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On the Origin of the Oklad Breccia on the Island of Brač (Southern Croatia)

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Key words: Maastrichtian, Carbonate rockfall breccia, Palaeostructural differentiation, Laramian tectonic movements

Abstract

The Oklad carbonate polymictic breccia from Novo Selo on the island of Brač is a product of the partial destruction of Upper Cretaceous deposits during the Maastrichtian. From a comparison of the lithostratigraphic units of the Upper Cretaceous with the textural and structural features of breccia, it is possible to determine the palaeomorphological pattern of its origin. At the end of the Maastrichtian plicative and disjunctive deformation took place on this part of the Adriatic carbonate platform, resulting in a steep palaeorelief, adequate for formation of the breccia.

1. INTRODUCTION

During previous geological investigation of the island of Brač insufficient consideration has been given to the problem of breccia deposits. This is especially true of the Oklad breccia, in the vicinity of Novo Selo (Fig. 1). The origin and stratigraphic position of the breccia in the Upper Cretaceous of the island of Brač has been a subject of special interest for many years. Therefore, its investigation was one of the primary purposes of the complex geological research carried out on the island of Brač in the last few years. Distinguishing between various types of breccias on the island is a very important criterion in the interpretation of a complex geological setting. This especially refers to the palaeomorphological aspects of the observed lithological variability, and to the influence of synsedimentary tectonics on the tectogenesis of this area, as well as on wider regions of the Adriatic carbonate platform.

2. A REVIEW OF THE STRATIGRAPHIC UNITS

The Upper Cretaceous deposits on the island of Brač are divided into several lithostratigraphical units (GUŠIĆ & JELASKA, 1990, and Fig. 2). In this brief review we will discuss only those providing information on the formation of the Oklad breccia.

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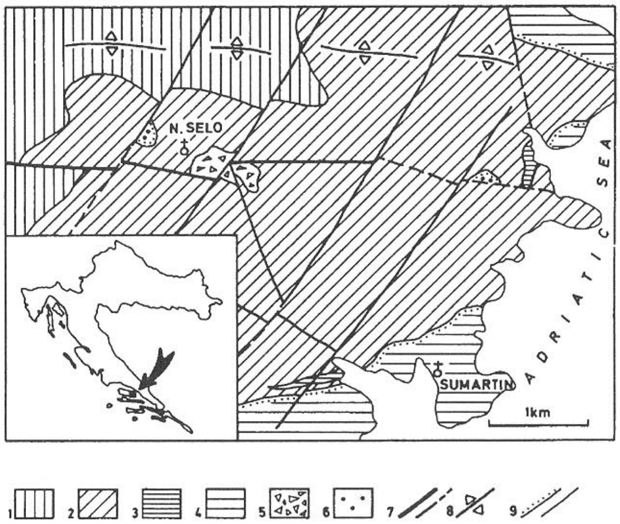

Fig. 1. Location and geological map of the study area (SE part of the island of Brač). Legend: 1) the Dol Formation - the Sivac Member; 2) the Pučišća Formation - the Brač "marble" Member and the Lovrečina Member; 3) the Pučišća Formation - the Rasotica Member; 4) the Sumartin Formation; 5) the Oklad breccia; 6) Alveolina-Nummulite limestones; 7) the fault of the 1st and the 2nd category; 8) the anticline axis; 9) transgressive and normal boundary.

The upper part of the *Dol Formation* (Fig. 2) comprises a lithofacies called the *Sivac micrite*. It is composed of grey biomicrites with numerous pelagic microfossils (calcisphaerulids, pithonellas, globotruncanids), and biodetritus of echinoderms and sponges, which indicate an Upper Santonian to Lower Campanian age. The *Sivac micrite* was deposited either in a deep marine environment or in a subtidal area with a strong pelagic influence, and has a thickness of 300-400 m. In the middle of the Campanian the influence of the open marine environment gradually diminished as the platform prograded.

Deposits of the *Sivac* lithofacies were finally buried by the bioclastic packstone-grainstone of *Brač "marble"*. This is the lowest member of the overlying formation (the Upper Campanian *Pučišća Formation*), which is characterised by facies variability. The deposits of the *Brač "marble" Member* were accumulated in the vicinity of rudistid biostromes, and are characterised by the predominance of this locally derived material. Only a small proportion of allochems consist of bioclasts of benthic foraminifera.

The second member of the *Pučišća Formation*, the *Rasotica Member*, is characterised by an abundance of

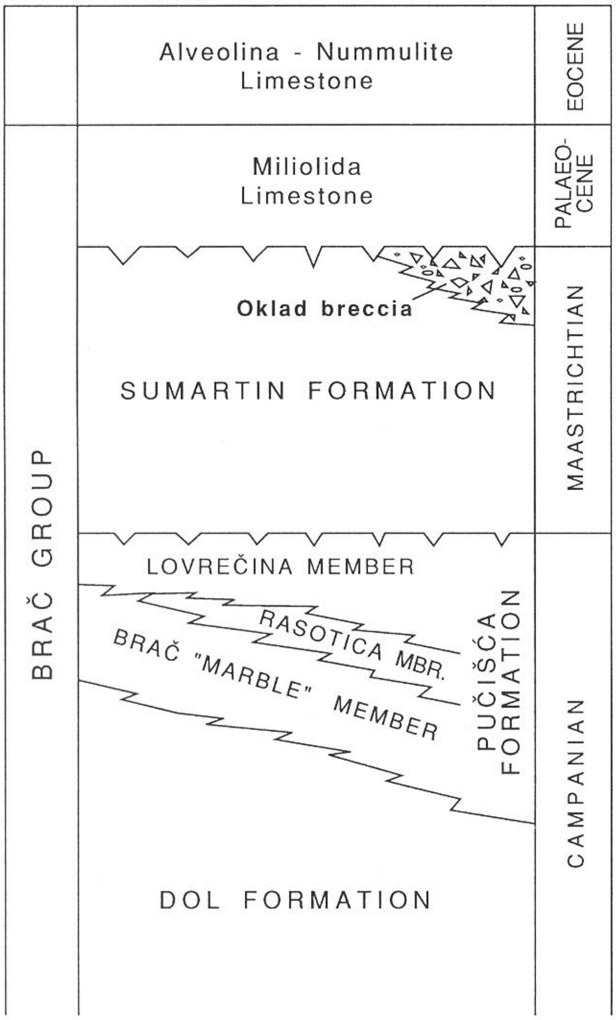

Fig. 2. Part of the column of the Upper Cretaceous deposits on the island of Brač (after GUŠIĆ & JELASKA, 1990).

rudist shells and debris with a foraminiferal-bioclastic wackestone/packstone matrix. In some places there are single-generation rudistid biostromes, which pass laterally into bioclastic material. The matrix is mostly dark brown, and sporadically almost completely black, as a consequence of the abundant bituminous matter.

The uppermost member of the *Pučišća Formation* is the *Lovrečina Member*. It is composed of shallowing-upward sequences of foraminiferal-peloidal-bioclastic wackestone and packstone, to fenestral mudstone and stromatolites. In addition to frequent vadoids, black-pebbles, spelaeothems and microcodia, desiccation cracks and karstification cavities filled with early-diagenetic dolomite are common.

The total thickness of the *Pučišća Formation* is about 60 m. The variability of facies in this formation is a consequence of a highly differentiated morphology, caused by distinct synsedimentary tectonics. The most intensive change in this area occurred at the end of the Campanian with a phase of emersion.

After the emersion, in the Maastrichtian, *Sumartin Formation* (GLOVACKI JERNEJ & JELASKA, 1986) was deposited. These sediments were accumulated in subtidal to intertidal environments, and can be divided

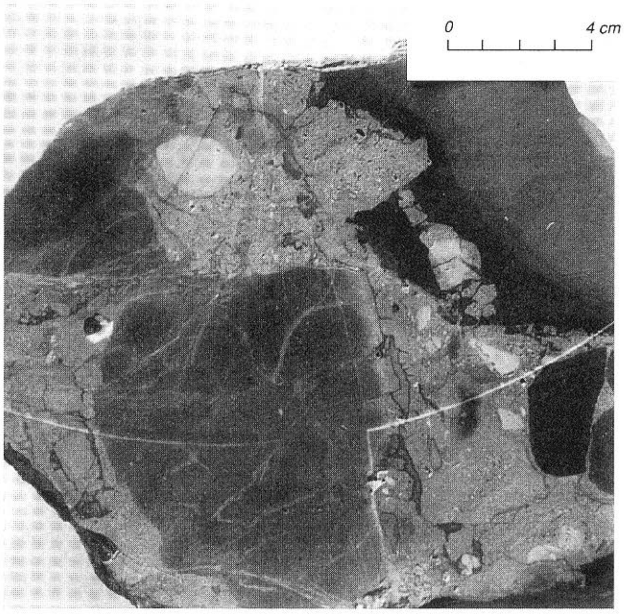

Fig. 3. Different clasts in the breccia. The contact with the underlying deposits to the lower right.

into two parts. The lower part consists of dolomites, rudistid biostromes, laminated micrites and dolomicrites with desiccation features. The upper part is composed of foraminiferal wackestones with shallowing-upward characteristics (commonly desiccation cracks, vadoids, tepee structures, caliche, etc.). The *Sumartin Formation* has a total thickness of approximately 200-250 m.

The thicknesses of formations mentioned above are average values for the entire island. It should be noted that the thicknesses of the younger stratigraphic members are highly variable, because of intensive palaeomorphological differentiation.

3. POSITION AND CHARACTERISTICS OF THE BRECCIA

The Oklad breccia stretches in a continuous, but irregular zone from Novo Selo towards the southeast for about 500 m. It is aligned with the apical part of the easternmost extension of the anticline of Brač (PRTOLJAN, 1989). The width of the zone is from 100 to 200 m, and the thickness of breccia deposits increases toward the southeast, with the maximum of more than 20 m in the Oklad quarry. The contact between the underlying *Brač "marble" Member* and the breccia is irregular and sharp, following the shape of the palaeorelief (Fig. 3). Its surface is inclined 15 to 20° toward the south and southeast. The upper part of the breccia, west of Novo Selo, is in contact with the Eocene nummulitic limestones.

The Oklad breccia is composed of different carbonate clasts and a rather high proportion of fine-grained carbonate matrix.

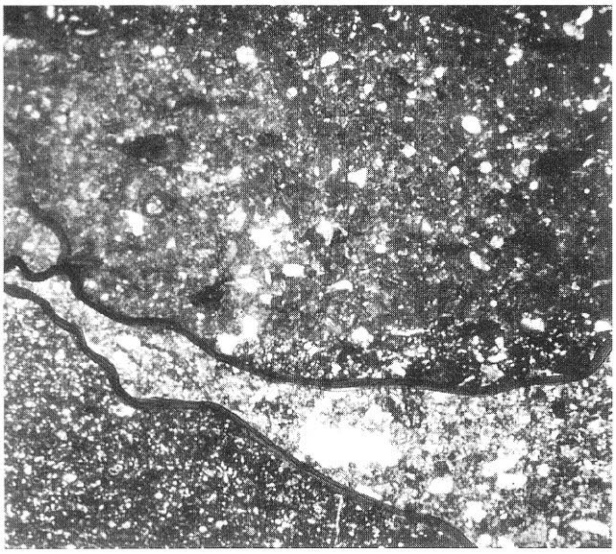

Fig. 4. The matrix between clasts of the Sivac micrite (lower left) and the Brač "marble" (upper part of the picture). x25.

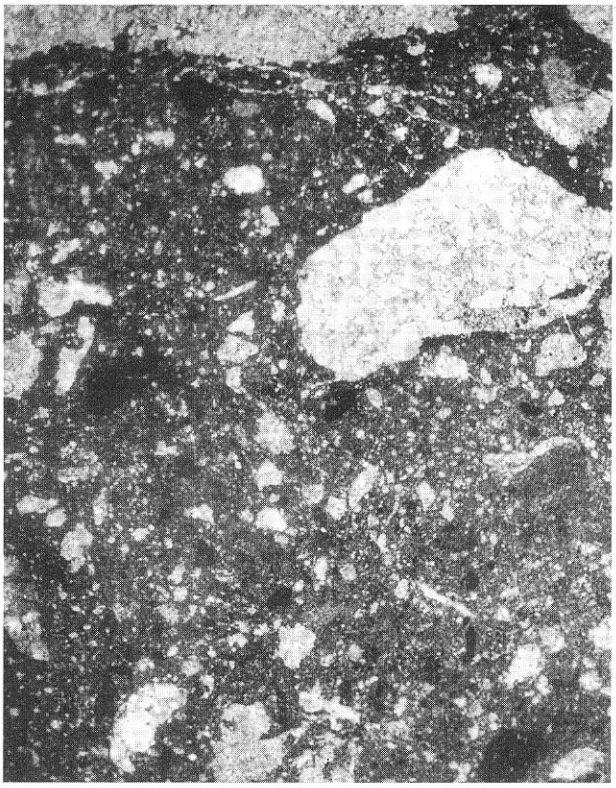

Fig. 5. Light-coloured clasts of early-diagenetic dolomite. x13.

The clasts are derived from the *Sivac micrite*, the *Brač "marble"*, the *Lovrečina Member* and the youngest *Sumartin Formation.* They have been formed in various environments, both spatially and temporally, and therefore fulfill the conditions for determination of polymictic breccias (RICHTER & FÜCHTBAUER, 1981).

The oldest clasts are those of the *Sivac micrite*, which are easily recognisable by their planktonic microfossil assemblage (Fig. 4). They are mostly subrounded, 5 to 10 cm in diameter, and compose only less than 10% of total clasts. As the immediate footwall of the Oklad breccia belongs to the younger, *Brač "marble" Member*, it could be concluded that the clasts of the *Sivac micrite* probably originated in the western part of the structure, i.e. from older deposits which emerged there during the time of the formation of the breccia.

Brač "marble" lithoclasts contribute only 3 to 5% of this deposit, while there are no clasts at all from the younger *Rasotica Member,* although the deposits of this member outcrop only 2 to 3 km to the east-southeast.

The most numerous clasts (>70 %) are those of the *Lovrečina Member*. They are also characterised by the largest dimensions, some of them reaching 1-1.5 m in diameter (Fig. 6). Scarce lithoclasts of early-diagenetic dolomites (Fig. 5) may also represent deposits of this member.

Fig. 6. Limestone clasts of the Lovrečina Member on the sawn surface of the quarry. Width of the photograph is 200 cm.

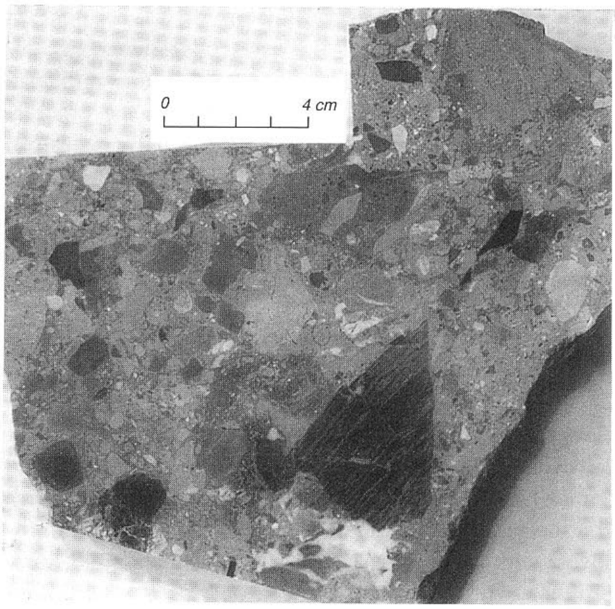

Fig. 7. Different fragments in the breccia including the clast of the older breccia.

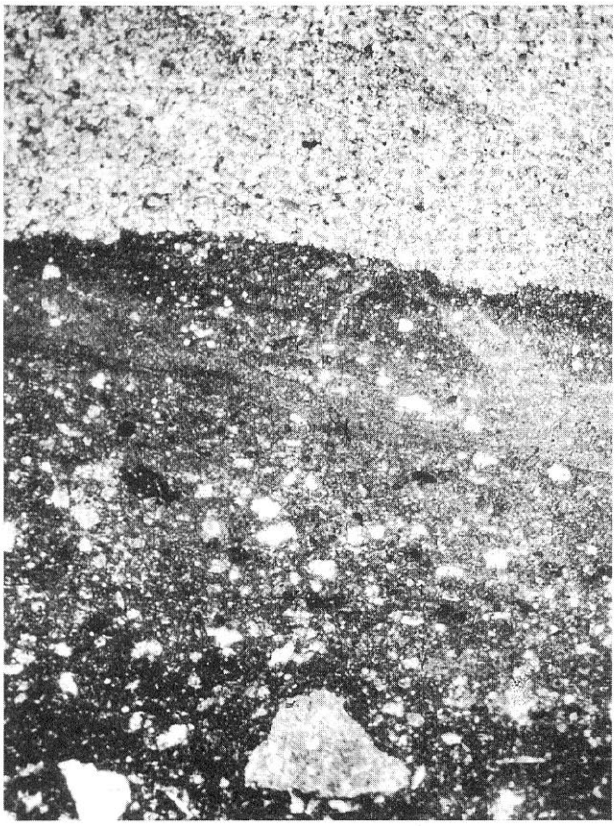

Fig. 8. Clast of the Brač "marble" in the lower part of the thin section. The upper part is dolomitized after lithification. x13.

Fig. 9. Cyclic infilling of fine-grained rock debris. x6.5.

The youngest clasts are foraminiferal wackestones of the *Sumartin Formation*, representing only 10 to 15% of grains.

The upper part of the breccia deposits is composed of subangular fragments of older breccias (Fig. 7). This is a result of the destruction of older, semilithified breccia deposits. Clasts were rounded during transport.

A common characteristic of the Oklad breccia is that most of the particles have a single straight edge, but show no preferential orientation. However, coarser clasts exhibit dense packing, as a consequence of very little displacement of clasts fractured during collapse. This results in a puzzle-like structure of the breccia. The angularity and the lack of plastic deformation of clasts indicate that the rocks were already lithified prior to destruction. Infrequent rounded clasts are not a consequence of abrasion during transport, but of partial solution and replacement with dolomite during late diagenesis.

The volume of matrix is relatively high, in some places up to 40%, particularly in parts with cm-sized clasts. Two generations of matrix can be distinguished. Although the first-generation matrix is mostly late-diagenetically dolomitized (Fig. 8), some undolomitized areas can be found, showing relics of micrite with marine biodetritus (bioclasts of echinoderms and molluscs) and small-sized lithoclasts of oligosteginid limestones. Biodetritus could be a part of the reworked rocks of the *Brač "marble" Member* from the immediate footwall, while lithoclasts probably represent fragments of somewhat older deposits of the Sivac micrite (Fig. 5). The second generation of the matrix represents a fine-grained rock debris poured in a few phases into the remaining intergranular space. The uppermost parts are filled with laminated internal sediment, produced by the repeatedly accumulating mud-sized fraction (Fig. 9). Similar macroscopical features are obvious on the sawn surfaces of the Oklad quarry (Fig. 10).

4. THE PALAEOMORPHOLOGICAL PATTERN OF THE ORIGIN OF THE BRECCIA

The recent position of the Oklad breccia in the structure of the island of Brač is a consequence of structural-tectonic deformations since the Maastrichtian. These periods of deformation have left imprints on the textural and structural characteristics of the breccia, enabling us to determine its palaeogeographical origin. There are no features which would indicate genesis similar to that discussed by KEITH & FRIEDMAN (1977) and FÜCHTBAUER & RICHTER (1983). The position, shape, inclination and stretching of the Oklad breccia are entirely different from those of the Novo Selo anticline. Therefore, we suppose that the origin of the breccia could be related to the disjunctive rather than the plicative tectonics. This is supported by the fact that the Novo Selo anticline at the beginning of the contractional tectonic phase had a rather small folding index (PRTOLJAN, 1989). Therefore destruction of its

Fig. 10. Pouring of fine-grained material into cavities (sawn wall of the quarry).

Fig. 11. Fill of a synsedimentary fissure (sawn wall of the quarry).

apex could not yield sufficient material to produce the breccia, as was the case for the Jelar breccia (BAHUN, 1974) or in other examples (e.g. STEIDTMANN & SCHMITT, 1988). Moreover, it is far more logical to expect destruction into metre-sized blocks from steep cliffs than from the gently inclined parts of the anticline under emersion. GUŠIĆ & JELASKA (1990) state that the Adriatic carbonate platform was, at the end of the Maastrichtian, highly tectonically disintegrated. They based their assertion on the fact that different units of the Upper Cretaceous were emergent over a rather small area during the upper part of the Maastrichtian.

Field investigations suggest that the clasts composing the breccia have been broken, crumbled down, crushed and transported over relatively short distances to the foot of the cliff. Several powerful stress events can be recognised, causing movement of metre-sized blocks, as well as reworking and fissuring of already semilithified older breccias. During the relatively calm periods matrix was poured into intergranular spaces. Few such events, characterised by the opening and succesive filling of the synsedimentary fissures, could be separated (Fig. 11). At the northern side of the quarry three superpositional flows of the rockfall breccia material can be recognised (Fig. 12). They have similar palaeotransport directions, pointing to a flow towards the east-southeast. The youngest, uppermost flow contains more frequent clasts of the oldest deposits, dolomitized *Sivac micrite*. The deposits of the *Sivac micrite* outcrop 1 to 2 km towards the west, thus it could be presumed that the clasts were transported from the west towards the east. This is probably the reason why clasts of the *Sivac micrite* are so small and scarce. Complete lithification, lack of the spelaeothemic effects and the clinoform shape of the breccia body indicate that the material was transported gravitationally to the water body, where it was deposited subaqueously. A necessary prerequisite for such deposition is gravitational tectonics capable of forming high relief (cliffs), from which material for the formation of the breccia was produced during each period of stress.

Fig. 12 Three flows of the rockfall material (sawn wall of the quarry).

The relatively small area covered by the Oklad breccia and rather large dimensions of the clasts are useful elements for the inference of high intensity palaeostructural changes over a rather small area at the end of the Maastrichtian. It may be concluded that the tectonic movements of that period had well-marked gravitational characteristics, giving rise to plicative structures typical during the initial shaping phase of the carbonate platform realm.

The final result of the Laramian contractional tectonic phase occured at the end of the Maastrichtian, when irregular emersion became widespread over the Adriatic carbonate platform (SLIŠKOVIĆ, 1983; JELASKA & OGORELEC, 1983; DRAGIČEVIĆ et al., 1992).

5. CONCLUSION

The Oklad breccia is composed of limestone clasts belonging to different lithostratigraphic units. They are ill-sorted, and range from 1 cm to 1.5 m in diameter. The oldest clasts are those of the Upper Santonian to Lower Campanian *Sivac micrite*, characterised by an abundance of pelagic particles. Clasts of the Upper Campanian *Brač "marbles"*, which are very scarce, are composed of bioclastic wackestone, packstone and floatstone with large foraminifera. The most frequent clasts are those of the *Lovrečina Member*, characterised by the early-diagenetically dolomitized fenestral micrite with fine debris of rudistid shells and foraminifera. The youngest are foraminiferal wackestone clasts of the *Sumartin Formation*. Common features of coarser clasts are their angularity and densely fitted texture. Sporadic rounded grains are primarily the result of late-diagenetic dolomitization. The proportion of the matrix is relatively high, in some places up to 40%. The first generation of the matrix is composed of a micrite with marine biodetritus, while the second is composed of fine-grained rock debris, which infiltrated the intergranular space in several successive phases. Finally the remaining pore space was filled by laminated muddy internal sediment.

The clasts in the breccia were broken, crumbled down, crushed and transported for a relatively short distance to the foot of the cliff, by the mechanism typical for rockfall breccia deposits. Several powerful stress events were recognised, causing movement of metre-sized blocks, as well as reworking and opening of fissures in already semilithified older breccias. During the relatively calm periods fine-grained matrix was poured into intergranular space and synsedimentary fissures.

From a study of the structural-textural features and the position in the structure of the island, the origin of the Oklad breccia is connected with the disjunctive movements during the Maastrichtian, during the initial phase of the Brač anticline formation.

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