The geological significance of Majstorska Cesta – a historical road on Velebit Mt. with a special review of Jurassic carbonate rocks

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Abstract
Majstorska Cesta is a historical road along Velebit Mt., NW of Sveti Rok, preserved in its original state since opening in 1832 and therefore added to the cultural heritage list of the Republic of Croatia in 2007. The road passes through sedimentary rocks ranging in age from Upper Carboniferous to Upper Paleogene, i.e. from 335 Ma until approx. 25 Ma old rocks (a time span of 210 Ma). These are mostly well exposed limestones and dolomites, sporadically clastics. Such rocks build up not only Velebit Mt., but also the entire Karst Dinarides. As such, they represent a unique natural museum important not only for the Croatian landscape, but also for all countries with shallow marine carbonates in the Mediterranean Region and wider, i.e. areas of Mexico, the Caribbean, along mountains like the Atlas, the Pyrenees, the Alps, the Carpathians, the Dinarides, the Helenides, the Pontides, the Taurides, the Iرانides and the Himalayas. The most important geological feature is a section from Mali Alan Saddle to Tulove Grede Ridge. It is a continuous section along the Jurassic carbonates, typical for the Karst Dinarides, of stratigraphic period from Hettangian to Middle Tithonian (201.3-148 Ma), comprising the typical (index) fossils and complete geological rock sections, including contact between Jurassic and Triassic rocks. The authors have researched Velebit Mt. since 1962 until recent times, and thus recognize the necessity to preserve the described Jurassic rock outcrops. They describe the geology of Majstorska Cesta from Sveti Rok to Obrovac.

Key words:
stratigraphy, carbonates, Jurassic, Majstorska Cesta, Velebit Mt, Karst Dinarides, Croatia

1. Introduction
Majstorska Cesta on Velebit Mt., connects Sv. Rok and Obrovac. It is protected as a natural monument, according to Croatian legislature. The road has been built over Upper Carboniferous, Middle and Upper Permian, Triassic, Jurassic, Cretaceous, Palaeogene and Quaternary rocks. The outcrops of Jurassic carbonates between Mali Alan Saddle and Tulove Grede Ridge are especially important, because they are of unique and scientifically important value in Croatia as well as worldwide.

The road transversely crosses almost a completely Jurassic sequence (201.3-148 Ma). It offers an exceptional view into the geological history of the Karst Dinarides, particularly the fossiliferous Jurassic rocks, comprising index fossils for a complete stratigraphic span, including contact with Triassic as well as Cretaceous and Palaeogene rocks. The Velebit Mt. Jurassic rocks were deposited on the Adriatic Carbonate Platform (AdCP; Vlahović et al., 2005), which existed during the Mesozoic Era over the area of the present-day Karst Dinarides. It comprises carbonate sequences of total thickness between 6 and 12 km. The size and age of the AdCP define it as a remarkable geological phenomenon in the world, which is continuously scientifically researched. Therefore, it is very important to preserve such localities and outcrops, keeping the evidence of the AdCP evolution intact.

With respect to the fact that Majstorska Cesta is already protected as tangible cultural heritage (under the category of protected cultural property), the exposed geological heritage can represent additional value for visitors. Such heritage must be described, explained and presented to the public in handbooks, informative pamphlets and signs.

The announcement of the renewal of this locality impelled us to prepare this review. This paper recommends that the representative and exceptional geological outcrops, from the Upper Palaeozoic to Mesozoic and Cainozoic, should be evaluated and considered as a part of national geological heritage. In that case, they would be preserved during the road reconstruction and presented to visitors on informative signs along the road. In this
way, visitors could also use this road as an educational trail. Visitors of the Nature Park would be able to appreciate interesting and informative descriptions of the particular sites and sections, beautiful viewpoints and geological history of Velebit Mt. and the Croatian karst.

2. History

Majstorska Cesta had been planned with the purpose to shorten the voyage from Vienna, as a capital and land-locked part of the Austro-Hungary monarchy, to Dalmatia and its administrative centre Zadar. The construction of that trans-Velebit road started in 1825, from Obrovac to Tulove Grede, crossing the Alan Depression, Mali Alan Saddle towards Sveti Rok. Frontier officer Josip Kajetan Knežić, the famous builder of mountain roads, prepared the first independent project and construction works.

The road is 41 km long. It was completed in 1832 and named Majstorska Cesta (= Craftsman Road). The name reflects the way in which Knežić built the road across the steep Velebit Mt. slopes, with numerous serpentines, among canyons and gulches, which represented great progress in road construction for that time. The maximal road dip was up to 5.5%, corresponding to current rules for road building (Cernički and Forenbaher, 2016). That new Velebit transversal had been used for trade and postal traffic between Vienna and Zadar, which lasted until the early 60’s of the 20th century, i.e. until the opening of the Jadran Highway (Jadranska magistrala), and later the Lika Highway (Lička magistrala) connecting Gračac, Brvno, Udina and Plitvička jezera. Majstorska Cesta passes near the geomorphologically famous feature Tulove Grede Ridge, which is composed of vertical carbonate plates, beams and pillars as well as the attractive Alan Depression.

Majstorska cesta is a historical Velebit pathway (see Figure 1) and that is the reason it was included on the list of cultural heritage of the Republic of Croatia in 2007. Its main value is the fact that the road has been preserved since 1832 with its original route from the Paljenik locality (see Figure 2) on the NW point of Sveti Rok to Obrovac (see Figure 3). Its cuttings and outcrops comprise the rocks of very wide stratigraphic range, from Upper Palaeozoic to Lower Cainozoic (i.e. Upper Carboniferous to Upper Palaeogene; 315 to 25 Ma, 290 Ma in total). Thus, the deposits along the road

![Figure 1: A geographic sketch map of the Majstorska Cesta location (after Cernički & Forenbaher, 2016; legend: 1 = Dalmatina Road, 3 = Obrovac roundabout and road toward Jesenice, 9 = Majstorska Cesta).

Figure 2: The start of Majstorska Cesta in Sv. Rok, on the crossroad with Dalmatina Road (a) and the original milestone from the 30’s in the 19th century (b).]
represent a natural geological museum of carbonates of the Dinaric Karst. The road was built from Obrovac to Sveti Rok, but the geological review in this paper runs in the opposite direction, thus respecting the rule that the oldest rocks are the first to be described. Figures 4 and 5 present the parts of the Basic Geological Maps of SFRY (1:100000), Obrovac (Ivanović et al., 1973) and Udbina (Šušnjar et al., 1973) sheets, with selected parts of the geological maps of Lika and Velebit where the road was constructed.

The first important geological research on Majstorska Cesta and the surrounding area took place in the 1st decade of the 20th century, with data presented on geological map sheets Medak – Sv. Rok (Koch, 1909a; Schubert, 1909a, 1909b) and their explanatory books (Koch, 1909b; Schubert, 1910). Since that time, until the research for the Basic Geological Map of SFRY 1:100000, i.e. for seven decades, no significant explorations had been recorded.

Nikler and Sokač (1968) published the biostratigraphical data from Velebit Mt. and Jelaska and Velić (1971) described the lithostratigraphy of the Lower Jurassic deposits exposed along the road. During the explorations for the Basic Geological Map, the sheets Udbina (Šušnjar et al., 1973) and Obrovac (Ivanović et al., 1973), as well as their explanatory books (Sokač et al., 1976 for Udbina; Ivanović et al., 1976 for Obrovac) were published.

Some valuable data was published in the guidebook of the 9th International symposium on fossil algae (Grgasović & Vlahović, eds., 2007) on Majstorska Cesta, where in the introduction Velić (2007a) described geological characteristics of Velebit Mt. Grgasović and Sokač (2007) presented Permian Mizzia Dolomites (Micijski dolomiti) in Sv. Rok, Grgasović (2007) Ladinian Diplopora Limestones, Sokač (2007a) Lower Jurassic Orbitopsella Limestones, Lithiotis Lime-

Figure 3: Toward the geological point near Majstorska Cesta in Obrovac, along the bridge on the E (right) bank of the Zrmanja River

Figure 4: A part of the Basic Geological Map of SFRY 1:100000, Udbina sheet (Šušnjar i dr, 1973) with a section of Majstorska Cesta in Sv. Rok; legend (for Fig. 4 and Fig. 5): C₃ = shales, sandstones, conglomerates and limestones, Upper Carboniferous; P₂ = conglomerates, Middle Permian; P₃ = Brusane sandstones, Middle Permian; P₄ = Mizzia dolomites, Middle and Upper Permian; T₁ = sandy dolomites and micaceous sandstones, Lower Triassic; T₁ = Diplopora limestones, Middle Triassic, Anisian; T₂ = Diplopora limestones with lenses of tuffitic siltites, Middle Triassic, Landinian; T₃ = Raibl siltstones, sandstones and conglomerates, Upper Triassic, Carnian and Norian; T₃ = Main dolomite (Hauptdolomit), Upper Triassic, Norian and Rhaetian; J₁ = Mali Alan, Lithiotid and Spotted limestones with dolomite intercalations, Lower Jurassic; J₂ = Alan limestones with dolomite intercalations, Middle Jurassic; J₃ = Alanc limestones and dolomites, Upper Jurassic, Oxfordian and Kimmeridgian; J₄ = Chypeina limestones with dolomite intercalations, Upper Jurassic, Kimmeridgian and Tithonian; K₃ = Limestones, dolomites and dolomite breccias, Lower and Upper Cretaceous; K₄ = Rudist limestones and dolomites, Upper Cretaceous, Cenomanian and Turonian; Pg, Ng = Velebit breccia and Promina conglomerates, Palaeogene and Neogene; pr = proluvial gravels and sands; al = alluvial deposits; b = pond deposits
stones and Spotted Limestones, Sokač (2007b) Upper Jurassic Limestones, and Velić et al. (2007) Oligocene – Miocene Jelar Breccia (i.e. Velebit Breccia). One of the more recent papers (Velić, 2010) presents a short description of Velebit Mt. geology. This paper describes the entire road section, with an emphasis on geological showpieces.

3. Results

Majstorska Cesta is described from the older toward the younger stratigraphic units, starting with the Sv. Rok locality, across Velebit Mt., towards Obrovac. At the start, from Paljenik to the centre of Sv. Rok, the road was first laid on the proluvial Quaternary deposits, and sporadically on the Carboniferous shales and sandstones and on the Lower Triassic micaceous sandstones.

In the majority of Sv. Rok, the road was built over the Middle Triassic Diplopora Limestones, and, near Šušentić, on the Permian Mizza Dolomites (see Figure 6). Further, up until Egeljac, it is positioned on the alluvial deposits between the Diplopora Limestones and the Mizza Dolomites.

On the northern slope of Velebit Mt., from Egeljac to Dacija, the road lies over the Middle Triassic, grey, marble-like, massive and karstified Anisian Diplopora Limestones, until halfway towards Crveni potoci (see Figure 5). Near the hill 852 and at the sharp bend, on the NE side of Šiljci Ridge, is a branch of the forest path into the geologically remarkable location Crveni potoci, about 600 m away. There is an open erosional contact between the Middle and Upper Triassic deposits, about 2 km long. Karstified grey Diplopora Limestones of Ladinian age have been deposited in a subtidal zone and overlain by brownish Raibl Clastics, dominantly siltites with sandstone and scarce conglomerate intercalations. These are terrestrial sediments, painting the nearby Crveni potoci (=Red Creeks) into a brownish-red colour (see Figures 7 and 8). Overlying, Upper Triassic, grey and brown Main dolomites, were deposited at the wide-spread tidal flat plains of the Tethys Ocean. Majstorska Cesta is, from the extension towards Crveni potoci and further into Dacija over a span of 3 km, still built over the Diplopora Limestones on the N slope of Šiljci Ridge (see Figure 9), all over the next eastern extension in the forest. From that crossroad to Mali Alan Pass, the road is located on the Upper Triassic Main Dolomite (see Figure 10), reaching the boundary between the Triassic and Jurassic deposits (see Figure 11).
herds’ settlements. The road then continues through the Lithiotis limestones, and bends towards the W, where there is a viewpoint over the Alan Depression. Here, the road is almost parallel with the strike of the Lower Jurassic limestones, with sedimentological textures visible on upper surfaces, like ripple marks (see Figure 13) and desiccation cracks (see Figure 14), along with the Lithiotid coquinas (see Figure 15).

At the hill 105 and the abandoned quarry of the Lithiotis Limestones (see Figure 20) a boundary between the Lithiotis and Spotted Limestones and Dolomites (see Figure 16) is visible. The road continues towards the S for about 2 km.

After 150 m, on the Spotted Limestone (see Figure 17) the road reached the Middle Jurassic Alan limestones (see Figures 18 and 19), with rare intercalations of brownish dolomites (see Figure 20). The limestones are mostly thick-bedded and highly karstified (see Figure 21), grey mudstones. At Kraljičina Vrata (= Queen’s Doors) point, in the road notch, a recumbent anticline...
alteration of greyish limestones and brownish, late diagenetic dolomites; limestones are rich in remains of the fossil calcareous algae, mostly of the genus *Palaeodasycladus*; strata thicknesses vary from 30 to 60 cm

occurs (see Figure 22), probably representing a syn-sedimentary sliding structure – slump.

Majstorska Cesta has been cut into by the Alan limestones up to a point 200 m S from Kraljičina vrata, where the boundary of the Middle and Upper Jurassic is exposed (see Figure 23), i.e. between the Middle Jurassic Alan Limestones and the Upper Jurassic Alanac Limestones and Dolomites. Alanac Limestones are very fossiliferous, comprising the abundant foraminiferal tests of genera *Andersenolina* and *Chablaisia*, located at hairpin-bends and all over the SI slope of the Kuće Marunića Ridge. There is contact with younger, Upper Jurassic, Clypeina Limestones, which spread toward Tulove Grede locality. On their N slope, there is a large sinkhole, created by the destruction of the subsurface cave roof. From the top, the valley Jurkovića Vrtni is composed
Figure 17: Toarcian Spotted Limestone with a well visible thin bedded pattern of the deeper sea environments; location about 50 m S from the abandoned quarry and elevation point of 1005 m (scale – geological hammer is 33 cm long)

Figure 18: The boundary between the Lower and Middle Jurassic carbonates (marked by a geological hammer): the topmost part of the Lower Jurassic deposits is composed of thin-bedded brownish dolomite of the Spotted Limestone Unit. The base of the Middle Jurassic deposits is represented with dark-greyish, thick bedded limestones of the lithostratigraphic unit Lower Alan Limestones and Dolomites

Figure 19: Karstified and fissured dark-greyish and greyish, thick-bedded Middle Jurassic carbonates of the lithostratigraphic unit Lower Alan Limestones and Dolomites

Figure 20: Alteration of greyish limestones and brownish dolomites, lithostratigraphic unit the Lower Alan Limestones and Dolomites

Figure 21: Weathered massive Upper Alan Limestones

Figure 22: Recumbent fold in the Middle Jurassic Upper Alan Limestones as a result of slumping (not tectonics) during the deposition on a subtidal slope, where calcareous detritus was deposited and reached the critical weight for the gravitational transport and folding of strata of Upper Jurassic Alanac and Clypeina limestones (see Figure 24).

The Tulove Grede complex represents a remarkable geomorphological landscape of Velebit Mt. They are built of the Velebit Breccia arranged in several rows of
carbonate panels and columns. Majstorska Cesta is cut into the breccia on the W side of Tulove Grede Ridge. Majstorska Cesta, from Tulove Grede to Zaton Plain, passes mostly through Velebit Breccia (see Figure 25), occasionally through the Lower Cretaceous limestones (see Figure 26). Before the crossing with the Obrovac roundabout, the road leaves the breccia and runs through the Lower Cretaceous limestones. The roundabout gives the best view of Tulove Grede and the S slope of Velebit Mt. where the road passes. At the very end, the road reaches the former alumina factory, where it passes over the Vrakon dolomites and dolomitic breccia and the Upper Cretaceous rudist limestones. The road ends at the bridge over Zrmanja River in Obrovac, in Promina conglomerates and sandstones (see Figure 27) with intercalations of marlstones.

5. Conclusion

The main geological values of Majstorska Cesta are:
• it is cut through the Younger Palaeozoic, Mesozoic and Cainozoic rocks, typical for the whole Karst Dinarides;
• Palaeozoic Carboniferous rocks in Sv. Rok and the surrounding areas, represent the basement of carbonate succession of the Karst Dinarides with a thickness of 5000-12000 m; only in the Lika foot-
hills of Velebit Mt. they are found in continuity with the younger rocks;

- Most of the rock types present along the road are rich in fossil content;
- part of the road, through the Alan Depression, from Mali Alan Pass to Tulove Grede, is the *locus typicus* of Jurassic shallow marine carbonate deposits for the entire Karst Dinarides;
- rocks along the road were presented on many geological excursions, from student’s fieldtrips to large domestic and international geological meetings;
- the road has been studied in numerous scientific papers, reports, projects, graduate and doctoral theses;
- detailed geoscientists’ research along the road made the construction of the Sv. Rok Tunnel possible, on the A1 Highway (with a margin error of strata positions of less than 1 m);
- the road was, and always will be an attractive location for scholar, student and scientific fieldtrips, as well as for guided sightseeing tours.

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Author Contributions

Ivo Velić: conceptualization, investigation, led the research and selected the fields for analyses, prepared the regional geology presentation and connected them with regional geology, writing — original draft. Josipa Velić: visualization, collected field data, writing - review & editing.

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Conflicts of Interest

The authors declare no conflict of interest.