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The “Orešje” Laramian Structure in the NE part of Medvednica Mt. (Croatia)

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Abstract

Structural features of Upper Triassic and Upper Cretaceous carbonate rocks of the Donje Orešje quarry were formed by tectonic deformation in temporally separated deformational events. The main structure is the complex Orešje structure with a N–S strike and E vergence. It is composed of several overturned anticlines in which either similar or different structural forms were observed. The structure was formed by Laramian movements during the Alpine orogeny when the main stress was oriented E–W. During the youngest Tertiary and Quaternary movements, the Orešje structure was influenced by a N–S oriented stress whch resulted in folding and rotation of the main structural form.

1. INTRODUCTION

Medvednica Mt. belongs to the mountain range which cannot be distinguished structurally or tectogenetically from other mountains of the Pannonian basin between the Sava and the Drava rivers. The same or similar structural morphologies were recognised within the rocks of this mountain, as occur in the other mountains of the area (JAMIČIĆ, 2000a). The formation of the structures was connected with tectonic events from the Palaeozoic to Quaternary periods which are tectonically clearly separated (JAMIČIĆ et al., 1985, and JAMIČIĆ, 1988, 1993, 1995b, 2000a, b). Based on the aforementioned papers, it has been proven that the tectonic events within the Laramian phase of the Alpine orogeny have resulted in formation of the important structures within the Upper Cretaceous and older rocks. The structures were finally shaped by the recent N–S oriented stress.

In the area of the Slavonian mountains, these events resulted in the formation of a complex structure Kik–Petrov vrh, defined as being approximately 10 km in length with a N–S strike and E vergence (JAMIČIĆ, 1988, 1993). On Požeška gora Mt. the structures in the Upper Cretaceous layers of the Bodljiš stream have been formed with the same E vergence and were also observed in the granitic–rhyolitic part of this mountain (JAMIČIĆ et al., 1985). Tectonic elements of this event can also be seen in the Ivanščica, Kalnik and Ravna gora Mts.

At the northeasternmost part of Medvednica Mt., approximately 4 km N of Zelina (Fig. 1), in the area of Donje Orešje village, the Upper Triassic and Upper Cretaceous carbonate deposits were discovered in a local quarry. Limestones containing hippuritids in the Donje Orešje area were first discovered by FOETTERLE (1861/62). They were described by GORJANOVIĆ-KRAMBERGER (1908) as hippuritid limestones and Gosau marls, whereas POLŠAK et al. (1978) have described in detail and documented by fossils four members of the Upper Cretaceous, ranging from Santonian to Lower Campanian in age. BASCH (1983) mentioned pelagic sediments and reefal limestones with marl intercalations in the area of the Donje Orešje. KOROLIJA et al. (1995) proved the presence of Upper Triassic limestones of Norian–Rhaetian age in the quarry, which are discordantly overlain by Upper Cretaceous rudist lithosomes.

2. METHODOLOGY

Detailed structural measurements of the Upper Triassic and Upper Cretaceous limestones on the open profile in the Donje Orešje quarry, defined the complex Orešje structure (Fig. 2) as being approximately 500 m long. During these explorations determination and classification at outcrops of all present discontinuity planes (bedding, faults and axial plane) and related structural elements were undertaken, and numerical measurements taken according to their shape and genesis. For the faults with records of tectonic transport, orientation of regional stress has been calculated by the left inclination of a-lineation (ζ). Since the most frequently measured discontinuity planes were the bedding planes which also mark the structure, a β-diagram has been made which allowed the position of the fold axis to be constructed. Among linear structural elements, the positions of fold axes and axes of r-tectonites have been measured. The presence of fracture systems parallel to the zone of axial plane of folds was determined, as well as conjugated fractures oriented obliquely to the

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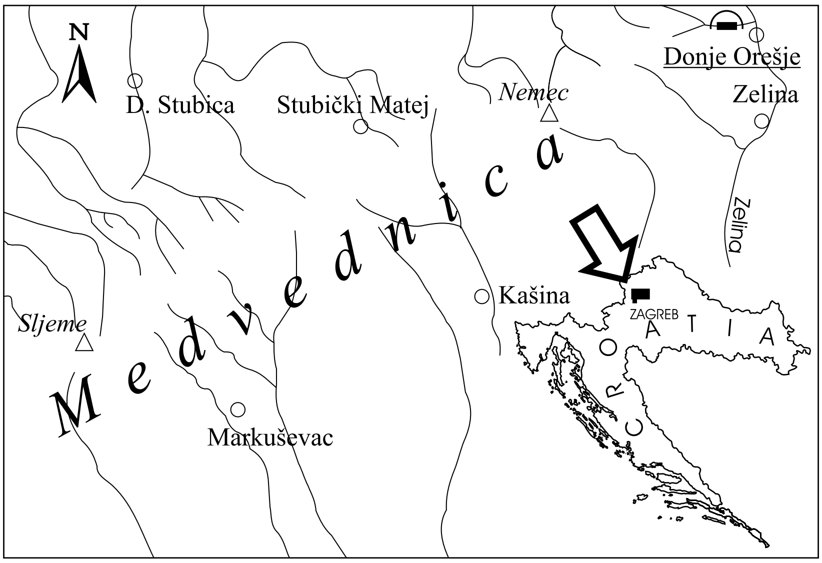

Fig. 1 Location map of the Donje Orešje quarry.

fold axis and fractures perpendicular to the fold axis. In the zones of intense tectonization, especially in the overturned limbs of the folds, schistosity subparallel to bedding planes occurs.

3. RESULTS

The complex Orešje structure is shown on Fig. 2, reconstructed on the basis of the observed and measured structural and tectonic data. It is composed of at least five anticlines, each showing a different grade of deformation and fold index, depending on their position in the complete structure and ductility of the available rocks present. It is visible for almost 450 metres, mainly in the southern part of the Donje Orešje quarry, which is open along an approximately E–W strike in the valley of the Šum stream.

At the easternmost part of the structure (Fig. 2), Upper Triassic (Norian–Rhaetian) limestones occur, in the form of an overturned anticline (Fig. 3). In contorted beds, up to 1.5 m thick, crushing of limestones as a consequence of folding is observed. Fractures oriented 207/13° which mark the axial plane of the fold, and fractures oriented 16/75° from the zone perpendicular to the fold axis were observed. On the strike-slip fault oriented 120/78°, a-lineation with left angle (ζ) of 3° has been measured.

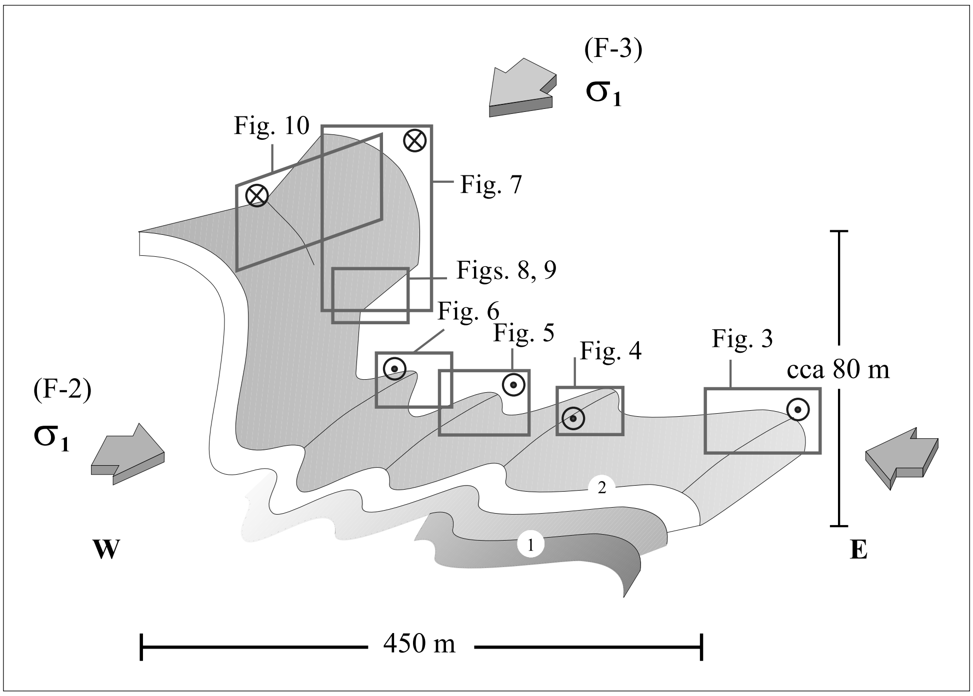

Fig. 2 The reconstruction of the Orešje structure: (1) Upper Triassic, (2) Upper Cretaceous.

Tectonic transport right-lateral to the fault plane has been observed and based on these data the main stress axis (σ_1) oriented 250/3° is defined resulting in the form of an overturned fold. The strike of the fold axis is approximately N–S with a gentle plunge toward the S. The inclination of the *b*-axis and axial plane of 13° towards the S is caused by younger tectonic events on a pre-formed structure under the influence of stress which was, during the Tertiary and Quaternary, active in a N–S direction. Deviation from the vertical axis (~15°) of fractures perpendicular to the *b* axis also took place during the younger kinematic event. Associated fracture systems in the normal limb of the structure described belong to the extensional fractures parallel to the *b* axis and were formed by the pushing aside and migration of beds towards the apical parts of the fold.

The next structure towards the W (Fig. 2) is composed of Cretaceous limestones and its structural features also show the character of an overturned anticline. Part of the structure is shown by the photograph (Fig. 4a). The normal limb (not visible on the picture), is cut off and pushed over the footwall of the anticline. Different structural elements are clearly observed showing the intensive folding and the compression of the space.

The most remarkable discontinuity planes are bedding planes. Their numerical measurements (8 data) are presented on a β-diagram (Fig. 4b). The maximum of the β-intersection (169/15°) as well as the sub maximum (339/11°) show the *b* axis strike of the complex Orešje structural segment. The other maxima are accidental intersections. Sigmoid folding of beds visible in the right part of photograph (Fig. 4a) is the consequence of reverse pushing of the hanging wall of the structure.

In the central parts of the photograph “boudinage” structures can be seen; their longer axis is oriented 158/13° and marks the *b*-axis as well, which completely coincides with values for the *b* axis of the structure obtained from the β-diagram.

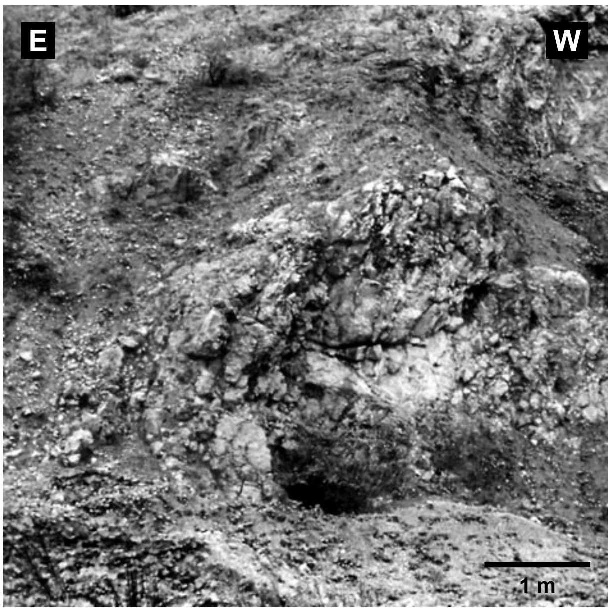

Fig. 3 The apical part of the anticline in the Upper Triassic limestones.

The fracture system, parallel to the photograph in Fig. 4a, belongs to fractures from the zone perpendicular to axis *b*. These are open fractures (1–2 cm in size) with an orientation 344/67°; their existence is connected to the extension of the structure parallel to the *b* axis. On their planes calcite coatings in forms of crystals which crystallized by migration from the source rock in open fracture systems are observed, so it could be assumed that these fractures are the youngest and that they were formed with the layer-parallel slip of limestone.

A new structure further towards the W in continuation (their photos can be merged) with the previously described structure (Fig. 4a), is shown in Fig. 5a. Here we can observe the apical part of the overturned anticline overthrust on the previously described structure from Fig. 4a.

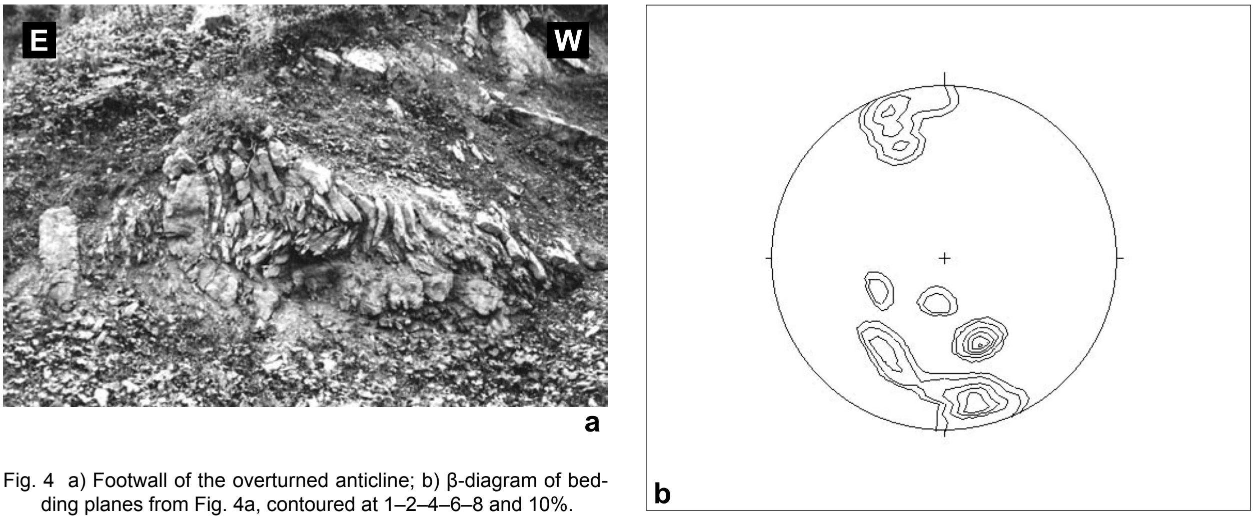

Fig. 4 a) Footwall of the overturned anticline; b) β-diagram of bedding planes from Fig. 4a, contoured at 1–2–4–6–8 and 10%.

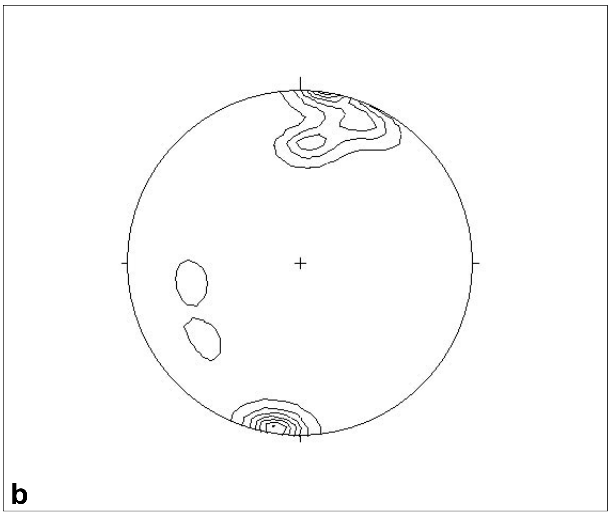

Fig. 5 a) Apical part of the overturned anticline in the Upper Cretaceous calcarenites; b) β-diagram of bedding planes from Fig. 5a, contoured at: 1–5–10–20–25 and 30%

A reverse fault is gently laid and covered by rockfall material. In contrast to the previously described structure, the folding index is smaller due to the presence of thicker calcarenite beds (in the right part of photograph). The main structural elements remain the same. In calcarenites the faults from the axial plane zone oriented 190/12° with a reverse type of transport of hanging wall are seen. The open fractures are clearly pronounced (187/78°) perpendicular to axis *b*. Similarly, calcite crystals have been observed on these fractures indicating extension parallel to the *b* axis during fold formation. The strike of the structure is approximately N–S as seen from the β diagram (Fig. 5b), made from measured bedding data (8 in total). A strike maximum of 189/6° defines the position of the *b* axis of the structure and is in complete accordance with measured data from the outcrop (189/4° and 18/6°).

The next structure available for observation extends further towards the W. It is composed of Upper Cretaceous platy limestones (Fig. 6) which are folded in metric folds of the "chevron" type. The fold orientation is N–S with E vergence. Apical parts of the folds are weakly pronounced or non-existant, as a result of their high folding index. Axial fold planes are oriented N–S and are inclined towards the W under the angle of 58°. Fracture systems appear parallel to the *b* axis, splitting the limestone beds into lithons a couple of centimetres up to one metre wide. Lithons are disjointed up to 10 centimetres and the interstitial space is filled by terrigenous material derived from the surface. Bed separation is noticed (105/4° and 285/74°) as a consequence of folding, indicating that the deformations did not take place at great depth. The fractures from the zone perpendicular to the *b* axis are also present (parallel to the photograph) with calcite coatings similar to those from Fig. 4a.

Fig. 6 Metre-sized chevron folds in platy Upper Cretaceous limestones.

In the furthest N–W part of Donje Orešje quarry, the apical part of an overturned fold composed of the Upper Cretaceous clayey limestones is exposed at a height of 12 m. This part of the structure (Fig. 7) is overthrust on the previously described folds and has been secondarily folded. The axial plane has E vergence and is relatively gently inclined. The beds are of 74/56° and 74/75° orientation. The fractures from the zone perpendicular to the *b* axis oriented 165/76° with calcitic crystal coatings are important. Sliding of hanging beds during folding resulted in the formation of a small cavern (in the lower part of the photograph), the axis of which is parallel to the *b* axis of this anticline structure (350/2°).

On the photograph (Fig. 8) taken on the left side of the cavern (Fig. 7), in the footwall part of the anticline fracture systems are visible (Riedl fractures, left of the hammer), which were formed by the influence of layer-parallel slip in the apical parts of the structure. The fractures formed domino structures. The intersection between bedding planes and fractures (347/2°) are entirely correlatable with values of the structural axis.

In the hanging wall part of the Orešje structure (Fig. 7) the fractures from the zone perpendicular and parallel to the *b*-axis are observed as well as a conjugate fracture system diagonal to the axis (Fig. 9). This fracture system is generally characterized by folded forms. The

Fig. 7 Overturned limbs of the fold composed of the Upper Cretaceous clayey limestones.

Fig. 8 Domino structures formed by layer-parallel slip.

fractures oriented 198/89° (left of the pen), are from the zone perpendicular to the *b*-axis, which correlates with all other measured data for the entire structure. The conjugate fracture system (below the pen) is oriented 328/62° and 233/64°, indicating that the fractures were created by the influence of stress oriented E–W. There are no traces of movements visible on them, although these should be expected. On the picture (right of the pen) scarce fractures from the zone of the axial plane oriented 276/38° are seen.

All the deformations described above were formed in a single tectonic event under a stress oriented E–W. The complex structure has a N–S strike with E vergence. It consists of several overturned anticlines (Fig. 2) that are mutually connected with synclines. However, in the overturned limb of the last described anticline, structures formed after the completed shaping of the Orešje structure have been found; similar structures are less pronounced in its other parts. Namely, there the synclinal folding near the E–W axis within the Upper Cretaceous clayey limestone is being observed. In the central part of this N–S oriented syncline shown on Fig. 10, layers of Tertiary deposits occur (Badenian), which were primarily discordant over the Orešje structure. Bedding planes of the Upper Cretaceous layers were oriented N–S before these deformations, with a plunge towards E, and were folded around an E–W axis. Bedding (55/58° and 130/28°) marks the new axis b_2 (126/29°) which correlates with field measurements. A major part of the *b*-axis plunge is caused by bed inclination before the deformation. On the photograph, the old fractures from the zone perpendicular to the b_1 axis are visible, which are rotated by younger tectonic processes around an approximately horizontal E–W axis. Their orientations are 150/88° (left part of the picture) and 350/42° (right part of the picture). During these deformational processes, the Badenian beds (in the upper parts of the photograph) were also folded and disintegrated. Only the fractures which are parallel to the axial plane of the newly formed structure b_2 appear.

4. CONCLUSION

Based on the detailed structural investigation of the Upper Triassic and Upper Cretaceous deposits in the Donje Orešje quarry, the complex structure of Orešje has been defined. It has been proven that it is composed of at least five mutually connected anticlines formed during the same deformation event. Dating of these events is defined by the position of Tertiary deposits which are discordant to the Orešje structure. By correlation of the characteristics and genesis of the structure with other parts of the area between the Sava

Fig. 9 A fracture system in the hanging wall of the overturned anticline.

Fig. 10 A syncline in the Upper Cretaceous layers formed by the youngest deformational event.

and Drava rivers, it can be concluded that the structure was formed during the Laramian movements within the Alpine orogeny. The structure is oriented N–S, with E vergence and was formed by the influence of the tangential stress oriented E–W. Similarly, almost the same structural forms, as mentioned in the introduction, could be found in the wider region of the Croatian part of the Pannonian Basin. Therefore these data should be taken into consideration for interpretation of the tectonic evolution of this part of the Pannonian Basin.

The youngest tectonic movements (Tertiary–Quaternary), caused by the N–S oriented stress, reshaped parts of the Orešje structure. They folded the discontinuity planes and inclined the structural axes along the E–W direction by approximately 10º. Based on the recent investigations these events corresponded to the transpression model (JAMIČIĆ, 1995a) under the influence of left (strike-slip) faults, when the separated blocks were moved apart and counter-clockwise rotated for 35–40° (JAMIČIĆ, 1981, 1988; MÁRTON et al., 1999, 2002).

Finally, it is important to conclude that Medvednica Mt. belongs to the Pannonian area, and that its tectonic evolution cannot be separated from the evolution of the other mountains of the area.

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