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Continental Subduction Tectonics in the High Karst Dinarides of Western Croatia

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Ključne riječi: Visoki krš, Gorski kotar, stratigrafija, tektonika, kontinentalna subdukcija.

Abstract

The faults confining Palaeozoic inliers surrounded by Mesozoic rocks, show that their relation is not a consequence of folding but of neotectonic uplift causing a rather uneven relief of the Palaeozoic units underlying the carbonate Mesozoic. The predominance of tectonic contacts indicates that similar relations exist even between the Triassic and the confined Jurassic outcrops exhibiting inverse and, consequently, allochthonous relations. The allochthony is also confirmed by karst relief within some Triassic dolomites related to the unexpected ground water flow between the swallow holes (ponors) and karst springs. There are also indications of inverse relations between the Triassic volcanics and Palaeozoic clastics. However, in the surrounding area a normal superposition between the Triassic and Jurassic is also noticed. Consequently the Triassic and Jurassic of the Fužine-Lokve area and of its environs may belong to two megatectonic units. Tectogenesis is explained by continental subduction of the Adriaticum under the Dinaricum.

Sažetak

Pružanje rasjeda koji zatvaraju paleozojske jezgre unutar mezozojskih okvira pokazuje da njihov odnos nije posljedica boranja, nego neotektonskog izdizanja. Zbog toga je oblikovan neravan reljef paleozojskih jedinica ispod karbonatnog mezozoika. Prevlast tektonskih kontakata upućuje na to da između trijaskih i okruženih jurskih izdanaka postoje inverzni pa, prema tome, i alohtoni odnosi. Alohtonija je također potvrđena krškim reljefom unutar nekih trijaskih dolomita povezanih s neočekivanim tokovima podzemne vode između ponora i krških izvora. Postoje i naznake inverznog odnosa između trijaskih vulkanita i paleozojskih klastita. Međutim, u okolici postoji i superpozicija između trijasa i jure. Prema tome, trijas i jura područja Fužine-Lokve i okolice pribrojeni su dvjema megatektonskim jedinicama. Tektogeneza se objašnjava kontinentalnom subdukcijom Adrijatika pod Dinarik.

1. INTRODUCTION

Although the Dinaric High karst area has been considered an allochthonous tectonic unit for decades (e.g., KOSSMAT, 1924), the interior relations, especially in Gorski Kotar, have remained an interesting topic of discussion to date.

The dominant opinion was that Gorski Kotar, within the tectonic allochthonous megaunit, exhibits an autochthonous setting characterized by folds and faults forming the Upper Palaeozoic, surrounded by Triassic and Jurassic rocks. The prototype of such an interpretation is the structural reconstruction of the area of Fužine (KOCH, 1925/26). Even, when inverse (possibly overthrusting) structures in some areas were recognized (KOCH, 1933; SALOPEK, 1960; HERAK et al., 1961; SAVIĆ, 1976; ŠIKIĆ, 1980), the tendency persisted to explain the observed inversions (including smaller overthrusts) as local phenomena only (GRIMANI et al., 1973; SAVIĆ & DOZET, 1985; SAVIĆ, 1990, etc.).

In a parallel way ever increasing importance was paid to a possible major allochthony caused by continental subductions even within the High karst area (HERAK, 1980, 1986, 1991; BLAŠKOVIĆ, 1991; TOMIĆ, 1993; PRELOGOVIĆ et al., 1995).

Therefore, an emendation of the local structural setting is required, in order to bring into balance minor phenomena with the major geotectonic concept. The Fužine-Lokve area is selected as an intricate example where allochthonous relations are rather veiled, and therefore several researchers suspect the idea of the interior allochthony.

New observations concern stratigraphic, tectonic, morphologic, and hydrogeologic relations.

2. STRATIGRAPHIC DATA

In the Fužine-Lokve area and its northwestern prolongation, Upper Palaeozoic, Triassic, and Jurassic outcrops are exposed, displaying specific features that may aid in reconstruction of tectonic relations (Fig. 1).

2.1. UPPER PALAEOZOIC

Since FOETTERLE (1855) determined Carboniferous fossils and VOGL (1913) Permian fossils, the age

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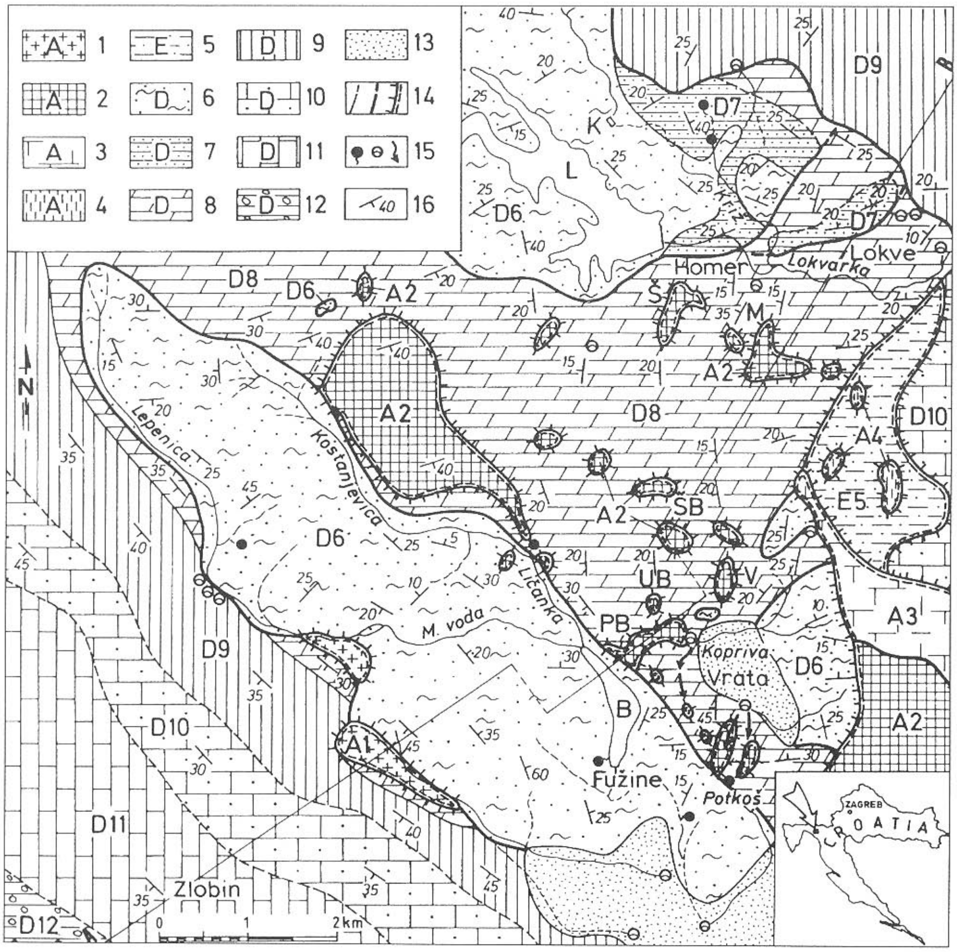

Fig. 1. Combined stratigraphic and tectonic sketch-map of the area around Fužine-Lokve, with compiled marginal data. Legend: A) Adriaticum; E) Epiadriaticum; D) Dinaricum; 1) Middle Triassic hornblende-andesite, 2) Lias with some Upper Triassic dolomites, 3) Dogger, 4) Malm; 5) Malm; 6) Palaeozoic with some Lower Triassic, 7) Lower Triassic clastics, 8) Upper Triassic, 9) Liassic limestones and dolomites, 10) Dogger, 11) Malm, 12) Lower Cretaceous with Tertiary carbonate megabreccias; 13) Selected Quaternary surfaces; 14) Boundaries: stratigraphic in general (partially faulted), main faults, uplifted tectonic windows (at the eastern margin geotectonic incorporation assumed); 15) Springs, ponors, groundwater direction between the ponors and the Potkoš spring; 16) Bedding; Storage basins: B) Bajer, L) Lokvarka, K) Križ; Hills: Š) Špičunak, M) Majnarovo, ŠB) Široko Brdo, UB) Usko Brdo, PB) Preradović Brdo, V) Viljak.

of the clastic areas in Gorski Kotar has been generally settled, but with sporadic changes of fossil ranges at single localities. Important increased knowledge of fossil remains have been provided by SCHUBERT (1907), SALOPEK (1949, 1962), KOCHANSKY-DEVIDÉ (1955), MILANOVIĆ (1982), and SVILKOVIĆ (see HERAK, 1985). General characteristics of the deposits are the prevalence of clastics with some lenses of limestones.

The most important Carboniferous fossil remains are found in the valley of Križ Potok north-west of Lokve. The most numerous are fusulinid foraminifera *Quasiendothyra* cf. *communis*, *Fusulinella simplificata*, *F. heraki*, *Pseudostafella* sp., *Triticites kochanskae*, *Paratriticites croaticus*, etc. They belong to the Upper Carboniferous, and despite possible resedimentation confirm the existence of an Upper Carboniferous marine environment.

The Lower and Middle Permian are proven by cephalopods *Gastrioceras*, *Agathiceras*, *Popanoceras*, *Medlicottia*, *Prosageceras*, *Paraceltites*, and fusulinids *Quasifusulina*, *Schwagerina*, *Paraschwagerina*, *and Zellia* cf. *heritschi* found in the area of Mrzla Vodica.

Near the village Vrata, north-east of Fužine, in a pebble of Lower Permian limestones (being a constituent of Upper Permian conglomerates) *Darvasites*, *Palaeospiroplectammina* and *Ammodiscus*, and the dasyclads *Anthracoporella* and *Vermiporella* have been determined. They confirm the existence of Lower Permian deposits in the area. The Middle Permian is also probably present and the sandstones and conglomerates probably continue until the end of the Permian, being the equivalent of Val Gardena (Grödner) facies, though exhibiting a greater range.

Generally, according to RAFFAELLI & ŠĆAVNIČAR (1968), the Upper Carboniferous, Lower and Middle Permian deposits are of flysch (graywacke) type, while the Upper Permian sandstones and conglomerates may be considered as molasse deposits. All the outcrops may belong to the structural megaunit Dinaricum.

Consequently, due to the Variscan orogeny (especially during the Saalian phase), the area was consolidated, though morphologically only slightly differentiated. Therefore, the Permian continues directly into the Lower Triassic. The lack of fossils makes the precise determination of their boundary impossible .

2.2. TRIASSIC

Transitional Permo-Triassic deposits consist of barite-bearing dolomites with cryptalgal fabrics indicating a tidal flat facies with elements of sabkha environment; the dolomites derive from aragonitic mud (PALINKAŠ & SREMAC, 1989). They are equivalents of similar deposits consisting of dolomites and/or clastics with evaporites in other areas of the Croatian Dinarides. The conformable transition between the Permian and the Triassic is obvious in the environs of Lokve (Homer) and Mrzla Vodica. The long standing supposition that the Lower Triassic deposits do not exist at all (SAVIĆ, 1990, etc.) has finally been resolved by means of index fossils found at several localities.

The Lower Triassic is proven by the bivalves *Anodontophora fassaensis*, *Pseudomonotis inaequicostata*, *Claraia clarai*, *C.* cf. *aurita*, and the foraminifer *Meandrospira iulia*, etc. (KOCH, 1925/26; ŠĆAVNIČAR & ŠUŠNJARA, 1967; ĐURĐANOVIĆ, 1967; BABIĆ, 1968; ŠĆAVNIČAR, 1973). According to ŠĆAVNIČAR (1973) the dolomites (locally associated with barite) are overlain by the following constituents: reddish micaceous sandstones and siltstones alternating with sandy dolomites and dolomitized oolitic calcarenites. Upwards, the sandstone-siltstone sequences are thinner and less frequent, while carbonate rocks prevail. The thickness varies, but does not exceed 100 m. The detritus was derived from Upper Palaeozoic land surfaces that were probably distant and of low relief. The sedimentation in a turbulent environment above the wave base is confirmed by ripple-marks, cross bedding, oolites, and the reduction of pelitic components.

The Middle Triassic sedimentary outcrops are not proven. Only the outcrops of hornblende-andesites (porphyrites) in the area of Gornji Benkovac and Lepenica west of Fužine (KOCH, 1933; VRAGOVIĆ & GOLUB, 1969) may be considered as Middle Triassic because they are comparable to Middle Triassic volcanics of the Adriatic region. Since they are overlain by Upper Palaeozoic and Lower Triassic deposits, their recent position may be the result of allochthonous tectonics. However, Middle Triassic deposits existed somewhere in the vicinity as confirmed by transgressive Carnian conglomerates that exceptionally contain Middle Triassic limestone pebbles with the dasyclads *Diplopora annulata* and *Macroporella beneckei*.

The Carnian is often in tectonic contact with Lower Triassic and sporadically Palaeozoic deposits. When this is not the case, the unconformity with the Lower Triassic and at places with the Permian is obvious. Carnian transgressive conglomerates contain, in addition to Middle Triassic pebbles, various components of Lower Triassic and even Palaeozoic provenance. Some of them are alien to the area where they are deposited (e.g., volcanic particles). Middle Triassic pebbles are not very common, and were derived from a more or less distant source. The association of Palaeozoic particles testifies to the great intensity of tectonic disturbances after the deposition of the Lower Triassic, which resulted in the emergence of Lower Triassic and Palaeozoic deposits. The transgression may have been earlier due to tectonic disturbances in the still undefined surroundings than in the area itself. The Carnian subsidence was coeval with that affecting Lika and Mt. Velebit but at the latter localities the transgressive components were only of Middle Triassic provenance. Therefore during the Middle Triassic the conditions in Gorski Kotar and the surrounding areas were different, while in the Upper Triassic the environments were more or less equal.

Carnian transgressive conglomerates in the investigated area are overlain by feldspathic sandstones alternating with dolomitic pelites. The sandstones become less and less frequent until grey clayey dolomites that are intercalated into the dolomites are observed. The dolomites increase vertically in frequency and finally prevail. They are laterally variable. The total thickness does not exceed 100m (ŠĆAVNIČAR, 1973). Microbial fossil remains are found only in the dolomites, i.e. oncoids ("*Sphaerocodium*"). Although they have a greater stratigraphic range, their abundance characterises the Carnian stage (HERAK, 1957). Norian and Rhaetian dolomites directly overlie the Carnian ones being sporadically replaced, especially in the Rhaetian stage by limestones that are overlain by Liassic deposits. Norian and Rhaetian dolomites are also of stromatolitic origin. Two types are distinguished: cryptalgal laminate structure and less abundant oncoids. Also cryptalgal "doloarenites" are present as products of the mechanical destruction of the former. Finally, recrystallized dolomites are to be found (ŠĆAVNIČAR, 1973). In the limestones of Preradović Brdo north of Fužine the foraminifers *Aulotortus gaschei*, *A. tumida*, *A. communis*, and probably *Glomospirella friedli* have been found.

The Triassic deposits belong mostly to the Dinaricum. Only the hornblende-andesites and some dolomite outcrops beneath the Lias (in tectonic windows) are to be attributed to the Adriaticum.

2.3. JURASSIC

Jurassic carbonate deposits are very frequent in Gorski Kotar and belong to the Lias, Dogger, and Malm. Each of these is represented by several well known biozones. Only Liassic outcrops that are confined within the Upper Triassic dolomites will be discussed here. They are distributed in an area several kilometers wide. Conventional interpretation described them as small synclines overlying the Upper Triassic dolomites. However, the beds are monoclinal with fault contacts toward the Upper Triassic dolomites, and exceptionally toward the Palaeozoic. Therefore, they have been reexamined. First, it was confirmed that all outcrops in question belong to the Lias. The most obvious localities are Majnarovo, Špićunak, Široko Brdo, Usko Brdo, Viljak, Preradović Brdo, and Plasa. Micritic limestones predominate, which in their lower part laterally and vertically alternate with brownish, partly bituminous dolomites. Upwards the dolomites gradually disappear, and the limestones are composed of biomicrite, fossiliferous micrite, fossiliferous floatstone, and rudstone. Biogenic particles include fragments of gastropods, bivalves, calcareous algae and other microfossils. At some localities (Viljak, Plasa), the remains of Lower and Middle Liassic microfossils *Palaeodasy-*

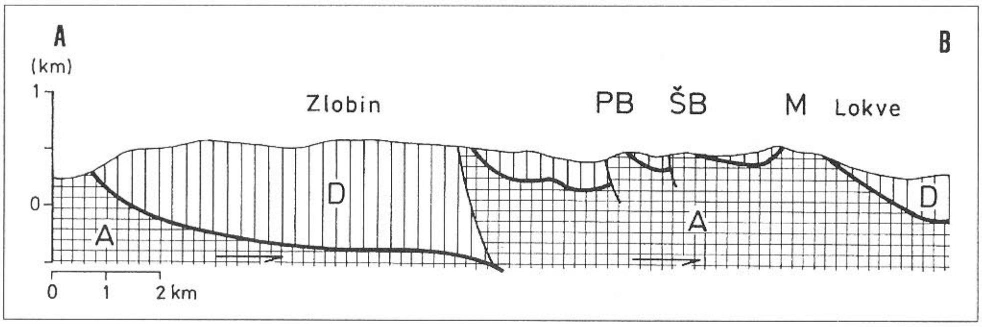

Fig. 2. Tentative simplified geotectonic model of the area around Fužine-Lokve: A) Adriaticum, D) Dinaricum; Hills: PB) Preradović Brdo, ŠB) Široko Brdo, M) Majnarovo.

cladus mediterraneus, *Favreina salevensis*, *Pseudocyclammina*, and *Thaumatoporella* have been observed. Conformable partly dolomitised dark limestone occurs with well preserved foraminifera: *Orbitopsella praecursor*, *Lituosepta recoarensis*, and *Pseudocyclammina liassica*. So far, in the area of investigation, Upper Liassic deposits have not been found. However, in the vicinity the Lias is overlain by Dogger (and Malm) carbonate rocks suggesting that the Lias of the Fužine-Lokve area, overthrust by Triassic dolomites, does not belong to the same tectonic unit with the more or less complete Jurassic sequence that evidently forms part of the Dinaricum. Consequently they may derive from the subducted Adriaticum. Only at the eastern margin are Jurassic elements of the Epiadriaticum registered.

3. TECTONIC DATA

Numerous tectonic contacts between different lithostratigraphic units in the Fužine-Lokve area testify to a very entangled structural pattern caused by vertical or subvertical displacements, not only of the lowerlying parts of the Dinaricum but also of some parts of the subducted Adriaticum. The first impression is that there are folds and normal faults due to compression and uplift. In fact, the faults at almost all the contacts, as well as disordered strikes show that there a common folding did not occur but there were differentiated vertical and subvertical movements, due to uplift, in an already disturbed terrain caused by continental subduction. In this way not only were the basal parts of the Dinaricum pushed out, but also the parts of the lowerlying Adriaticum. Hence, fault contacts are obvious even at places where a normal superposition should be expected. The cross-section (Fig. 2) is a tentative explanation of the observed surficial facts, without pretension to be a final solution.

4. GEOMORPHOLOGIC DATA

Palaeozoic areas are normally lower than the surrounding carbonate peaks. Only between Fužine and Gornji Benkovac does a relatively elevated ridge exist, i.e., at places where Triassic andesites underlie the Palaeozoic. It is curious that the margins of the Palaeozoic deposits are more eroded than the axial part. Furthermore, the margins consist of Carboniferous beds rather than the Permian which would be expected in the case of a normal anticline. In the Lokve-Mrzla Vodica area andesitic outcrops are lacking and erosion occurred even in its middle parts.

Triassic clastic outcrops encircle the Palaeozoic, while the dolomites extend between them and the Liassic carbonate peaks. In the case of normal folding Triassic dolomites and Liassic limestones should form synclinal units. Instead, even these contacts are of a tectonic type. During normal superposition, this relationship could be caused either by the uplift of the surrounding Triassic dolomites, or the subsidence of the Liassic limestones. Both cases would be relatively impossible to explain. Therefore, it is necessary to look for additional parameters that may help to resolve the problem. For example, some karst forms (dolines, uvalas, ponors) are present at the surface of the Triassic dolomites, where they should not exist if the dolomites were underlain by Triassic and Palaeozoic clastics. However, the structure is easily explained by acceptance of allochthonous relations as assumed in the foregoing sections. In this case the underlying Liassic limestones are at places uplifted through the allochthonous Triassic dolomites producing tectonic contacts, while generally they underlie the Triassic dolomites resulting in the possibility of both a karst ground water net and small surficial karst forms. Therefore, Liassic limestones with some Upper Triassic dolomites are assumed to belong to the subducted Adriaticum beneath the Dinaricum.

5. HYDROGEOLOGIC DATA

The water net of the investigated area consists of lost streams, particularly the Ličanka and Lokvarka.

The Ličanka issues at the contact between the disintegrated Liassic limestones and Triassic dolomites. The question is why the springs are lacking at other identical contacts. Moreover, at some places ponors are present, probably where the Palaeozoic in contact with Triassic dolomites is deep enough to form a true barrier despite the possibility that it is underlain by Mesozoic carbonate rocks. Some downstream periodic springs at the contact of Liassic limestones (with a small cave) and the Palaeozoic are of the same character. The catchment area consists not only of Liassic limestones but also of karstified Triassic dolomites that confirms the morphological indication of their inverse position. Such a position is obvious in the case of the Potkoš spring at the contact of the Triassic dolomites with the Palaeozoic at the southwest margin of the Plasa ridge (Fig. 1). It is clear that the ponor at the northeast foot of the same ridge is in direct contact with the spring flowing through the underlying Liassic limestones. Less obvious is the connection (proven by dye tests performed in 1946 by L. DANČEVIĆ), between the Kopriva ponor at the western margin of the Vrata depression and the Potkoš spring. The ponor is located in the Triassic dolomites close to the contact with Liassic limestones that crop out over a limited surface, enclosed by Triassic dolomites. This connection is possible only in the presence of an obvious fault directed toward the spring or without underlying Liassic limestones. The fault does not exist. However, some small outcrops of the tectonically underlain Liassic limestones follow the ridge in the direction of the spring. All this suggests allochthonous conditions in the area, confirming the considerations based on stratigraphic, tectonic and morphologic data.

The springs of Lokvarka are more or less normal, issuing in Palaeozoic and Triassic clastic terrains. The same may be said for Križ Potok. More difficult is to understand the ponors of Lokvarka. The first ponor is registered within the Triassic (Carnian) dolomites between Homer and Lokve. Also the main ponor of Lokvarka is within the Triassic dolomites. They would be difficult to understand without allochthonous tectonics.

6. CONCLUSION

The reexamination, on the basis of continental subductions, of stratigraphic, tectonic, geomorphologic, and hydrogeologic relations in the Fužine-Lokve area in Gorski Kotar, though fragmental, suggests an alternative model of the tectonic setting and tectogenetic development of the area in question. The main assumption concerns the direct tectonical superposition of the Dinaricum upon the Adriaticum, without the elements of the Epiadriaticum (with the exception of the eastern margin). It is supposed that the subduction was combined by subsequent gravitational displacements. Therefore, Epiadriatic elements may be preserved northwards in the subsurface, i.e., outside the investigated terrain. A less probable possibility may assume the presence of unexposed remains of the Epiadriaticum between the Dinaricum and Adriaticum. Our simplified cross-section (Fig. 2) is based on the first assumption. Therefore, it is not proposed as a solution without possible emendation concerning the interior covered by the Dinaricum, but only as a model adapted to subductional displacements that, in our opinion, are present. The emendation of wider regional geotectonic relations requires analogous reinterpretation of surficial data of the surrounding territory.

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