UDK 552.54(497.4):537.533.35
Review article/Pregledni članek

ISSN 1580-2949
MTAEC9, 44(4)173(2010)

# MIDDLE TRIASSIC DRY-LAND PHASES IN SOUTHERN SLOVENIA

## SREDNJETRIASNE KOPENSKE FAZE V JUŽNI SLOVENIJI

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*Prejem rokopisa – received: 2009-11-20; sprejem za objavo – accepted for publication: 2010-03-18*

In the Middle Triassic lithostratigraphic sequence of southern Slovenia and neighbouring Gorski Kotar, Croatia, three dry-land phases have been recognized: 1 – between the Lower and Middle Triassic, 2 – in between the Anisian stratigraphic sequence, and 3 – between the Anisian and Ladinian beds. Traces of the Anisian volcanism have also been discovered. The dry-land episodes of the non-deposition and volcanic activity are ascribed to synsedimentary tectonic movements of the Alpine tectonic cycle. However, new data enable a new approach to the paleogeographical evolution of the area. In the Triassic "Dolomite" Complex, lenses of kaolinite deposits occur, representing an important correlation horizon for the basal Ladinian beds. They consist chiefly of kaolinite and quartz admixed in smaller quantities by hematite, goethite, nontronite, gibbsite, groutite and montmorillonite. The kaolinite deposits were formed in a marsh with weathering of the pyroclastic materials.

Key words: carbonate, clastic and volcanic rocks, dry-land phases, Middle Triassic, External Dinarides, Slovenia, SEM, EDS, XRD

V srednjetriasnem litostratigrafskem zaporedju južne Slovenije in sosednjega Gorskega Kotarja (Hrvaška) so ugotovljene tri okopnitve, in sicer: 1 – med spodnjim in srednjim triasom, 2 – v aniziju ter 3 – med anizijem in ladinijem. Odkriti so tudi sledovi anizijskega vulkanizma. Okopnitve in vulkanizem povezujemo s sočasnimi tektonskimi premiki Alpidskega tektonskega cikla. Novi podatki omogočajo nov pogled na paleogeografski razvoj obravnavanega ozemlja. V triasnem dolomitnem kompleksu se pojavljajo leče kaolinitnih usedlin, ki so pomemben korelacijski horizont za bazalne ladinijske plasti. Sestojijo v glavnem iz kaolinita in kremena, katerima so v manjših količinah primešani hematit, goethit, nontronit, gibbsit, groutit in montomorilonit. Kaolinitne usedline so nastale v močvirju pri razpadu piroklastičanega materiala.

Ključne besede: karbonatne, klastične in vulkanske kamnine, kopenske faze, srednji trias, Zunanji Dinaridi, Slovenija, SEM, EDS, XRD

## 1 INTRODUCTION

The territory that is in question, covers the southern Slovenia and the extreme northern parts of Gorski Kotar, which belongs to neighbouring Croatia. In the framework of the elaboration of the Basic Geologic Map on the scale of 1 : 100 000 the systematic regional geologic researches included among other Kočevje and Gorski Kotar [1] areas, White Carniola (Bela krajina) [2] and central Slovenia [3], that lie on the topographic Maps Grosuplje (No 45), Ribnica (No 54), Kočevje (No 55) and Črnomelj (No 56) on the scale of 1 : 25 000. In the last ten years the Geological Survey of Slovenia performed a detailed geological mapping for the elaboration of the Geologic Maps of Slovenia on the scales 1 : 25 000 and 1 : 50 000. The Map Sheet Grosuplje 1 : 25 000 consists of 25 sections on the scale of 1 : 10 000 embracing about 675 km². Also elaborated and digitalized is the Map Sheet Grosuplje on the scale 1 : 25 000. On the Map Sheet Grosuplje 1 : 25 000 lies among other Bloška planota that was the central part of our researches.

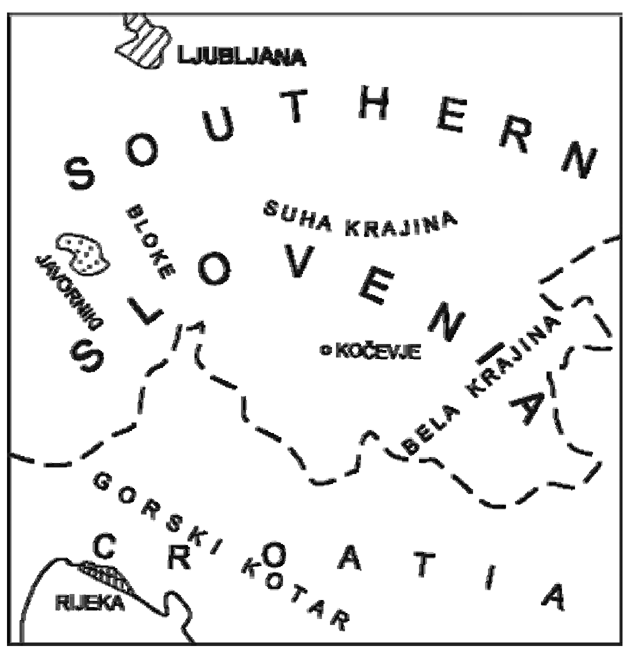


**Figure 1:** Location sketch map of the study area
**Slika 1:** Položajna skica obravnavanega ozemlja

In southern Slovenia the dry-land phases and interruptions in sedimentation appear in different, and mostly in two, lithostratigraphic sequences: 1) in the variegated heterogeneous Triassic (Schytian-Carnian) chiefly clastic sedimentary succession of Kočevje, Carniola (Bela krajina) and Gorski Kotar, and 2) in the monotonous, light Middle Triassic "Dolomite" Complex on Bloke plateau.

The purpose of this work was to find answers and evidence for the following questions: What is the real age of the "Dolomite" Complex and its parts? Was the sedimentation of the "Dolomite" Complex continuous or interrupted? Are in the Triassic "Dolomite" Complex of Bloke plateau also present the Anisian, Ladinian and Cordevolian beds? How many interruptions occurred in the complex, and how long did they last? Finally, the aim of this paper is also to explain the particularities of the paleogeographical evolution of the study area during the Triassic period.

The listed problems required detailed stratigraphic investigations of the Middle Triassic "Dolomite" Complex and adjacent beds in the field and additional systematic laboratory examinations (**Figure 1**).

From the geographical point of view the investigated area belongs to the Lower and Inner Carniola (Dolenjska, Notranjska) [17,21], while, geologically and geotectonically, however, to the Slovenian and Dinaric Carbonate Platforms and the Lower and Inner Carniola Blocks [4,6,19].

## 2 EXPERIMENTAL PROCEDURES

In the past, geological researches in Slovenia were focused on systematic regional and detailed geological mappings of the considered area for the elaboration of the Basic Geological Map SFRY on the scale of 1 : 100 000 on the Map Sheet Ribnica (OGK I – RI). In the past ten years a detailed geological mapping for the Geological Map of Slovenia 1 : 50 000 on the Map Sheet Grosuplje 1 : 25 000 (GKS-GR) was achieved. It was accompanied by systematic laboratory examinations (a determination of the macro- and microfossils, XRD, geochemical and sediment-petrographic analyses and SEM/EDS analyses). The main mapping methods for the elaboration of the OGK I-RI were the mapping of all the exposures and the tracing of contacts, whereas the main methods for the elaboration of the GKS-GR were the mapping of motorway traces as well as stratimetric measurements and sedimentologic research of well-exposed representative cross-sections (stratimetric profiling).

Carbonate rocks were arranged according to FOLK's [23] and DUNHAM's [24] classifications, whereas the clastic sediments were defined regarding FOLK's [23] and PETTIJOHN's [25] classifications.

For the detailed analysis six selected rock samples were taken from three different regions in wider Bloke area, two from Puharje, two from Kaplanovo and two from Žgajnarji (**Table 1**). The elemental analyses of all six samples were performed using a field-emission scanning electron microscope JEOL JSM 6500F equipped with an EDS analyzer. Due to their very soft nature and the high crumbling tendency the samples were only carefully ground with 500 SiC paper. The accelerating voltage of the primary electron beam was 15 kV and the probe current was 0.2 nA.

**Table 1:** Designations of six selected samples that were taken at different places close to the Bloke region
**Tabela 1:** Oznake šestih izbranih vzorcev, ki so bili odvzeti na različnih mestih blizu področja Bloke

| Sample designation | Name of the sample by the place where it was taken |
|---|---|
| 1 | Puharje 1 |
| 2 | Puharje 2 |
| 3 | Kaplanovo 1 |
| 4 | Kaplanovo 2 |
| 5 | Žgajnarji 1 |
| 6 | Žgajnarji 2 |

With the aim to obtain information about the minerals present in the rocks, the phase analyses were performed using Philips Analytical X-ray diffraction (XRD) using Cu$K_{\alpha 1}$ radiation (0.15406 nm) in the $2\theta$ range from 0 to 70°.

The fraction of each mineral present in the six analysed samples was calculated from the XRD measurements and verified with EDS. The fraction of each mineral is expressed in approximate integer values, rounded up to 10 % or 5 %.

## 3 RESULTS

### *3.1 Geology*

For the explanation of the paleogeographic development of the southern part of the Slovenian territory in the Middle Triassic period it is useful to recall the geological column of the clasticly developed Kočevje region and on the other side of the calcareously developed Bloke plateau (Bloška planota).

#### *3.1.1 Geological column of the Kočevje region*

The geological column of the Kočevje region consists of two parts: the lower clastic part and the upper carbonate part. The lower part is composed of the carbonate clastic Carboniferous, Permian and Triassic systems and the upper part involves the Upper Triassic series as well as the Jurassic and Cretaceous systems.

In the Kaptol-Mošenik cross-section south of Kočevje [26] the clastic formation of the Younger Paleozoic beds is subdivided into three lithostratigraphic units, which are in analogy with similar developments in Gorski Kotar and Ortnek [20] attributed to the Lower Permian (Trogkofelian). A relatively shallow sedimentation area, where the Lower Permian clastic rocks originated, began in the time of the ***Saalian movements*** to rise, so that the Kočevje and Gorski Kotar areas were in the Middle and Upper Permian dry land where in that time no significant folding occurred. During a slow uplifting a relatively flat mainland originated, built of pretty clayey micaceous sediments with interbeds of compact quartz sandstones and conglomerates. The dry land was the product of the activity of the final strokes of the ***Hercynian orogeny***. The elevation of the considered area was accompanied by a fault tectonics in Gorski Kotar; however, with a weak magmatic activity as well [25].

The conclusions related to the dry land could also be deduced to the stratigraphic gap of the Scythian beds lying discordantly upon the Lower Permian bed. For the tectonic-erosional character of this boundary speaks also about 20-cm-thick limonite crust in the Gorski Kotar region [26–29] on the boundary between the Younger Paleozoic and Triassic sediments, that is a product of the strong oxidizing conditions. The elevation of the considered territory that began on the boundary between the Lower and Middle Permian in the time of the Saalian phase, continued uninterruptedly into the ***Pfälzian phase***, with which the Hercynian tectogenetic cycle in

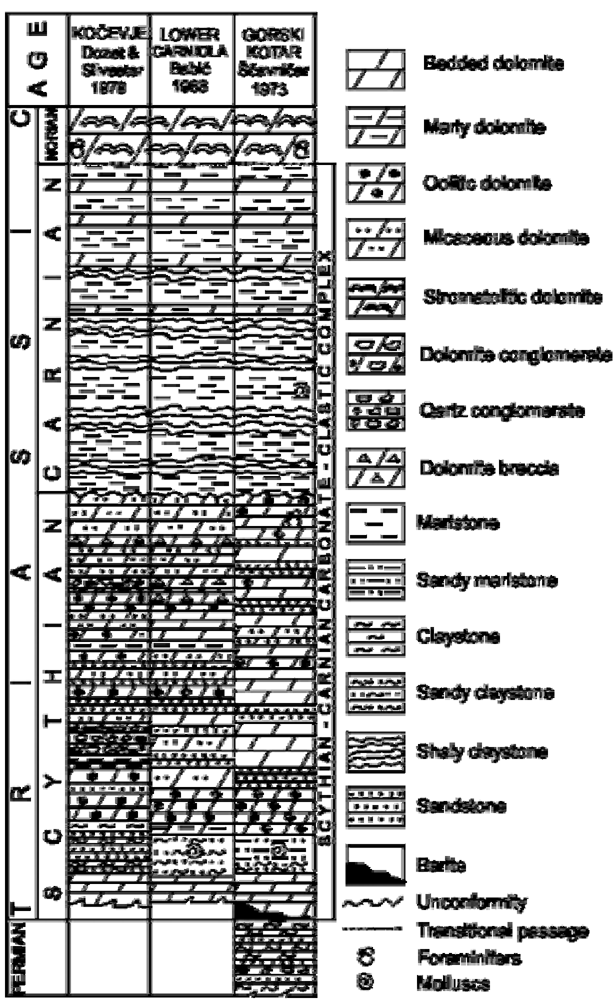


**Figure 2:** Correlation of the Scythian-Carnian carbonate-clastic succession of Kočevje, Gorski Kotar and Lower Carniola

**Slika 2:** Primerjava skitsko-karnijskega karbonatno-klastičnega zaporedja Kočevske, Gorskega Kotarja in Dolenjske

the Alps was ended. The Hercynian orogeny in the Dinarides area was followed by a common descending and afterwards the transgression of the Lower Triassic sea, which is according to U. Premru [16] closely connected with the extinguishing Herzynian orogenetic cycle. In the Triassic sea in the Kočevje, Gorski Kotar and Bela Krajina areas, a pretty variegated clastic-carbonate succession of sediments originated (**Figure 2**), of which the lower part is of Scythian and the upper one of Carnian age [10–13,30,31]. They are distinguished between themselves according to lithology, mineral composition, heavy minerals, geochemical composition, cement, diagenesis, source material, environment, Energy-index and climate.

In the Scythian part of the clastic-carbonate succession oolitic and sandy dolomite prevail, and there is also less of the sandy dolomitic marlstone, claystone, micaceous sandstone and intraformational conglomerate. The Carnian (Julian and Tuvalian) beds are composed of red dolomitic marlstone containing interbeds of yellowish, greenish grey and grey dolomite as well as greenish grey claystone. Between heavy minerals turmaline prevails in the Scythian beds, and zircon in the Carnian beds.

The Scythian and Carnian sediments originated in a shallow sea and semiarid climate. The mainland in the background of the sedimentary basin was low. Toward the end of the Lower Triassic epoch the Kočevje region began slowly to uplift, as consequence of the ***Old Slovenian phase*** [32]. The elevation of the terrain is evidenced by interbeds of breccias and conglomerates in the Triassic sedimentary succession in the Kočevje region [9,32], the Gorski Kotar region [33–35] and the Lower Carniola (Dolenjska) region [34–37].

The continuous shallowing of the already relatively shallow Lower Triassic sea brought on a differentiation of the sedimentary area and finally originated the positive paleostructure comprising the Kočevje region, Bela krajina and Gorski Kotar [22]. The new dry land was gently anticlinally folded [38], and the folding was locally accompanied with weak radial tectonics. These events caused a reduction and later a complete interruption of the sedimentation in this part of the Dinarides, that lasted until the transgression of the Carnian (Julian) sea. The emersion in the Kočevje region lasted through the whole Anisian, Ladinian and Cordevolian epochs. With respect to the existence of dry land it is concluded with reference to the absence of the Middle Triassic and Lower Carnian (Cordevolian) rocks in this area, too.

### *3.1.2 "Dolomite" Complex on Bloke plateau*

On the northeastern border of the Bloke plateau the Middle Triassic sedimentary succession occurs in a carbonate development, in which dolomite greatly prevails; therefore, it was denominated as the "Dolomite" Complex (**Figure 3**). In this Complex also more or less dolomitized limestones and even pure limestones occur,

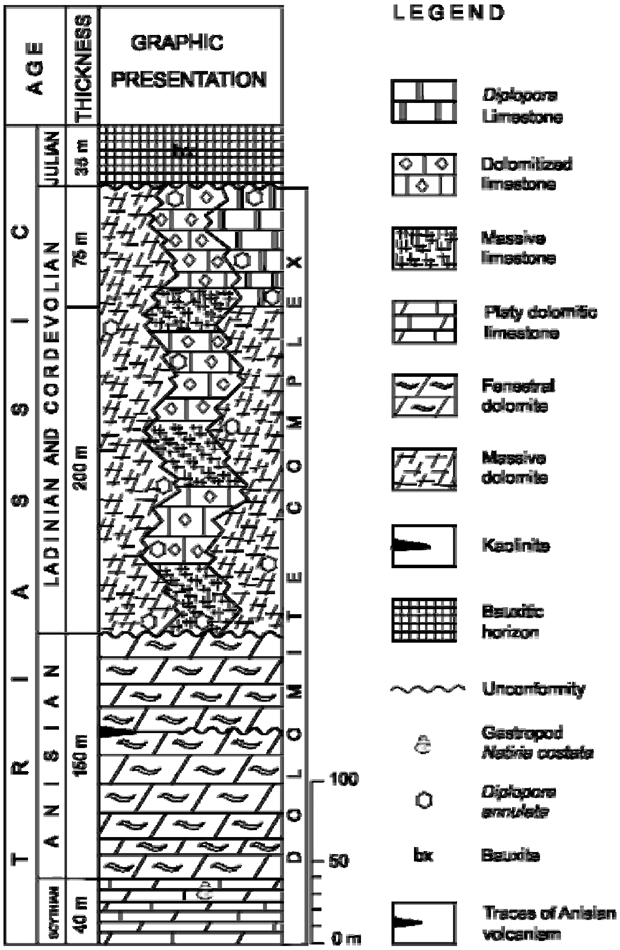


**Figure 3:** Geologic column of the "Dolomite Complex" with its footwall and hanging wall beds
**Slika 3:** Geološki stolpec "Dolomitnega" kompleksa s talninskimi in krovninskimi plastmi

that are due to the numerous dasycladal mostly rock-forming algae of the *Diplopora* genus, known under the name ***Diplopora Limestones*** and occurring in the complex above all in the uppermost part. In the Basic Geologic Map of SFRY on the scale 1 : 100 000 BUSER [3,39] ascribed the considered the "Dolomite" Complex to the Cordevolian substage, that is considered in Slovenia for several ten years already as belonging to the Lower Carnian substage. The dolomite or carbonate development of the Triassic beds also occurs in other parts of Slovenia and it is ascribed to its dissimilar age, from Anisian to Norian and Rhaetian [3,5,14,15,41–44].

### *3.1.3 Stratigraphic position*

In the considered area the "Dolomite" Complex occurs mostly to an incomplete extent, since its uppermost or lowermost or both parts are tectonically cut off or eroded. In the valley of the Black Ravine (Črni potok) at Karlovica is exposed the footwall of the "Dolomite" Complex, represented by a several ten-meters-thick stratigraphic sequence of rosy, grey, platy dolomitic limestone, in which in the Škrilje and Podgozd areas the gastropod *Natiria costata* was found [3], that in Slovenia occurs in the uppermost Scythian beds. The conodont analysis of the samples from the beds at Podgozd was not positive [45].The hanging wall of the "Dolomite" Complex and their contacts are exposed on Veliki Vrh, where concordantly upon the "Dolomite" Complex is located a red pelitic and poorly oolitic iron-rich bauxite representing the basal horizon of the Julian beds. Concordantly upon the 30-meters-thick band of Carnian (Julian and Tuvalian) beds rests a dolomite in the Lofer development belonging to the Main Dolomite Formation. The "Dolomite" Complex thus lies concordantly between the Schythian and Julian-Tuvalian beds and represents, supposing that the sedimentation was uninterrupted, the Anisian, Ladinian (Fassanian and Langobardian) and Lower Carnian (Cordevolian) beds.

### *3.1.4 Lithology*

The stratigraphic sequence of carbonate rocks denominated as the "Dolomite" Complex, originated on the Slovenian and Dinaric Carbonate Platforms, is not a homogeneous lithologic unit, since in some sections it includes, beside the dolomite, also, a strongly dolomitized limestone and bedded biostromal *Diplopora Limestone*. Also there, where the "Dolomite" Complex is built of pure dolomite, exists a certain heterogeneousity of the carbonate sequence as with regard to sedimentologic properties in the considered area, the lower and upper parts can be distinguished.

In the about 120-meters-thick interval of the lower part of stratigraphic sequence of the "Dolomite" Complex alternate light-grey to very-light-grey bedded fenestral, laminated and very fine-grained dolomites. The ***fenestral dolomite*** is a dolomite with numerous more or less parallel shrinkage pores. They may be an open space in the rock or completely or partly filled with secondarily introduced sediment or cement. The ***laminated dolomite*** is rare. In the rock the lamination is not produced by stromatolitic crusts, but by numerous, with stratification parallel, shrinkage pores filled with sparry calcite, limonite or sediments. The fine-grained dolomite (microdolosparite) does not show any porosity, whereas, the porosity of the laminated dolomite consists mostly of horizontal pores. The described carbonate sediments originated in a shallow lagune in an intertidal and supratidal environment. The types of carbonate rocks show that the Energy-index of the sea was low.

In the middle and upper part of the "Dolomite" Complex there is an about 350-to-400-meters-thick sedimentary succession built chiefly of massive and, here and there, bedded dolomite. The ***dolomite*** of the middle and upper part of the "Dolomite" Complex is mostly very light grey to almost white and sometimes it is bluish white, also the stratification of this sediment is rare. Almost always it is coarse-grained, respectively very coarse-crystallized, which speaks for its origin at a late diagenesis of the *Diplopora* ***Limestone***. Usually, it is quite porous. The pores occur mostly in places that in former times were dasycladal algae. The pores and fine cracks are filled as a rule with fine dolomite crystals. The porosity of the rock is intragranular, sometimes, however, it is represented by isolated pores and fine cracks. The massive dolomite is compact and it is usually crumbling because of the coarse-grained texture. During weathering it disintegrates into a dolomitic sand, mylonite and ultramylonite.

The ***Diplopora Limestone*** is bedded and light grey, medium grey to grey or rosy. According to the texture it belongs to biosparite, bointrasparite, biolithite and rarely biomicrite. Commonly, it contains on the bed surfaces numerous round, oval and oblong sections of dasycladal algae of the genus *Diplopora*, that are mostly rock-forming. Diploporas lived on vast grasses on the bottom of the Cordevolian shallow and warm sea. More or less well-preserved *Diplopora* remains can also be found in the dolomite. Algae are better preserved in the limestones than in the dolomites. On the northern Borderland of the Bloke plateau we found in the *Diplopora Limestone* also an about 7.5-meters-thick interbed of bedded medium-grey stromatolitic limestone. The *Diplopora Limestone* passes laterally and vertically into the more or less dolomitized limestone or dolomitic limestone. In southern Slovenia in some places we come across larger complexes of dolomitic limestones. It is interesting and important that the dasycladacean are well-preserved in the dolomitic limestone as well. On the other hand, well-preserved dasycladacean remains are very rare due to diagenesis in the coarse-grained dolomite.

### *3.1.5 Tectonics*

Our researches showed that in the Middle Triassic period there were three dry-land phases:

The first phase began already at the boundary between the Scythian and Anisian (Kočevje area and wider surrounding), the second one took place in the middle of the Anisian stage (Bloke plateau and environs) and the third phase was discovered somewhere in the middle part of the "Dolomite" Complex representing the boundary between the Anisian and Ladinian stage.

The first epeirogenic phase, denominated as ***Kočevje epeirogenic phase*** [9] is the largest phase especially with respect to the time of its lasting (from the end of the Scythian to the Julian). Besides the Kočevje region it also affected the White Carniola and Gorski Kotar area as well as some places in the Lower Carniola northwest of Kočevje. Unequal strongly intensified epeirogenic activity formed a positive structure with the centre in the Kočevje area. Upon the gently convexed antiform no sedimentation occurred. Evidence for the dry land is the absence of Anisian, Ladinian and Cordevolian rocks in the Kočevje region; however, primary exposures of the above-enumerated beds were not found in the White Carniola and Gorski Kotar as well. Anisian, Ladinian and Cordevolian rocks are also not found in the Triassic cross-sections of the Kočevje, White Carniola and Gorski Kotar regions. The Triassic columns consist of variegated (prevalently red) clastic sediments and more ore less frequent interbeds of dolomites and dolomitic marlstones. The lower part of the many-coloured clastic-carbonate succession belongs to Scythian; the upper one, however, to the Carnian. This is evidenced by macro- and microfossils as well as with petrographic-sedimentologic methods, heavy metals analysis and with XRD methods [28,30,35]. Since on the boundary between the Scythian and Carnian sequences there are no Anisian, Ladinian and Cordevolian rocks, and because the Carnian sedimentary succession starts nowhere with a thicker horizon of basal breccia or conglomerate, we believe that orogenetic forces and fault tectonics in that time were not present and that the newly formed dry land was flat and built of fine- and very fine-grained sediments.

Traces of the second Middle Triassic dry-land phase are exposed on the top of the lower third of the "Dolomite" Complex in the upper part of the sequence of light bedded fenestral dolomite, which is, according to its concordant position upon the rosy grey, thick-plated dolomitic limestone containing the gastropod *Natiria costata* and with reference to sedimentologic characteristics, attributed to the Anisian. The main evidence for this dry land phase, that was the shortest and the weakest at all three, is a 0.75-m- to 1.5-m-thick lense-like interbed of pale greenish kaolinite. The darker greenish tuff, however, speaks for volcanic activity [18] in the Anisian epoch. Otherwise, the Anisian volcanic rocks are more wide-spread in the Croatian territory [46].

The third Middle Triassic dry-land phase is discovered in the "Dolomite" Complex of Bloke plateau on the boundary between the underlying light fenestral dolomite, to which we ascribed the Anisian age, and the overlying very light grey to almost white massive coarse-grained porous dolomite, that in spots lies under the medium-grey to rosy bedded biostromal *Diplopora Limestone,* which is attributed in Slovenia to Cordevolian and Lower Carnian. The evidence for the Middle Triassic phase is based on finding 0.5- to 1.25-thick lense-like interbeds of kaolinite, bauxite and iron crust on the boundary between the Anisian light bedded fenestral dolomite and the Carnian-Ladinian white coarse-grained massive dolomite.

### *3.1.6 Paleogeography*

The relatively shallow sedimentary environment in which the Lower Permian clastic rocks were deposited, began at the end of the Lower Permian during Saalian movements to elevate so that the Kočevje and Gorski Kotar area was in the Upper Permian a dry land. In this area in that time no important folding occurred. During the slow uplift a relatively flat dry land originated, built of clayey sediments with interbeds of sandstones and conglomerates. This dry land was a consequence of the activity of the last strokes of the Hercynian orogeny [27,28].

After the last strokes of this orogeny (Pfälzian phase) the transgression of the Scythian sea takes place. The Scythian sediments originated in a very shallow sea, in between the intertidal band with erosional activity of the sea currents and waves on half-consolidated sediments of the sea bottom, that were mixed with a fine-grained dolomitic matrix. The Scythian intraformational conglomerate speaks, above all, for a shallow sea that from time to time flew off and was followed by drying out (desiccation) and cracking of the half consolidated mud material, of which fragments were afterwards rounded by sea currents. The material supply from the land was pretty considerable.

Wave ripple marks and cross-stratification in the Scythian sediments point to a turbulent shallow sea. The dry land in the vicinity of the sedimentary area had to be low and flat, since from this dry land came only fine and very fine rock material.

The absence of coarse-grained and non-sorted rock material speaks for the conclusion, that in the vicinity of the considered area in the Middle Triassic there were no mountains or higher elevated dry land. After the deposition of the Scythian sediments, the Kočevje region was elevated and a gently convexed antiform originated, upon which there was no sedimentation until the transgression of the Carnian sea.

The similar Scythian sedimentation on the Slovenian Carbonate Platform also originated on the Bloke plateau and in its surroundings, with a distinction that it was more calcareous.

In the Anisian epoch the carbonate platform in southern Slovenia became larger and more stable. The rock material supply from the land was insignificant. Monotonous sedimentation of light dolomites point at a stable shelf and sedimentologic properties of the carbonate rocks indicate a neritic sedimentation in the tidal area. In the middle of Anisian epoch the intensified epeirogenic movements assisted the forming of short-lasting local dry land with traces of volcanism, bauxite and kaolinite were preserved on the surface.

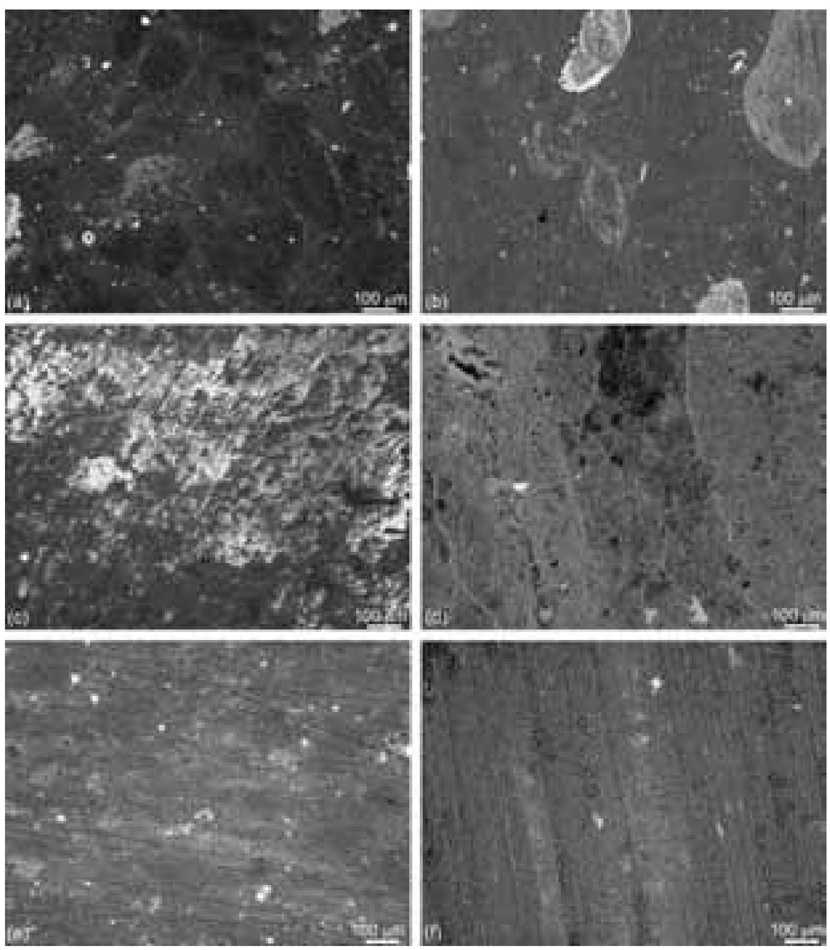

**Figure 4:** BE images of all six samples performed on an area 1.17 mm × 0.88 mm. The chemical inhomogeneity is shown by the lighter and darker areas in the micrographs

**Slika 4:** Slike, dobljene z odbitimi elektroni vseh šestih vzorcev, posnete na področju velikosti 1,17 mm × 0,88 mm. Kemijska nehomogenost se kaže v porazdelitvi temnejših in svetlejših področij na sliki

Greater activity of the Anisian volcanoes was recorded in the Croatian territory [46]. After the short-lasting dry land, that can be temporally correlated with the Monte Negro orogenic phase, repeatedly followed a neritic sedimentation on the carbonate platform, equal as before to the short-lasting interruption of sedimentation.

On the boundary between the Anisian and Ladinian stage followed a new, still more intense dry-land phase, which is evidenced by here and there preserved lenses of bauxite, kaolinite and iron crusts. In the whole area of southern Slovenia originated then on the Dinaric Platform carbonate sediments in a shallow sea. In the shallow and warm sea grew calcareous algae, forming numerous submarine lawns. With their coalcareous skeletons they contributed most to the origin of several hundreds of meters thick limestone sequence. Later the *Diplopora Limestone* changed at late diagenesis in part or completely into a coarse-grained (crystallized) dolomite [47].

The part of the "Dolomite " Complex, originated after the Anisian/Ladinian dry-land phase, the Slovenian geologists attributed to the Lower Carnian respectively to Cordevolian. In S. Buser's, and A. Ramovš's opinions [7] the algal species *Diplopora annulata* Schafhäutl occurring in southern Slovenia only in the Cordevolian beds, represents a guide fossil for this area. In our opinion, it was formed in the Langobardian and Cordevolian epoch.

The dry-land phases were detected and evidenced by the following signs and materials: erosion surfaces, barite-filled pockets, continental breccias and conglomerates, paleokarstic phenomena, red residual sediments, kaolinite deposits, as well as iron and kaolinite crusts.

Upon the size and thickness of the lense-like kaolinite deposits, that range normally from 4 to 9 meters and amount in spots even to 17.5 meters, influenced also the morphology of the solid rock. Namely, the kaolinite deposits were not formed or accumulated upon the elevated parts of the paleorelief. The paleorelief served only as a trap for the considered deposits [50]. The kaolinite deposits start in rare places with a thin layer of basal calcareous breccio-conglomerate with a kaolinite matrix.

The kaolinite deposits originated most probably from a pyroclastic material that was deposited into a marsh and there changed into the kaolinite [51–53].

### 3.2 Laboratory examinations

#### 3.2.1 SEM/EDS analysis

Semi-quantitative EDS analyses of all six selected samples were obtained. BE images of the investigated samples are shown **Figure 4**. The rocks are not homogeneous and consist of areas with different chemical compositions. The higher intensity of the backscattered electrons represents a lighter colour in the BE image; therefore, it can be concluded that such areas consist of elements having higher atomic numbers. The overall elemental analyses of all six samples are shown in **Table 2**. All the samples have approximately mass fraction 60 % of oxygen, the exception being sample 4, where the content of oxygen is less than half, most probably due to the higher amount of iron. Silicon and aluminium are the next two most represented elements. In sample 1 the mass fraction of aluminium is almost 26 %, while in sample 2, 5 and 6 the content of aluminium is close to 17 % and in other samples it is of 8 %. The higher content of silicon is in sample 3 (27 %) followed by sample 4 and 5 (approximately 19 %) and there is near 10 % in samples 1 and 4. Iron gives the colour of the rocks; the higher content of iron and their oxides give a more reddish colour to the samples. The highest content of iron, of approximately 28 %, was found in sample 4, it was in sample 2 at 4.7 %, in samples 1 and 5 at 2.7 %, in sample 3 at 1.6 % and in sample 6 at 0.4 %. Some of the samples also contain a minor content of titanium, magnesium and some other elements presented in **Table 1**. The EDS spectra of all the examined samples are presented in **Figure 5**. In each sample a few spot

**Table 2:** Chemical composition of six samples determined with EDS on a field of view 1,17 mm × 0.88 mm; mass fractions *w*/%, mole fractions *x*/%

**Table 2:** Kemična sestava šestih vzorcev določena z EDS-analizo na vidnem polju 1,17 mm × 0,88 mm; masni deleži *w*/%, molski deleži *x*/%

| | | O | Mg | Al | Si | K | Ca | Ti | Fe |
|---|---|---|---|---|---|---|---|---|---|
| Sample 1 | *w*/% | 60.0 | – | 25.7 | 10.9 | – | – | 0.6 | 2.7 |
| | *x*/% | 72.8 | – | 18.5 | 7.5 | – | – | 0.3 | 0.9 |
| Sample 2 | *w*/% | 59.5 | – | 17.1 | 18.6 | – | – | – | 4.7 |
| | *x*/% | 72.9 | – | 12.4 | 13.0 | – | – | – | 1.7 |
| Sample 3 | *w*/% | 57.9 | 2.3 | 8.3 | 27.0 | 2.2 | 0.6 | – | 1.6 |
| | *x*/% | 71.2 | 1.9 | 6.0 | 18.9 | 1.1 | 0.3 | – | 0.6 |
| Sample 4 | *w*/% | 51.9 | – | 8.4 | 9.4 | – | – | 2.0 | 28.3 |
| | *x*/% | 73.1 | – | 7.0 | 7.6 | – | – | 0.9 | 11.4 |
| Sample 5 | *w*/% | 60.5 | 0.3 | 17.4 | 18.7 | – | – | 0.4 | 2.7 |
| | *x*/% | 73.3 | 0.2 | 12.5 | 12.9 | – | – | 0.2 | 0.9 |
| Sample 6 | *w*/% | 61.2 | – | 17.9 | 20.0 | – | – | 0.5 | 0.4 |
| | *x*/% | 73.3 | – | 12.7 | 13.6 | – | – | 0.2 | 0.1 |

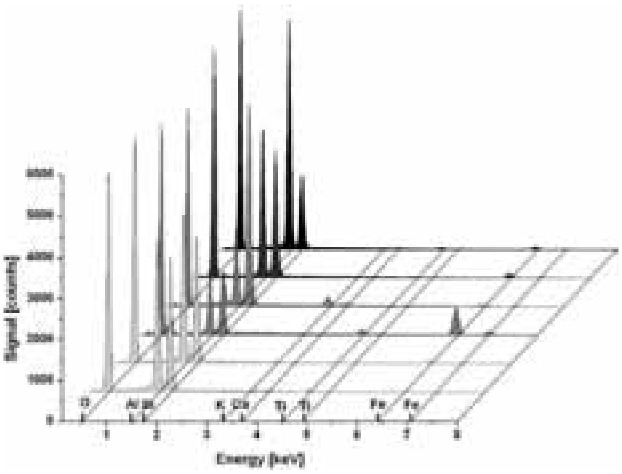


**Figure 5:** EDS spectra of all six samples taken for an area of 1.17 mm × 0.88 mm

**Slika 5:** EDS spektri šestih vzorcev posneti na področju 1,17 mm × 0,88 mm

analysis were performed, which clearly demonstrate the scattering of individual elements over the sample, especially iron, titanium and also silicon as well as aluminium, while oxygen is almost the same in all the examined samples. The results of the chemical composition of the individual small areas of sample 2 are shown in **Figure 6** and **Table 3**.

**Table 3:** Chemical composition of individual small areas of sample 2 determined with EDS; mass fractions *w*/%, mole fractions *x*/%

**Table 3:** Kemična sestava posameznih manjših področji vzorca 2 določena z EDS-analizo; masni deleži *w*/%, molski deleži *x*/%

| | | O | Al | Si | Ti | Fe |
|---|---|---|---|---|---|---|
| Spectrum 1 | *w*/% | 49.5 | 10.4 | 11.2 | 1.2 | 27.7 |
| | *x*/% | 70.4 | 8.8 | 9.0 | 0.5 | 11.3 |
| Spectrum 2 | wt.% | 54.5 | 14.1 | 15.2 | 0.8 | 15.4 |
| | *x*/% | 71.5 | 11.0 | 11.4 | 0.3 | 5.8 |
| Spectrum 3 | *w*/% | 60.8 | 17.6 | 18.7 | 0.2 | 2.7 |
| | *x*/% | 73.5 | 12.6 | 12.9 | 0.1 | 0.9 |
| Spectrum 4 | *w*/% | 58.5 | 16.1 | 17.1 | 0.4 | 7.9 |
| | *x*/% | 73.1 | 7.0 | 7.6 | 0.9 | 11.4 |
| Spectrum 5 | *w*/% | 54.5 | 13.4 | 14.4 | 0.7 | 17.0 |
| | *x*/% | 72.0 | 10.5 | 10.8 | 0.3 | 6.4 |

### *3.2.2 XRD analysis*

**Figure 7 to 12** shows the XRD spectra of six samples with labeled constituting minerals. The XRD results correspond very well with the EDS elemental analyses taking into account that there are some elements that cannot be analyzed, e.g., hydrogen, and that light elemental analysis is not very precise when using EDS. This analysis is difficult because of their low photon energy, what may lead to high absorption in the specimen and in the components of the spectrometer [48]. Sample 1 is dark-red oolitic pisolitic bauxite or boehmite bauxite with some minor minerals such as hematite, kaolinite, nantronite and berthierine (**Figure 7**). The share of the boehmite phase is at 60 %, while the share of other minerals is approximately 10 % for each. Sample 2 is red pelitic bauxite or iron kaolinite (**Figure 8**). The ratio of the kaolinite mineral to the hematite is 8 to 2. Sample 3 is a quartz sandstone with a tuff admixture (**Figure 9**). The content of quartz is 80 %, while in the other two phases it is 10 % for each. Sample 4 is an iron-kaolinite-rich phase (**Figure 10**) where the

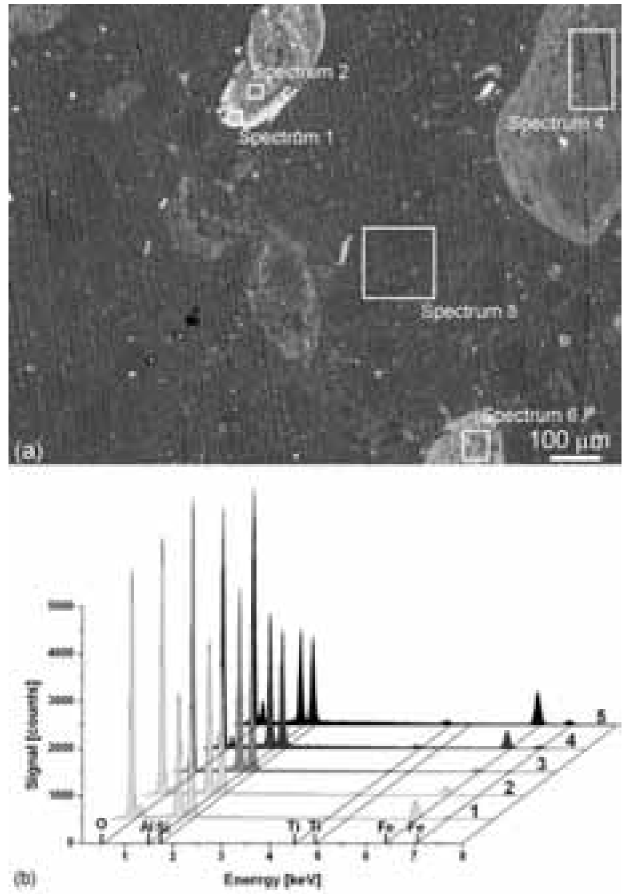


**Figure 6:** (**a**) BE image of sample 2 with marked areas of EDS analysis; (**b**) five EDS spectra performed on different areas

**Slika 6:** (**a**) Slika odbitih elektronov vzorca 2 z označenimi mesti EDS analize; (**b**) pet EDS spektrov, posnetih na različnih področjih

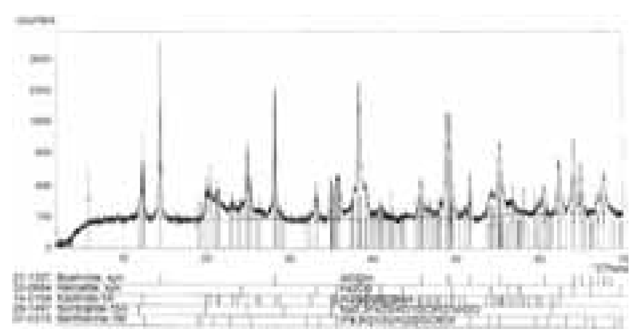

**Figure 7:** XRD-spectrum of sample 1 with labelled constituted minerals of analysed rock

**Slika 7:** XRD-spekter vzorca 1 z označenimi minerali, ki sestavljajo analizirane kamne

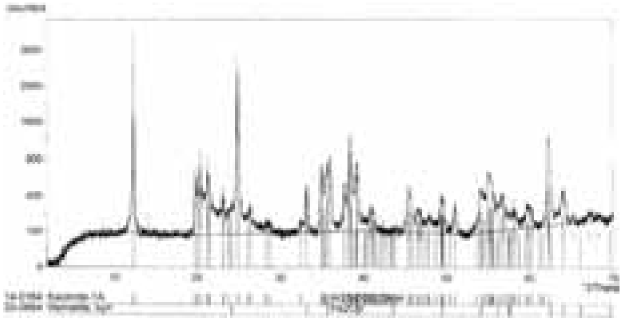

**Figure 8:** XRD-spectrum of sample 2 with labelled constituted minerals of analysed rock
**Slika 8:** XRD-spekter vzorca 2 z označenimi minerali, ki sestavljajo analizirane kamne

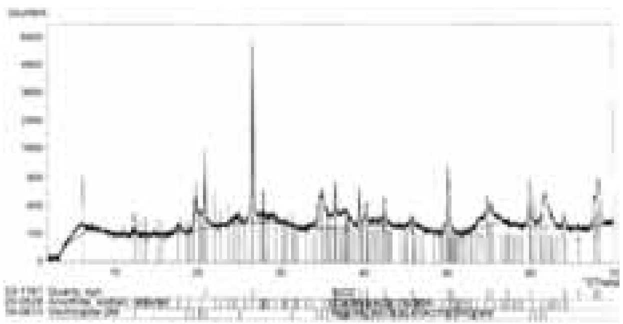

**Figure 9:** XRD-spectrum of sample 3 with labelled constituted minerals of analysed rock
**Slika 9:** XRD-spekter vzorca 3 z označenimi minerali, ki sestavljajo analizirane kamne

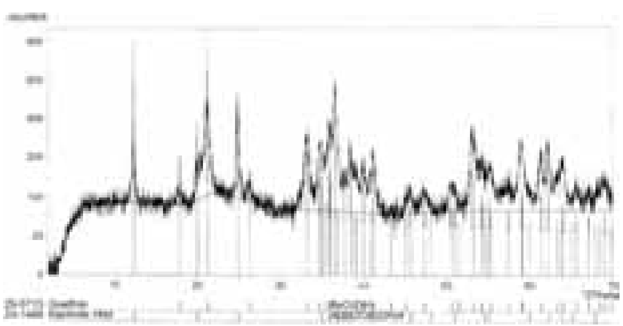

**Figure 10:** XRD-spectrum of sample 4 with labelled constituted minerals of analysed rock
**Slika 10:** XRD-spekter vzorca 4 z označenimi minerali, ki sestavljajo analizirane kamne

ratio of the goethite and kaolinite are 6 to 4. Sample 5 is kaolinite with the addition of iron in the goethite phase (**Figure 11**). The content of kaolinite in sample 5 is 70 %, while goethite and nontronite are represented each as 10 %, and gibbsite and groutite as 5 % each. Sample 6 is pure kaolinite (**Figure 12**).

## 4 CONCLUSIONS

In Southern Slovenia – which in the Scythian and Anisian epoch belonged to the Slovenian Carbonate Platform including the whole Dinarides and from the Upper Cordevolian to the end of the Mesozoic period to the Dinaric Carbonate Platform – two Triassic sedimentary developments can be distinguished: the clastic and the carbonate. The clastic development occurs in the Kočevje and Bela krajina regions, while the carbonate appears in the Bloke plateau and in some other places in Slovenia. In the last three years we focused our research work on the Bloke plateau area, to the "Dolomite" Complex in particular.

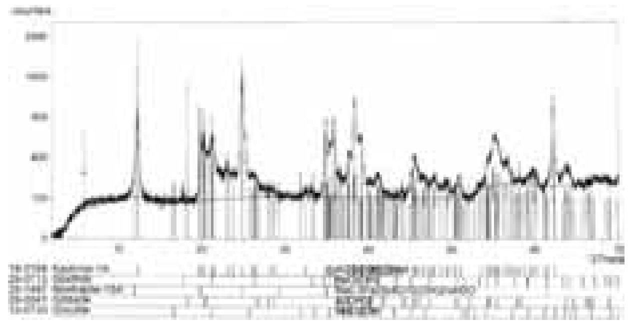

**Figure 11:** XRD-spectrum of sample 5 with labelled constituted minerals of analysed rock
**Slika 11:** XRD-spekter vzorca 5 z označenimi minerali, ki sestavljajo analizirane kamne

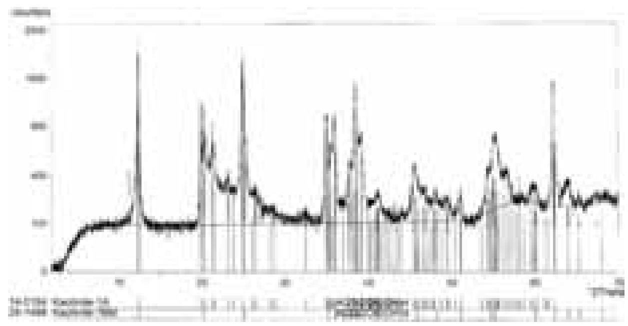

**Figure 12:** XRD-spectrum of sample 6 with labelled constituted minerals of analysed rock
**Slika 12:** XRD-spekter vzorca 6 z označenimi minerali, ki sestavljajo analizirane kamne

With systematic regional and detailed geological and laboratory researches we came to the following conclusions:

1. The "Dolomite" Complex on the Bloke plateau is not a homogenous lithologic unit, but it consists of two, and in some places even of three or four, rock sequences.
2. In the Kočevje region, there was no sedimentation in the Anisian, Ladinian and Cordevolian epochs, since there are no Middle Triassic and Lower Carnian (Cordevolian) rocks exposed at the surface, and because these rocks do not crop out anywhere in the White Carniola and Gorski Kotar, as well.
3. The sedimentation in the "Dolomite" Complex of the Bloke plateau was not continuous; it was interrupted two times for a certain time: in the middle of the

Anisian epoch and on the boundary between the Anisian and Ladinian stage.

4. About S. Buser and A. Ramovš statement [7], i.e., that in southern Slovenia the dasycladal species *Diplopora annulata* Schafhäutl occurs only in the Cordevolian beds, we came to the conclusion that it was so only there, where the Ladinian is clasticly developed. In other places in Slovenia, however, we have also the Middle Triassic carbonate development ("Dolomite" Complex), where according to our data, the beds containing diploporas extend into the Ladinian stage as well. The considered dry-land phase started probably already in the topmost Anisian and lasted for some time into the Ladinian epoch (probably in the whole Fassanian). Afterwards, started the sedimentation of the *Diplopora Limestone* of the coarse-grained dolomites, that fill the Ladinian and Cordevolian interval of the Triassic lithostratigraphic column [15–17,49].
5. In the Anisian epoch volcanoes very probably also erupted.

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