenites

2nd SHOWCASE OBJECT – (4002) MAIN TOWER IN POČITELJ

0 walls:

Turonian-Santonian	Upper Cretaceous	Greyish to light grey massive and thick-bedded limestones of packstone-wackestone texture

1 Roof of the main tower

Dretelj platy limestone	Cenomanian	Light grey to light brownish platy limestone with horizontal lamination

2 Southeast entrance

Turonian-Santonian	Upper Cretaceous	Greyish to light grey massive and thick-bedded limestones of packstone-wackestone structure
Dretelj platy limestone	Cenomanian	Light grey to light brownish platy limestone with horizontal lamination

3 Western part of the tower

Dretelj platy limestone	Cenomanian	Light grey to light brownish platy limestone with horizontal lamination
Turonian-Santonian	Upper Cretaceous	Greyish to light grey massive and thick-bedded limestones of packstone-wackestone texture

4 Door belvedere

Turonian-Santonian	Upper Cretaceous	Greyish to light grey massive and thick-bedded limestones of packstone-wackestone texture

5 Entrance to the tower

Turonian-Santonian	Upper Cretaceous	Greyish to light grey massive and thick-bedded limestones of packstone-wackestone texture
Tenelija and Miljevina	Miocene	Dark grey to yellowishg-grey massive and thick layered oolitic limestone and calcarenites

6 Window on the south side

Turonian-Santonian	Upper Cretaceous	Greyish to light grey massive and thick bedded limestones of packstone-wackestone texture
Dretelj platy limestone	Cenomanian	Light grey to light brownish platy limestone with horizontal lamination

3rd SHOWCASE OBJECT – (4003) VELAGIĆ MILL IN BLAGAJ

0 walls:

Turonian-Santonian	Upper Cretaceous	Greyish to light grey massive and thick bedded limestones of packstone-wackestone texture

1 Main roof (west)

Podveležje platy limestone	Albian - Cenomanian	Light grey to yellow thin bedded mudstone-packstone; outcrops over a very large area

1 Main roof (east)

Podveležje platy limestone	Albian - Cenomanian	Light grey to yellow thin bedded mudstone-packstone outcrops over a very large area

2 Way to the mill

Alluvial sediments	Quaternary	Whitish, yellowish, greyish to brownish small to large well-rounded pebbles and cobbles originated from Jurassic, Cretaceous and Paleogene rocks

3 Entrance to the mill

Turonian-Santonian	Upper Cretaceous	Greyish to light grey massive and thick bedded limestones of packstone-wackestone texture
Tenelija and Miljevina	Miocene	Dark grey to yellowish-grey massive and thick-layered oolitic limestone and calcarenites

4 Hearth

Turonian-Santonian	Upper Cretaceous	Greyish to light grey massive and thick-bedded limestones of packstone-wackestone texture

5 Millstone

Turonian-Santonian	Upper Cretaceous	Greyish to light grey massive and thick-bedded limestones of packstone-wackestone texture

4th SHOWCASE OBJECT – ČARŠIJSKA MOSQUE IN STOLAC

0 walls:

Foraminiferal limestones	Early-Middle Peleogene	Light grey massive micritic limestone with foraminifers (Alveolinae & Nummulites)
Podveležje platy limestone	Albian - Cenomanian	Light grey to yellow thin-bedded mudstone-packstone; outcrops on the very large area

1 Main roof of mosque:

Podveležje platy limestone	Albian - Cenomanian	Light grey to yellow thin bedded mudstone-packstone; outcrops over a very large area

2 Minaret

Foraminiferal limestones	Early-Middle Peleogene	Light grey massive micritic limestone with foraminifers (Alveolinae & Nummulites)
Tenelija and Miljevina	Miocene	Dark grey to yellowish-grey massive and thick layered oolitic limestone and calcarenites

3 Main entrance of the mosque

Podveležje platy limestone	Albian - Cenomanian	Light grey to yellow thin-bedded mudstone-packstone; outcrops over a very large area
Foraminiferal limestones	Early-Middle Peleogene	Light grey massive micritic limestone with foraminifers (Alveolinae & Nummulites)

4 Cistern

Foraminiferal limestones	Early-Middle Peleogene	Light grey massive micritic limestone with foraminifers (Alveolinae & Nummulites)

5 Fountain (shadrvan) - roof

Podveležje platy limestone	Albian - Cenomanian	Light grey to yellow thin-bedded mudstone-packstone; outcrops over a very large area

6 Muslim tombstone

Tenelija and Miljevina	Miocene	Dark grey to yellowish-grey massive and thick-layered oolitic limestone and calcarenites

5th SHOWCASE OBJECT – LALIĆA TOWER HOUSE IN MOSTARSKA VRATA

0 walls:

Cenomanian-Turonian	Upper Cretaceous	Greyish to whitish massive and thick-bedded limestone
Middle Paleogene (clastics, carbonates)	Middle Eocene	Yellow to brownish thin to thick-layered marly limestones to sandstones with macroflora and mollusc remains

1 Main roof:

Mostarska vrata platy limestone	Albian-Cenomanian	Grey platy stromatolitic limestone with sporadical chert alteration

2 Front door

Cenomanian-Turonian	Upper Cretaceous	Greyish to whitish massive and thick-bedded limestone

3 Stairs

Cenomanian-Turonian	Upper Cretaceous	Greyish to whitish massive and thick-bedded limestone
Middle Paleogene (clastics, carbonates)	Middle Eocene	Yellow to brownish thin to thick layered marly limestones to sandstones with macroflora and mollusc remains

4 Cistern

Cenomanian-Turonian	Upper Cretaceous	Greyish to whitish massive and thick-bedded limestone

5 Loophole

Mostarska vrata platy limestone	Albian-Cenomanian	Grey platy stromatolitic limestone with sporadical chert alteration
Cenomanian-Turonian	Upper Cretaceous	Greyish to whitish massive and thick-bedded limestone
Middle Paleogene (clastics, carbonates)	Middle Eocene	Yellow to brownish thin to thick-layered marly limestones to sandstones with macroflora and mollusc remains

6 Wall shelf

Cenomanian-Turonian	Upper Cretaceous	Greyish to whitish massive and thick-bedded limestone
Middle Paleogene (clastics, carbonates)	Middle Eocene	Yellow to brownish thin to thick-layered marly limestones to sandstones with macroflora and mollusc remains

The main source areas of limestones used in the selected objects are shown on Fig. 5.2.

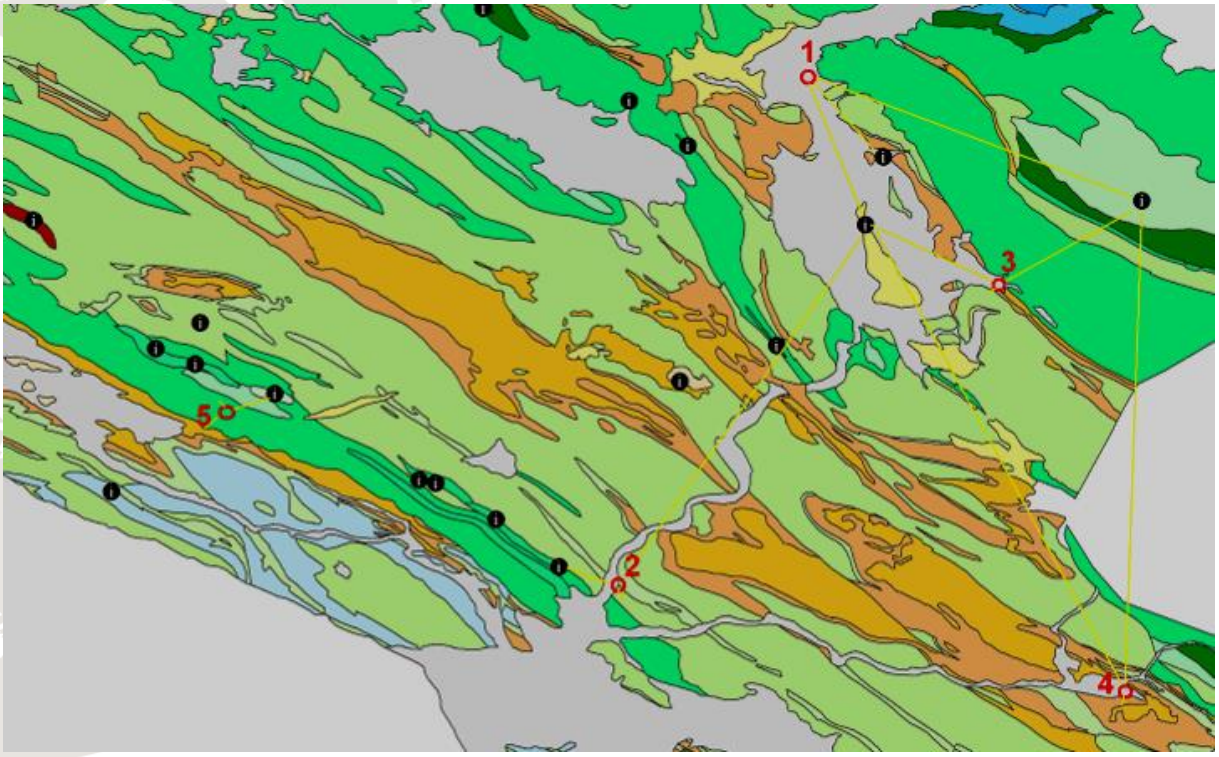

Figure 5.2. Map of the source areas (labelled with yellow lines) of the limestones used in the selected objects (1 – 5, marked in red).

5.4 PHOTODOCUMENTATION OF SHOWCASE OBJECTS

5.4.1 SHOWCASE OBJECT – (4001) "Bišćević House", Mostar

Entire house

0 walls

1 main roof

2, 3 small roofs

4 entrance gate

Paleogene foraminiferal limestone

Quaternary clastic-carbonate breccia

5.4.2 SHOWCASE OBJECT – (4002) MAIN TOWER IN POČITELJ

Entire house

0 walls

1 Roof of the main tower

2 Southeast entrance

3 Western part of the tower

4 Door belvedere & 5 Entrance to the tower

6 Windows on the south side

Upper Cretaceous (Turonian-Santonian) rudistic limestone with rudist (radiolitids) coquinas just next to the base of the tower

Neogene (Miocene) marly-sandy thin (platy) limestone (Miljevina) above the entrance door
Bituminous (anoxic) structure, visible in Cenomanian platy limestone – some kind of fossil flora, and fish parts

5.4.3 SHOWCASE OBJECT – (4003) VELAGIĆ MILL IN BLAGAJ

Entire house

0 walls

1 Main roof (west)

1 Main roof (east)

2 Way to the mill

3 Entrance to the mill

4 Hearth

5 Millstone

5.4.4 SHOWCASE OBJECT – ČARŠIJSKA MOSQUE IN STOLAC

Entire house

0 walls

1 Main roof of mosque

2 Minaret

3 Main entrance of the mosque

4 Cistern

5 Fountain (shadrvan) - roof

6 Muslim tombstone

Many parts of original (Podveležje) platy limestone from the main roof behind the mosque

Close-up of the handmade cross-section of Podveležje (Albian-Cenomanian) platy limestone

A number of small, clearly visible whitish Alveolina foraminifers in this Lower Paleogene limestone in the wall next to the mosque

One small house near the mosque, with roof of original (before the war of 1992-94) platy limestone

5.4.5 SHOWCASE OBJECT – LALIĆA TOWER HOUSE IN MOSTARSKA VRATA

Entire house

0 Walls

1 Main roof

2 Front door

3 Stairs

4 Cistern

5 Loophole

6 Wall shelf

Cross-section of Mostarska vrata (Cretaceous) platy limestones with visible synsedimentary structure

Upper Cretaceous (Cenomanian-Turonian) limestone in old dry-wall next to show-case object with rudists and rudist debris

Paleogene (Middle Eocene) layered and platy sandstone with many fossils of land and marine fauna

Paleogene (Middle Eocene) layered sandstone with fossilized leaves of terrestrial flora

5.5 SUMMARY: SHOWCASE OBJECTS

Analysis of all five selected show-case objects revealed that all objects are roofed with Cretaceous platy limestones, more precisely, with Albian-Cenomanian platy limestones. Since all of these objects represent historic buildings (dating back to the Ottoman era, 16th century) that have been through many wars, their roofs have been almost entirely restored with platy limestone several times. However, at show-case objects nr.1, nr.3 and nr.4 mainly Cretaceous platy limestones quarried from the original site on the southern slopes of the mountain Velež (Podveležje site) were used to restore the roofs. The original types of platy limestone on the roofs of show-case objects nr.2 and nr.5 originate from sites in the immediate vicinity: the Dretelj site from the Cenomanian age, and the Mostarska vrata site of Albian-Cenomanian age, respectively. Cenomanian types of platy limestones from the Bileća site (in Rep. Srpska, not included in this project) and from the previously mentioned Podveležje site were used for the restoration of these objects.

All other parts of the selected objects, walls in particular, are mainly built of rudist limestones of the Late Cretaceous (Cenomanian-Turonian) age, and partly of foraminiferal limestones of the Early Paleogene age, and were very likely taken from quarry-sources in the immediate vicinity of the objects. One point of particular interest is the frequent use of the youngest Neogene (Miocene) marly limestone types, the so-called “tenelija” and “miljevina” stones, which can be observed on four out of the five selected objects. Despite their relatively poorer quality, these types of oolitic and micritic limestones have been widely

used for building since the early Middle Ages, largely owing to their easy treatment and suitability for sculpting. Analysis showed that these types of platy limestones were used in parts of the lintel, walls and window frames at show-case objects nr.1, nr.2 and nr.3, while in show-case object nr. 4. they were used to fashion Muslim gravestones and one part of the minaret. In addition to Neogene sedimentary rocks, some other types of sedimentary rocks were observed in the show-case objects: Quaternary breccias and Quaternary alluvial pebbles, which were used in show-case objects nr.1 and nr.3. Thin-layered, Paleogene fossiliferous sandstones were used in various parts of show-case object nr.5.

6 GENERAL SUMMARY AND CONCLUSIONS

Analysis of selected show-case objects showed that all objects are roofed with Cretaceous platy limestones, more precisely, with Albian-Cenomanian platy limestones. Since all of these objects represent historic buildings (dating back to the 16th century, during the Ottoman era) that have endured many wars, their roofs have been almost entirely restored with platy limestones several times. Other parts of many objects (houses), particularly walls, are largely built of rudist limestones of the Late Cretaceous (Cenomanian-Turonian) age, and partly of foraminiferal limestones of the Early Paleogene age, very likely originating from the immediate vicinity. One point of particular interest is the frequent use of the youngest Neogene (Miocene) marly limestone types, the so-called “tenelija” and “miljevina” stones, which can be observed on four out of the five selected objects. Despite their relatively poorer quality, these types of oolitic and micritic limestones have been widely used for building since the early Middle Ages, largely owing to their easy treatment and suitability for sculpting.

The best examples of good practice in the use of Cretaceous platy limestone as building material appear: in the Old City of Mostar, which is included on UNESCO's list of protected sites; in the medieval Old Town of Počitelj, in Blagaj and Stolac, and in many other very old buildings and objects. Examples of poor practice in the project area can be observed in the use of the youngest Miocene platy marly limestone for walls and for stairs in particular, where we find many instances of acute wear and degradation over time.

It is important to note that even today, laws and regulations related to the commercial exploitation of mineral resources in the Federation of Bosnia and Herzegovina are not well defined. This is especially true at the federal level, with the consequences clearly visible in the field, particularly in small, local and illegal quarries. However, the possibilities for further exploitation of platy limestone in the project area can be generally assessed as potential to highly potential. [The **Podveležje site** exhibits the greatest potential, owing to its large spatial extent, succession thickness, and the very high quality of platy or well-bedded limestone there. As a result, platy limestones from the Podveležje site are being exploited today in numerous small quarries and represent the most commercial type of platy

limestone in the project area, exploited and supplied by many stone dealers and suppliers in Herzegovina. Another particularly valuable, high-quality Albian-Cenomanian platy limestone site lies in a very large elongated zone, approx. 9 km long and 0.5 to 0.7 km wide, in the northern part of the **Raška gora** karst plateau. This site was discovered, described and evaluated in detail during the process of fieldwork for this project. Furthermore, in the eastern part of the **Zvirovići site** polygon, high quality platy limestones exhibit a high potential for further exploitation and use in building and construction, especially for the roofing of houses. Platy limestones from the Zvirovići and Podveležje sites also represent the most extensively and commercially used platy limestones in architecture and construction from among all of the platy limestones from all of the described sites.

Based on all output results, it can be concluded that Cretaceous platy limestones of Neocomian to Cenomanian age are, over the whole project area, the most suitable for further exploitation. These high potential Cretaceous limestones can be quarried at three sites: at the Podveležje, Raška gora and Vrdi sites. All belong to the same horizon (megasequence), located directly in front of the high karst overthrust, just below the highest Bosnia & Herzegovina mountains of Velež, Čabulja, Prenj and Čvrsnica. Another high-potential site belongs to the long polygon of Cenomanian platy limestone north of Čapljina, with several active and very large quarries at the Zvirovići locality. In addition to the above-mentioned PL site, other important and high-potential sites with large spatial extents of Cretaceous platy limestone are the Dretelj-Zvirovići zone and the Drinovci and Boricevac Lower Paleogene site, where very high quality platy limestones also occur.

The majority of platy limestone sites are positioned within the Cenomanian stage (~ 100 to 94 million years BP = lower part of the Upper Cretaceous).

Almost all of the Cretaceous and Paleogene platy limestone sites are formed in shallow marine environments, while the youngest Miocene deposits formed in continental freshwater environments.

7 REFERENCES

BARUDŽIJA, U. (2008): Depositional and diagenetic processes within Upper Albian sediments in Istria, Croatia; PhD dissertation, 153 p.; RGN Faculty, University of Zagreb (in Croatian).

BEHLILOVIĆ, S. (1964): Geologija Čabulja planine u Hercegovini. Posebna izdanja Geološkog Glasnika, knj. IV, Geološki zavod, Sarajevo

CARBONE, F., PRATURLON, A. & SIRNA, G. (1971): The Cenomanian shelf-edge facies of Rocca di Cave (Prenestini Mts., Latium). Geologica Rom., 10: 131-198, Roma.

CARBONE, F. & CATENACCI, V. (1978): Facies analysis and relationships in Upper Cretaceous carbonate beach sequences (Lepini Mts., Latium). Geologica Rom., 17: 191-231, Roma.

DURN, G., OTTNER, F., TIŠLJAR, J., MINDSZENTY, A. & BARUDŽIJA, U. (2003): Regional Subaerial Unconformities in Shallow-Marine Carbonate Sequences of Istria: Sedimentology, Mineralogy, Geochemistry and Micromorphology of Associated Bauxites, Palaeosols and Pedo-sedimentary Complexes. Field trip guidebook : evolution of depositional environments from the palaeozoic to the quaternary in the Karst Dinarides and the Pannonian Basin / 22nd IAS Meeting of Sedimentology / Vlahović, Igor ; Tišljar, Josip (eds.). - Zagreb : Institute of Geology Zagreb , 2003. 209 - 255.

GLAMUZINA, G. (2010): Paleontološki značaj krednih sedimenata u Hercegovini. - Rudarsko-geološki glasnik 14, 29-41, Mostar.

GLAMUZINA, G. (2012): Biofacijesne karakteristike srednjeg eocena područja Čitluka. Magistarski rad, 109 pp. Univerzitet u Tuzli, Rudarsko-geološko-građevinski fakultet, Tuzla.

GLAMUZINA, G. (2013): Paleontološko-paleoekološke osobine pločastih vapnenaca u Hercegovini (Paleontological-paleoecologic features of platy limestones in Herzegovina). – Rudarsko-geološki glasnik 17, 101-119, Mostar.

GUŠIĆ, I. & JELASKA, V. (1990): Stratigrafija gornjokrednih naslaga otoka Brača u okviru geodinamske evolucije Jadranske karbonatne platforme (Upper Cretaceous stra-tigraphy of the Island of Brač within the geodynamic evolution of the Adriatic carbonate platform). – Djela Jugo-slavenske akademije znanosti i umjetnosti, 69, Institut za geološka istraživanja, Zagreb, 160 p.

HRVATOVIĆ, H. (2005): Geological guidebook through Bosnia and Hercegovina. Geological Survey of Federation of Bosnia and Hercegovina, Sarajevo, 163 p.

JURKOVŠEK, B. (2010): Geološka karta severnega dela Tržaško-komenske planote 1 : 25.000 - Tolmač (Geological Map of the Northern Part of the Trieste-Komen Plateau 1:25 000 - Explanatory Book), Geološki zavod Slovenije, Ljubljana: 72 p.

JURKOVŠEK, B., TEŠOVIĆ, C.B., KOLAR-JURKOVŠEK, T. (2013): Geologija Krasa. Geološki zavod Slovenije, 205 p, Ljubljana.

MARINČIĆ, S., MAGAŠ, N. & BENČEK, Đ. (1971): Osnovna geološka karta SFRJ M 1:100 000, List Ploče (Basic geological map of SFRY 1:100 000. The Ploče sheet). Zagreb.

MOJIČEVIĆ, M. & LAUŠEVIĆ, M.(1973): Osnovna geološka karta SFRJ M 1:100 000, List Mostar (Basic geological map of SFRY 1:100 000. The Mostar sheet). Beograd.

MOJIČEVIĆ, M. & TOMIĆ, B. (1982): Osnovna geološka karta SFRJ M 1:100 000, List Kalinovik. (Basic geological map of SFRY 1:100 000. The Kalinovik sheet). - Geoinženjering Sarajevo (1969-1977), Savezni geološki zavod Beograd.

NATEVIĆ, Lj. & PETROVIĆ, V. (1967): Osnovna geološka karta SFRJ, M 1:100 000, List Trebinje (Basic geological map of SFRY 1:100 000. The Trebinje sheet). Beograd.

OREČ, F., ŠARAVANJA, K. & GRBEŠA, I. (2013): Graditeljska baština od kamena na području općine Posušje s posebnim osvrtom na stanje objekata od miljevine. – E-Zbornik, br.6, 112-127, Građevinski Fakultet, Sveučilište u Mostaru, Mostar.

PAVLOVEC, R., DROBNE, K. & SLIŠKOVIĆ, T., (1989): Problemi biostratigrafije paleogena u Hercegovini. – Zbornik referata naučnog skupa ''Minerali,stijene, izumrli i živi svijet Bosne i Hercegovine'', Zemalj. muzej BiH, Prir.nauke, 131-134, Sarajevo.

RAIĆ, V., AHAC, A. & PAPEŠ, J. (1967): Osnovna geološka karta SFRJ M 1:100 000, List Imotski (Basic geological map of SFRY 1:100 000. The Imotski sheet Sarajevo.

RAIĆ, V. & PAPEŠ, J.(1977): Osnovna geološka karta SFRJ M 1:100 000, List Metković (Basic geological map of SFRY 1:100 000. The Metković sheet). Beograd.

SLIŠKOVIĆ, T., PAPEŠ, J.,RAIĆ, V. & LUBURIĆ, P. (1962): O stratigrafiji i tektonici južne Hercegovine. – Geol. glasnik, 6, 111-140. Sarajevo.

SLIŠKOVIĆ, T. (1963): Stratigraphisch-palaontologische Untersuchungen der Kreideschichten des Velež-Gebirge und des Podvelež. – Bull. Sci.Cons. Acad. Yougosl. 8 /3-4, Zagreb.

SLIŠKOVIĆ, T. (1968): Biostratigrafija gornje krede južne Hercegovine. – Glasnik Zemalj.muzeja BiH, Prir.nauke, (N.S.), 7, 5-66. Sarajevo.

SLIŠKOVIĆ, T., PAVLOVEC, R., & DROBNE, K. (1978): Stariji paleogen u južnoj Hercegovini. – Zbornik radova 9.kongr.geol.Jugosl., 125-128, Sarajevo.

ŠARAVANJA, K., MARIJANOVIĆ, P. (2004): Arhitektonsko-građevni i tehnički kamen na području Hercegovine, European Conference on Raw Materials and Coal – New Perspectives, Sarajevo, 2004.

ŠARAVANJA, K., MARIĆ, T. & ŠARAVANJA, D. (2013): Analiza rezultata ispitivanja arhitektonsko-građevnog kamena s područja Hercegovine i jugozapadne Bosne. – E-Zbornik, br.6, 40-57, Građevinski Fakultet, Sveučilište u Mostaru, Mostar.

TIŠLJAR, J. (2001): Sedimentologija karbonata i evaporita. Institut za geološka istraživanja Zagreb, 375 p, Zagreb.

Appendix 1. List of the geological units shown on the 1:250,000 map of Herzegovina

BiH-Silurian-Devonian

BiH-Devonian

2 - Carboniferous, Permian (clastics and carbonates)

3 - Lower Triassic

BIH-Triassic magmatites and metamorphites

4 - Middle Triassic (clastics)

5 - Middle Triassic (carbonates)

6 - Upper Triassic

7 - Lower Jurassic

8 - Lower-Middle Jurassic

9 - Middle Jurassic

10 - Upper Jurassic

11 - Lower Cretaceous (Berriasian – Aptian/Albian)

12 - Albian – Cenomanian (limestones)

14 - Cenomanian – Turonian

15 - Turonian – Santonian

17 - Maastrichtian-Paleocene (Kotišina+Tilovica)

18 - Early-Middle Peleogene (Foraminiferal limestones)

19 - Early-Middle Peleogene (Flysch)

20 - Late Paleogene-Oligocene (Promina)

22 - Neogene

23 - Quaternary

Appendix 2. List of typical quarries of building limestones in Herzegovina

ID_locality (consecutive numbers)	ID geol. unit (geological map 1:250,000)	Name of building (platy) limestone type	Basic lithology	Paleontological characteristics	Age
5001	7	Lithiotis limestone	Platy, layered and massive dark brown limestones and dolomitic bituminous limestones	bivalves (Lithioitis sp, Chlamys subulata etc.), Pentacrinus sp., terrestrial flora (Equisetites columnaris) etc.	Lower Jurassic
5002	11	Orahov do limestone	Massive, light gray to grayish-brown limestone, of wackestone-packstone structure with dolomite lenses	Salpingoporella annulata, Favreina sp., Thaumatoporella parvovesiculifera etc.	Early lower Cretaceous
5007	11	Galit (Tvrda ljut)	Dark gray and rose limestone dolomitic breccia with large limestone fragments in dolomite matrix	small thin-shelled bivalves	Albian - Cenomanian
5009	14	Rujan, Kočerin	Dark gray dolomite, dolomitic breccia and dolomitic limestone	very rare rudists, small nerineid gastropods etc.	Albian - Cenomanian
5020	14	Kušanovac - Crne Lokve limestone	Grayish to light grayish dolomitic limestone, limestone and dolomitic-limestone breccia	rudists (Neocaprina, Durania, Sauvagesia, Radiolites etc.), Actaeonella(Trochactaeon) gastropods	Cenomanian-Turonian
5021	15	Raška gora limestone	Light gray to pure white massive limestone with recrystalized matrix and marble look	caprinid rudists (Neocaprina gigantea, Neocaprina sp., Caprinula etc.), radiolitids, Chondrodonta and other non-rudist bivalves, nerineid and actaeonellid gastropods, corals etc.	Cenomanian-Turonian

5022	14	Gradac limestone	Brownish, light gray to whitish dolomitic limestone	radiolitid rudists, Chondrodonta bivalves etc.	Cenomanian-Turonian
5024	14	Osoje limestone	Whitish-gray massive or layered biomicritic limestone	radiolitid (and ocassionally hippuritid) rudists etc.	Cenomanian-Turonian
5025	14	Kljenak limestone	Breccia-like limestones of redish matrix with many grayish to brownish dolomite-limestone clasts	radiolitid rudists etc.	Cenomanian-Turonian
5027	15	Lipovice limestone	Grayish to light gray massive and thick bedded limestones of packestone-wackestone structure	radiolitid rudists biostromes and floutstone lenses	Turonian-Santonian
5028	15	Greda limestone	Dark to light gray massive to thick bedded limestones	radiolitid biostromes and floutstone, rare hippuritids etc.	Turonian-Santonian
5029	15	Rozi mramor - limestone	Light redish, pinkish to brown-grayish massive limestone with breccia textures and intercalation	radiolitid biostromes and floutstone, rare hippuritids etc.	Turonian-Santonian
5030	15	Hercit - Inka limestone	Grayish to whitish massive and thick bedded limestone	radiolitid biostromes, nerineid gastropods, corals, briozoa, rare hippuritids	Turonian-Santonian
5031	15	Bosiljna limestone	Light grayish to whitish massive limestone, with biosparite structure and glassy shine	radiolitid rudists (Distefanella, Sauvagesia, Radiolites, Durania etc.), rare hippuritids and gastropods of acteonellidae and nerineidae	Turonian-Santonian
5032	15	Dračevo-veselje unito	Light to dark greyish micritic massive limestone	radiolitid bistromes and floutstones, rare hippuritids	Campanian-Maastrichtian

5035	18	Opine limestone	Light gray massive micritic limestone with Foraminifers (Alveolinae & Nummulites)	numerous benthic foraminifers of alveolinidae and nummulitidae family	Early-Middle Paleogene (Foraminiferal limestones)
5038	18a	Konjovac - Fossil	Dark gray, bluish to brownish cleavage (platy) and massive limestones and calcarenites with many whitish sections of marine fossils	numerous marine fauna: corals (colonial & solitary), briozoa, gastropods, bivalves, echinoids, worms, shark's teeth	Middle Paleogene
5041	22	Mukoša - tenelija and miljevina	Dark grey to yellovish-gray massive and thick layered oolitic limestone and calcarenites	numerous fresh water (lake) molluscs - Congeria, Valenciennesia bivalves, gastropods, terrestrial flora,	Miocene

Appendix 3. List of selected platy limestone geological units (polygons) shown on 1:50,000 map

ID (polygon = platy limestone type shown on map 1:50,000)	ID geol. unit (geological map 1:250,000)	Name of platy limestone type	Basic lithology	Paleontological characteristics	Age
5003	11	Vrdi platy limestone	Greyish to brownish platy limestones of mudstone-wackestone structure	foraminifers, algae, Nerinea gastropods etc.	Late lower Cretaceous
5004	12	Drinovci platy limestone	White and light gray platy limestone with stromatolites and chert intercalations	primitive rudists, small bivalves etc.	Late lower Cretaceous
5005	12	Podveležje platy limestone	Light gray to yellow thin bedded mudstone-packstone outcrops on the very large area	fish fossils, caprinid rudists, Nerinea gastropods etc.	Albian - Cenomanian
5006	12	Raška gora platy limestone	Light gray to whitish platy limestone with sporadic or rary dolomitic platy limestone lenses	small bivalves whith thin shells, foraminifers	Albian - Cenomanian
5008	12	Mostarska vrata platy limestone	Gray platy stromatolitic limestone with sporadically chert alteration	small fish fossils, ichnofossils, possible amonite imprints	Albian - Cenomanian
5010	14	Grabova draga 1 platy limestone	Light-gray platy stromatolitic limestone	numerous small bivalves fossils	Lower Cenomanian
5011	14	Radišići platy limestone	Light gray to white platy limestone and dolomitic limestone with slump structures	radiolitid rudists, rare Chondrodonta bivalves ..	Lower Cenomanian
5012	14	Zvirovići-1 platy limestone	Grayish to light grayish platy limestone with chert and stromatolitic lamination	radiolitid rudists (Durania, Praeradiolites) cenomanian foraminifera etc.	Cenomanian
5013	14	Zvirovići-2 platy limestone	Light grayish to brownish platy limestone with horizontal and stromatolitic	fish fossils, rudists (Praeradiolites, Radiolites, Ichthyosarcolites etc.)	Cenomanian

			lamination		
5014	14	Proboj platy limestone	Light gray to whitish gray platy limestone with stromatolitic lamination and slump textures	radiolitid rudists (Praeradiolites, Radiolites etc.), Chondrodonta bivalves	Cenomanian
5015	14	Miletina platy limestone	White and light gray platy and thin layered limestone	caprinid rudists (Caprinula, Caprina, Ichthyosarcolites, Schiosia, Monopleura etc.), Chondrodonta and Neithea bivalves, Nerinea gastropods etc.	Cenomanian
5016	14	Klobuk platy limestone	Grayish to grey-brownish platy limestone with slump micro-folds and lamination	radiolitid rudists, Chondrodonta bivalves etc.	Cenomanian
5017	14	Dretelj platy limestone	Light grey to light brownish platy limestone with horizontal and stromatholitic lamination, sporadicaly with reefoidal bioclastic limestone lenses	Chondrodonta bivalves in general domination with radiolitid rudists (Prearadiolites, Radiolites etc.)	Cenomanian
5018	14	Žovnica (Polog) platy limestone	Gray thin-bedded - platy fine grained limestones	Chondrodonta bivalves in general domination with radiolitid rudists	Cenomanian
5019	14	Mostarsko blato platy limestone	Light gray thin-bedded -platy fine grained limestones with stromatolitic lamination	radiolitid rudists (Radiolites, Durania, Praeradiolites etc.), Chondrodonta bivalves	Cenomanian
5023	14	Gornji Crnač platy limestone	Grayish to brownish thin layered and platy limestone with dolomite lenses and slump structures	radiolitid rudists etc.	Cenomanian-Turonian
5026	14	Slipčići platy limestone	Light to dark grey platy and thin layered limestone	rare rudists etc.	Cenomanian-Turonian

5033	15	Kolojanj platy limestone	Light to dark grayish platy limestone with lamination, micritic structure and chert bituminous nodulas	fish fossils, radiolitid rudists, terrestrial flora remains etc.	Campanian-Maastrichtian
5034	18	Boricevac platy limestone	Dark to light gray thin bedded, platy and laminated limestone	brackish gastropods (Melanopsidae etc.)	Paleocene
5036	18a	Grabova draga 2 platy limestone	Light gray platy and thin bedded limestone with mudstone-wackestone structure	numerous very large benthic foraminifers of nummulitidae family, large oyster bivalves-Pycnodonta gigantica, other marine bivalves, gastropods, echinoids, decapods, cephalopods, brachiopods etc.	Middle Paleogene
5037	18a	Tepčići platy limestone	Light to dark grayish platy limestone with slump structures and fossils	bivalves (Ostrea, Corbula, Lucina etc.), cerithid gastropods, terrestrial flora etc.	Middle Paleogene
5038	18a	Konjovac - Fossil	Dark gray, bluish to brownish cleavage (platy) and massive limestones and calcarenites with many whitish sections of marine fossils	numerous marine fauna: corals (colonial & solitary), briozoa, gastropods, bivalves, echinoids, worms, shark's teeth	Middle Paleogene
5039	22	Trn miljevina - platy limestone	Dark gray to yellowish-brown thin layered and platy calcarenites and marly limestones	numerous fresh water (lake) molluscs - Congeria bivalves, gastropods, terrestrial flora	Neogene
5040	22	Posušje miljevina - platy limestone	Dark gray to yellowish-brown thin layered and platy calcarenites and marly limestones	numerous fresh water (lake) molluscs - Congeria bivalves, gastropods, terrestrial flora, fish fossils etc.	Neogene