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New Data on the Stratigraphic Position, Mineralogy and Chemistry of Nanos Bauxite Deposits and Adjacent Carbonate Rocks, Slovenia

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Abstract

The bauxite deposits occur along the Lower Kimmeridgian-Upper Kimmeridgian contact in the Nanos area. The main bauxite minerals are boehmite and gibbsite. The Nanos deposits are an example of bauxites deriving from limestone residuum, aeolian material and alluvium. Some Jurassic marly, calcareous rocks proved relatively high in alumina, iron and silica, and are probably a significant source of bauxite material. The Nanos bauxites are compared with late Jurassic bauxites from the western Istria.

1. INTRODUCTION

On the eastern slope of Mt. Nanos, about 40 km southeast of Ljubljana, there occur several minor bauxite outcrops of Malm age. The largest one is situated at Železni Klanec (Fig. 1). The bauxite deposits of Nanos lie somewhat discordantly on the slightly karstified surface of the Lower Kimmeridgian calcareous beds. The bauxites indicate widespread emersion and are concordantly overlain by the Upper Kimmeridgian shallow water succesion.

This study of the Jurassic Nanos bauxites was carried out in 1986 and included in "The Thematic Geologic Map of Slovenia 1:50 000", as a part of the macroproject "Jurassic in the Outer Dinarides". The quantitative mineralogical composition of the bauxite samples was determined by X-ray diffraction involving twenty-eight samples of different types of bauxites. More than a hundred chemical analyses of different types of bauxites were undertaken for this study. The texture and structure of the samples were studied at outcrop, on polished hand specimens, and under the microscope in thin-sections. The colour determinations of the bauxite deposits and adjacent carbonate rocks are based on the Munsell Rock Colour Chart.

In order to achieve a better understanding of the origin of the bauxite, the authors also studied the sedimentary-petrographic characteristics of the calcareous rocks underlying and overlying the bauxite deposits, as well as the influence of tectonic processes on sedimentation.

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2. PREVIOUS INVESTIGATIONS

The genetic relationships between red clay (terra rossa) and bauxites were first studied by TUĆAN (1912) and KIŠPATIĆ (1912) who found that the red clay is an insoluble limestone residue very similar to bauxite. The first exploration of the Nanos bauxites was carried out by the Italian tradesman RIZZATO, probably in 1935. TIRINGER (1954) gave a review of the up-to-date knowledge of the Slovenian bauxite ore deposits. PLENIČAR (1975) described the oolitic bauxites and iron-ore deposits in Nadrta, Hrušica and Nanos. BERCE (1956) surveyed the iron-ore deposits of Slovenia. GRUBIĆ (1956) dealt with the stratigraphic position of bauxites in the Dinarides. BUSER & LUKACS (1966, 1973) reported upon the results of geological bauxite explorations in Slovenia. ŠINKOVEC (1974) described the Jurassic clayey bauxites of western Istria and discussed the weathering products of the Upper Triassic of middle Dalmatia (ŠINKOVEC et al., 1975). GREGORIČ (1969) studied the origin of the red brown soil (terra rossa) lying on the Triassic dolomites in southern Slovenia. SAVIĆ et al. (1983) described the Malmian terrigenous layers of Kamenjak from the Gorski Kotar area. More recently MAKSIMOVIĆ & BUSER (1986) analysed the geochemical characteristics of some karstic bauxites from Slovenia.

3. STRATIGRAPHIC POSITION OF THE BAUXITES

The bauxites of the Nanos area are interbedded in the Malm shallow water carbonate sedimentary succession. Their stratigraphic position is very clear from fossil evidence. The bauxites occur in a stratigraphic interval between the Lower and Upper Kimmeridgian. They lie slightly discordantly upon the oolitic and reefal calcareous strata, and are concordantly overlain by Upper Kimmeridgian "Clypeina" limestones.

In the reef limestones which underlie the bauxites the following fossils were found: *Pseudocoenia tabulata* ERRENST, *P. slovenica* TURNŠEK, *Comoseris baltovensis* RONIEWICZ, *Thamnasteria lobata* (GOLDFUSS), *Calamophylliopsis flabellum* (MICHELIN), *C. moreauana* (MICHELIN), *Actinostromaria concentrica*

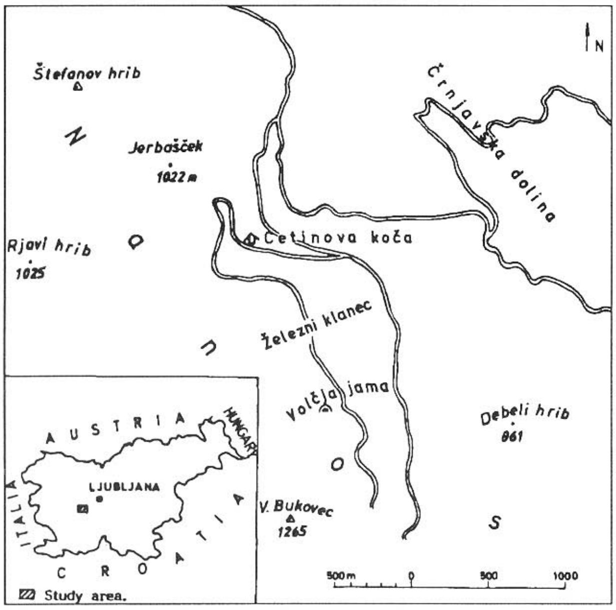

Fig. 1. Location map of Nanos bauxite deposits.

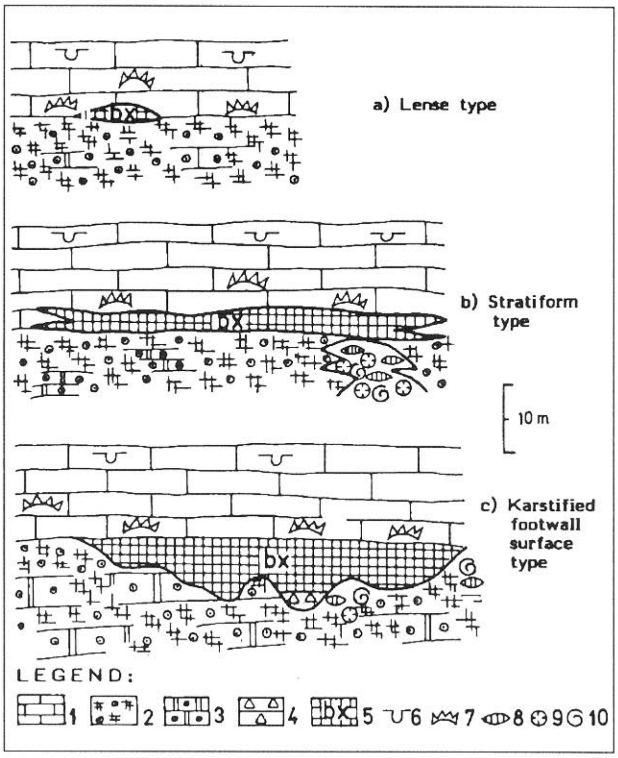

Fig. 2. Types of bauxite bodies. 1 - Hanging-wall "Clypeina" limestone; 2 - Footwall massive limestone; 3 - Footwall poorly bedded oolithic limestone; 4 - Basal breccia; 5 - Bauxite; 6 - Tintinnids; 7 - *Clypeina jurassica*; 8 - Hydrozoans; 9 - Corals; 10 - Molluscs.

MILAN, *Stylosmilia pumila* (QUENSTEDT), *Meandrophyllia amedei* (ETALLON), *M. edwardsi* (MICHELIN), *Mixastraea danubica* RONIEWICZ, *Andemantastraea dreyfussi* BEAUVAIS, *Allocoenia trochiformis* ETALLON, *Meandraraea gresslyi* ETALLON, *Chaetetopsis crinita* NEUMAYR and *Nerinea* sp.

In the footwall oolitic facies the following microfauna and microflora have been found: *Cladocoropsis mirabilis* FELIX, *Kurnubia palastiniensis* HENSON, *Trocholina elongata* (LEUPOLD), *Trocholina alpina* (LEUPOLD), *Salpingoporella annulata* CAROZZI, *Thaumatoporella parvovesiculifera* (RAINERI), Verneulinidae and Textulariidae.

In the lowermost layer of the limestone, lying concordantly on bauxites, we found, in addition to algae *Clypeina jurassica* FAVRE, *S. annulata*, *T. parvovesiculifera*, Textulariidae and Verneuilinidae. Somewhat higher in the overlying calcareous succesion *Campbelliella striata* (CAROZZI), and foraminifera *Kurnubia palastiniensis* HENSON were also found.

3.1 THE UNDERLYING CARBONATE SUCCESION

The Nanos bauxite deposits lie on a sedimentary succesion which is commonly divided into two parts. In the lower part there is a prevalence of micritic and biomicritic lagoonal Cladocoropsis limestones without significant dolomitization, while in the upper part there is an occurence of oolitic limestones with minor reefs, which are more or less highly selectively dolomitized.

In most cases, the bauxites of the study area lie directly upon the high-energy sediments. Relatively few bauxite deposits have so far been known to lie on the low energy micritic limestones. It is however obvious that the latter were also deposited in large amounts, since they form the main constituent of the basal calcareous breccia with bauxite matrix.

The most common and frequent facies in the lower part of the beds are micritic and pelmicritic limestones. These are intercalated with oncolitic limestones which were formed in a restricted lagoon, and sporadically contain foraminiferal and algal biopelmicrites, as well as biopelmicrosparites. Relatively frequent, and most typical of the lower part of the underlying succesion, are biomicrites with the sponge *Cladocoropsis mirabilis* FAVRE. In the lagoon, biosparites and biointrasparites with benthic foraminifera, algae, and echinoderms were found to be well developed. Relatively rare, but nevertheless typical were also biostromal limestones with brachiopods.

The carbonate succesion described is both lithologically, and in terms of age, very similar to the sediments of the uppermost part of the Monsena micrites and Lim pelletal limestones in western Istria, named and described by VELIĆ & TIŠLJAR (1988). These were deposited either in a shallow subtidal lagoon environment and/or a restricted shoal with low-water energy, or in an environment of the shallow subtidal and/or open lagoon in the interior of a carbonate platform (VELIĆ & TIŠLJAR, 1988).

The upper part of the Lower Malm is characterized by massive oolitic limestones. The most extended and typical facies in this part of the Lower Malm are those of oolitic, intraoolitic and reef limestones. Corals and hydrozoans were the main reef-bulding organisms. These massive oolitic limestones are often more or less intensively late-diagenetically dolomitized, and correspond to the shallow water limestones of the Muča unit (western Istria), with their typical tidal-bar winnowed carbonate sands. They originated from the transport of the ooid sand and fossil detritus, carried by tidal streams and waves to be deposited on a tidal sand bar, and are composed of bioclastic peri-reefal limestones, hydrozoan and coral limestones, and oolites (TIŠLJAR & VELIĆ, 1987; facies 4, 5, 6).

The fauna and flora of the footwall carbonate rocks belongs to the *Salpingoporella sellii* cenozone (Oxfordian and Lower Kimmeridgian), while the fossils collected in the hanging-wall beds appertain to the *Clypeina jurassica* cenozone (Upper Kimmeridgian and Tithonian).

3.2 THE OVERLYING CARBONATE SUCCESION

The concordantly overlying Upper Malm beds consist of limestones, dolomites and breccias. More than 100 metres of the Upper Malmian sedimentary succesion was studied. The Nanos Upper Malmian sedimentary succesion is characterized by rhythmic sedimentation of algal and stromatolitic limestones and dolomites, calcilutites, intrasparites and biointrasparites. The limestones were deposited in a restricted shelf environment. Stromatolitic and fenestral layers indicate intertidal conditions of sedimentation. Limestone breccia with calcitic and bauxitic cement and bauxite were formed on the dry land.

In the layers which overlie the bauxite deposits, the predominant facies are those of peritidal fenestral limestones and of late diagenetic dolomites, i.e. facies 1 and 7 (TIŠLJAR & VELIĆ, 1991). The peritidal fenestral limestones facies is composed of rhythmically deposited micrites, pelmicrites, biomicrites, stromatolites and peritidal intraformational breccias. The limestones contain numerous fenestrae and solution vugs. The late diagenetic dolomite facies includes crystalline dolomites which contain relics of various limestones. The dolomites were formed by the late-diagenetic dolomitization of the Upper Malmian limestones.

4. FORM AND DISTRIBUTION OF THE DEPOSITS

In the Nanos region the bauxites occur along the Lower Kimmeridgian-Upper Kimmeridgian contact, extending in a southeastern-northwestern direction. The bauxite horizon is not continuous, and laterally, wedges out abruptly in most cases, while no facies equivalents can be found elsewhere. In the study area, eight rather small deposits have so far been found, occuring as small flat lenses, pockets and funnel-like bodies, filling out depressions in the underlying carbonate rocks. Their thickness varies from a few centimeters to almost 10 metres and usually diminishes gradually in the northwestern and southeastern direction. The most frequent thickness is 2 to 5 metres. The footwall surface is more or less karstified. At some places the bauxite horizon begins with calcareous breccia and conglomerate, cemented by reddish and yellowish calcite and/or bauxitic clays. The overlying carbonate layers generally repose concordant upon the bauxite with a flat surface. Transgressive calcareous conglomerates and breccias, cemented by calcite and/or bauxitic clays, are also found sporadically at the base of the overlying carbonate succesion. The types of bauxite bodies are shown in Fig. 2.

5. BAUXITE DEPOSITS

In the Nanos region the most complete picture of bauxite sedimentation has been observed at the Železni Klanec deposit. The central and some of the upper part of the deposit consist of pure bauxite accompanied in many places by a greater or lesser amount of iron-rich bauxite, which grades laterally and vertically into bauxitic clays. At the Železni Klanec deposit, the iron-rich bauxites are rare and usually form only small patches or thin layers in the normal ore, but they become dominant in the lower, upper and marginal parts of some other smaller Nanos deposits. At certain places, some uppermost and lowermost parts of the deposits consist of low calcareous bauxite.

Seven characteristic horizons were established in the Železni Klanec bauxite deposit (Fig. 3); these occur from bottom to top in the following order:

1. The basal horizon is represented by a light grey (N 7) homogenous, calcareous breccia-conglomerate. It is composed of poorly rounded and angular fragments of light grey (N 7) Lower Malm micritic limestone and moderate brown (5 YR 4/4), greyish orange (10 YR 7/4), moderate pink (5 R 7/4), pelitic to arenitic bauxite matrix. The size of the fragments generally ranges from 0.5 cm to 7 cm. The rock is unsorted. Usually a brown bauxitic ring around the fragments can be observed. The basal breccia-conglomerate is developed only at a few places. The bauxite layers lie mostly directly upon the Lower Malm limestones. The thickness of the basal horizon is about 10 to 50 cm.

2. Over the basal calcareous breccio-conglomerate lie greyish orange (10 YR 7/4), greyish yellow (5 Y 8/4), and light brick red (5 R 6/6), pelitic and/or oolitic bauxite with a dark blue metallic colour and thin (1 mm to 2 mm) layers upon the fissure surfaces. The ooids are of the same colour as the groundmass, and are 0.1 - 0.75 mm in diameter. Sorting is very poor. At some places lateral transitions to moderate reddish orange (10 R 5/6) and orange red pelitic, alevritic and oolitic bauxite can be observed. The thickness of the horizon is about 2.5 metres.

3. These are succeeded by the horizon of the dark brick red (5 R 5/6) laminated (22 mm to 10 mm) oolitic bauxite. The lamination is not the result of grain size differences but is caused by the different colours of par-

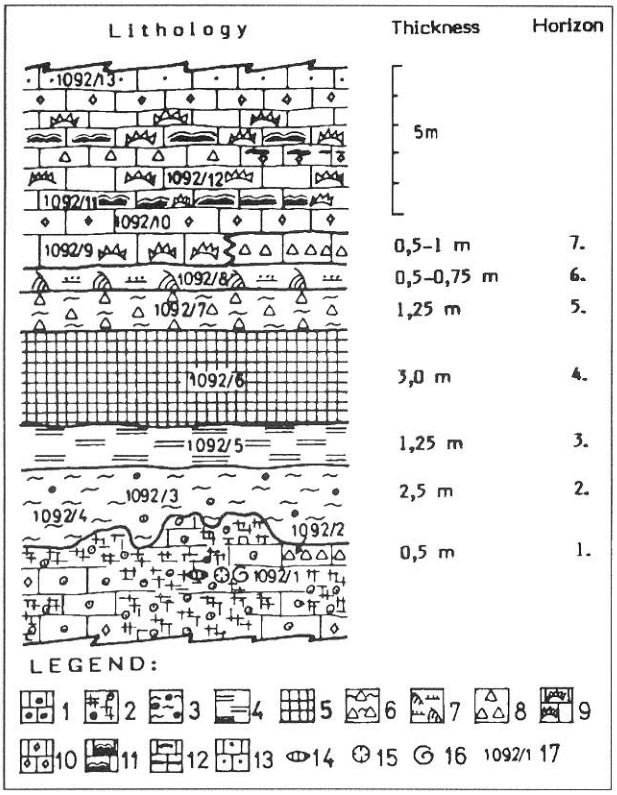

Fig. 3. Železni klanec bauxite deposit. 1 - Footwall oolithic limestone; 2 - Footwall massive limestone; 3 - Yellow, orange and light brick-red, mostly pellitic and arenitic bauxite; 4 - Dark brick-red laminated bauxite; 5 - Dark brownish-red massive oolithic bauxite; 6 - Bauxitic breccia; 7 - Cross-bedded bauxite; 8 - Limestone breccia with bauxitic matrix; 9 - Hanging-wall "Clypeina" limestone; 10 - Intraclastic limestone; 11 - Stromatolitic limestone; 12 - Fenestral limestone; 13 - Grainy limestone; 14 - Hydrozoans; 15 - Corals; 16 - Molluscs; 17 - Samples.

ticular laminae. Light red (5 R 5/6), greyish orange pink (10 R 7/2), light to moderate brown (5 YR 5/4) and greyish pink (5 R 7/2) laminae alternate. All laminae are of oolitic bauxite. The grains are commonly 0.05 - 0.5 mm in diameter. Larger grains (0.75 - 1 mm) are rare. The colour is greyish-pink (5 R 8/3), greyish yellow (5 Y 8/4), medium dark grey (N 4) to greyish black (N 2). The grains are poorly sorted, but sizes of 0.1 - 0.2 mm are predominant. The rock also comprises larger (up to 5 mm) fragments of pale pink (5 R 8/4), fine-grained oolitic bauxite. In the uppermost part of this horizon, a small patch of dark-yellowish orange (10 YR 6/6) oolitic bauxite was found. The thickness of the horizon is 1.25 metres.

4. The next horizon consists of dark brownish red (5 R 5/6) compact oolitic bauxite. The grain diameters vary between 0.025 and 0.5 mm. The degree of sorting is moderate. Larger grains (0.5 - 1 mm) are rare, and grains within the size range 0.1 mm to 0.2 mm are predominant. This horizon is 3.0 m thick (Fig. 3).

5. The fourth horizon of the bauxite deposit at Železni Klanec is overlain by a mottled intraformational bauxite breccia-conglomerate. It is composed of poorly rounded, nodular, oval, and rarely rounded greyish-red (5 Y 3/2) pebbles of pelitic, alevritic and oolitic bauxite in a pale brown (5 YR 8/2) oolitic bauxite groundmass. The sizes of the ooid grains range from 0.025 to 0.5 mm. Larger ooids are rare. Some of them are pisoids and spastoids. The thickness of the fifth bauxite horizon is 1.25 metres.

6. The sixth horizon is formed by oolitic bauxite with cross-bedding and graded-bedding structures. The thickness of the horizon is 0.5 to 0.75 metres.

Horizon 7 is discontinuous. At some places the bauxites are overlain by light grey (N 7 calcareous breccia or brecciated limestone, consisting of 5-30 cm fragments of grey (N 5) micritic limestone cemented with calcitic cement, and yellowish grey bauxitic matrix. The fragments are much more common than the matrix. The thickness of the uppermost breccia horizon is 0.5 - 1 m. The transition from bauxite to calcareous breccia is abrupt.

5.1. TEXTURE

The textures of Nanos bauxites are quite variable. The changes in texture often occur both verticaly and lateraly. The Nanos bauxites consist of the following main textural elements: bauxite groundmass, bauxite pebbles, ooids, spastoids, pisoids and detrital mineral grains. The groundmass is the basic, most essential and widespread textural element.

Considering the prevailing role of particular textural elements, it is possible to distinguish pelitic, psammitic, oolitic, spastolitic, pisolitic, breccioidal, breccio-conglomeratic and conglomeratic texture.

Pelitic and psammitic textures are quite frequent, particularly in the groundmass of the bauxites. Oolitic texture is predominant both in the bauxites and in bauxitic clays. Breccioidal texture occurs in resedimented bauxite.

5.2. COLOUR

A detailed description of colours has been already given in the description of the bauxite sedimentary succesion at the Železni Klanec deposit. It is evident from the cross-section that the colour of the bauxites - in which iron is the main source of pigment - becomes increasingly intense from the bottom to the top of the succesion. Generally, the basal bauxite deposits are yellow, passing upward successively to orange-red, brick-red and finally a dark brownish-red colour. This rule does not apply everywhere. The colour of particular layers or horizons often changes both laterally and vertically. Generally speaking, the bauxite succesion can be divided with respect to colour into two parts: the lower part yellow to orange-red, and the upper part brick-red to brownish-red. At the Železni Klanec deposit the brownish-red colour is predominant. The iron-rich bauxites are darker in colour. In the adjacent much smaller Nanos bauxite deposits the predominantly occuring colours are yellow, orange-yellow and orange-red.

5.3. MINERALOGY

The quantitative mineralogical composition of 28 samples was determined by x-ray diffractometry. The results are given in Table 1.

From Table 1 it is evident that goethite, boehmite, kaolinite and gibbsite are the main mainerals of the Nanos Jurassic bauxite. The kaolinite amount in the bauxites is high, thus the Nanos bauxites containing more than 25 % of clay minerals belong, according to the classification of BARDOSSY & NICOLAS (1973), to the group of clayey bauxites.

5.4. GEOCHEMISTRY

About one hundred and twenty chemical analyses were performed on fifteen samples from the Nanos bauxite deposits and adjacent carbonate rocks. The selected chemical analyses refer to some extended types of bauxites, which are described in the bauxite cross-section at Železni Klanec. The chemical composition of the Nanos Jurassic bauxites is shown in Table 2.

The analyses show that the alumina content of the Jurassic bauxites of the Nanos area is medium to high, Fe_2O_3 and SiO_2 high, and loss on ignition relatively low (11.71-43.54 %). The Al_2O_3 content in the Nanos bauxites varies from 0.47 % to 59.46 %. The Fe_2O_3 content is relatively low (0.05 % to 24.40 %) in the lower part of the bauxite deposits and generally much higher in the upper part of the deposits. The highest content (38.45 %) was established in the many-coloured laminated more or less oolitic bauxite. The content of SiO_2 ranges from 0.01 % to 39.26 %. Generally speaking, it is higher in the lower part and lower in the upper part of the deposit. The highest value

No.	Sample	M/I	CHL	KAO	GIB	BOE	LEP	GOE	HEM	ANA	QTZ	PLA	PYR	GYP
	Locality: Železni Klanec													
1	1092/3A	2		52		43	0	2	0	0				
2	1092/3B	16		67		0	0	13	0	4				
3	1092/4A	6		12		61	6	8	0	7				
4	1092/5A	1		12		65	11	3	3	5				
5	1092/5 B	0		70		9	0	21	0	0				
6	1092/6A	0		3		73	0	0	19	3				
7	1092/6B	7		7		77	0	3	0	5				
8	1092/7A	6		12		65	4	5	2	5				
9	1092/7B	1		10		84	0	2	0	3				
	Locality: Veliki Bukovec													
1	PO-24-1VB	0	0	17	0	27		49	0	0	0	0	6	0
2	PO-24-2VB	0	0	11	0	65		20	3	0	0	0	0	0
3	PO-24-3VB	0	0	12	0	48		35	0	0	0	0	0	0
4	PO-24-4VB	0	0	23	0	32		41	4	0	0	0	0	0
5	PO-24-5VB	0	0	11	8	48		32	1	0	0	0	0	0
	Locality: Volčja Draga													
1	PO-24-1	0	0	20	0	39		41	0	0	0	0	0	0
4	PO-24-2	1	0	0	5	65		0	26	2	2	0	0	0
11	PO-24-4	0	0	6	7	57		0	24	4	1	0	0	0
14	PO-24-5	0	0	13	0	73		4	2	0	0	0	0	0
	Locality: Cetinova koča													
3	PO-24-1ŽK	21	29	0	26	0		0	6	0	12	6	0	0
17	PO-25-2	2	0	42	0	0		58	0	0	0	0	0	0
18	PO-25-5	5	0	20	13	0		39	18	3	1	0	0	0
19	PO-25-6	1	0	29	6	16		45	0	2	0	0	0	0
	Locality: Jerbašček													
5	PO-24-2J	0	0	23	0	18		53	0	0	0	0	6	0
8	PO-24-3J	0	0	21	12	9		53	0	0	0	0	6	0
12	PO-24-4J	0	0	26	0	0		67	0	0	0	0	7	0
15	PO-24-5J	0	0	29	0	64		0	0	0	0	0	8	0

Table 1. Mineral composition of the bauxites (in %). Legend: M/I - muscovite/illite; CHL - chlorite; KAO - kaolinite; GIB - gibbsite; BOE - boehmite; LEP - lepidocrocite; GOE - goethite; HEM - haematite; ANA - anatase; QTZ - quartz; PLA - plagioclase; PYR - pyrite; GYP - gypsum.

Sample	Al_2O_3	Fe_2O_3	SiO_2	CaO	MgO	SO_3	TiO_2	Na_2O	K_2O	Ign.loss
Locality: Železni Klanec										
1091	0.47	0.12	0.01	54.90	0.30	0.49				43.54
1092/3A	38.93	7.30	37.90	0.36	0.96	1.79				12.59
1092/3B	35.50	9.58	39.19	0.39	0.90	1.36				12.82
1092/4A	50.91	14.38	18.22	0.44	0.50	2.53				12.89
1092/5A	27.91	38.45	19.65	0.42	0.15	1.66				11.71
1092/5B	35.79	9.81	39.26	0.33	0.51	1.30				12.81
1092/6B	55.16	17.60	12.18	0.39	0.36	2.16				11.97
Locality: Volčja jama										
PO-24-1	47.75	20.48	15.89	0.25	0.29		1.56	0.08	0.59	13.03
PO-24-2	53.59	21.22	9.84	0.15	0.36		2.09	0.16	0.61	11.87
PO-24-5	59.46	9.31	14.00	0.20	0.28		2.01	0.08	0.66	13.90
PO-24-6	41.08	24.40	18.71	0.25	0.31		1.66	0.07	0.49	12.90
Locality: Cetinova koča										
PO-26	2.76	0.05	0.36	54.03	0.05		0.05	0.05	0.05	42.56
PO-26/2	31.90	12.07	37.61	1.16	0.43		1.10	0.11	1.39	14.13
PO-26/3	32.04	10.48	38.86	0.45	1.02		1.20	0.09	1.10	14.69
PO-26/6	35.15	21.39	22.95	0.35	0.87		1.71	0.12	0.82	13.56

Table 2. Chemical composition of the bauxites (in %).

(39.26 %) was detected in the yellowish bauxite in the lower part of the deposit. The TiO_2 content increases from bottom to top of the deposit, and from northwest to southeast. The highest value of TiO_2 is 2.09 %. All CaO values are below 1 %. The MgO values are somewhat higher than the CaO ones, but still always below 1 %. The SO_3 content was detected in seven samples measured from Železni klanec and varies from 0.49 % to 2.53 %. The sodium (Na_2O) content is generally very low ranging from 0.05 % to 0.16 %. The potassium (K_2O) content is much higher than the sodium one, and ranges from 0.05 % to 1.39 %.

5.5. SOURCE MATERIAL AND BAUXITIZATION

Since it has been established that the Outer Dinarides carbonate platform was composed mainly of limestone and dolomite containing the same elements which are found in bauxites, we conclude that the bauxites were derived from their insoluble residue. We conclude therefore that the Jurassic bauxites studied in the Nanos region originated also from the insoluble residue of the footwall carbonate rocks. During the Lower Kimmeridgian-Upper Kimmeridgian, a phase of emersion occurred, with favourable climatic conditions and strong chemical and physical weathering of more or less marly and clayey limestones and dolomites took place. Their insoluble residues contributed the material for the bauxites. Several hundred metres of limestones and dolomites could have been dissolved in this way. Therefore the original thickness of the Mesozoic carbonate succesion must have been greater than it is at present.

There are, however, two objections to the residual theory of the Nanos bauxites, these are: a) the high purity of the greater part of the preserved Jurassic carbonate rocks, and b) the relatively short-lasting Kimmeridgian continental phase. For these two reasons it seems highly probably that the source material of the Jurassic clayey bauxites of Nanos may also have originated in the great part from the aeolian material and alluvium.

5.6. PALAEORELIEF, TRANSPORTATION AND THE ENVIRONMENT

The Nanos bauxites treated in this study developed during the Late Kimmerian emersion phase. The movements that created the dry land were mainly of the epeirogenic type. This is suggested by the biostratigraphy and by the concordance or slight discordance (5° to 10°) of bauxites and their footwall and hanging-wall carbonate rocks. The Late Kimmerian epeirogenic movements, together with the fault tectonics, produced a palaeotopography on which weathering, leaching, dissolving, karstification and denudation subsequently took place. Karstification was soon interrupted and entirely halted by the bauxitization and deposition of the bauxitic material particularly of the terra rossa type.

In order to interpret the genesis and mechanisms of transportation and sedimentation, primary sedimentary structures have been used. The more or less common structures which characterize the various Nanos bauxite deposits may be divided into three groups) bedding structures, non-bedding structures and extant structures.

Most of the studied bauxite deposits have a massive, non-stratified structure. This structure is typical especially of pelitic deposits. In smaller occurrences in the Nanos area, a faint stratification may be observed. A similar stratification also occurs in the lower part of the Železni Klanec deposit. On the other hand, the bauxitic clay and the bauxites in the upper part of the Železni Klanec deposit are relatively well stratified. They are thinly bedded and laminated. Two types of lamination were found there: parallel horizontal lamination and cross lamination. Cross-bedding is well developed in the coarser bauxite deposits. It is a common structure in deposits of fluvial and marine origin. It was produced by swift locally changing-water-currents. Graded-bedding is produced by deposition from currents of decreasing intensity. Ripple marks are formed on the surface of non-cohesive sediments of sand and silt. Mud cracks were formed by the shrinkage of bauxitic clay in the course of drying under atmospheric surface conditions. Load casts were produced by gravitational settling shortly after deposition.

The texture and structure of the Nanos bauxites indicate the presence of aqueous transportation. The low relief allowed only limited water transport up to at most a few kilometers. The small, poorly-rounded detrital and bauxitic grains indicate low current and alluvial transport. On the basis of the bauxite textures and detrital grains, we conclude that the transportation and redeposition occurred repeatedly and in several stages. Finally, the material was accumulated with the help of water flows in karstic depressions. The transportation occurred mostly in the form of mud. At some places, torrential mud-flow also occurred as is shown by some conglomeratic textures.

In the Nanos Jurassic bauxites we have established two types of sedimentation: continental and shallow-water, probably marine. This is most evident in the cross-section at Železni Klanec.

The yellow, orange and orange-red, massive, predominantly pelitic bauxite originated in our opinion from dry land by the weathering and leaching processes in the carbonate footwall. The bauxites were partly formed in situ, but for the most part they were resedimented, as is evident from the texture and detrital grains found in them. Transport was carried out by water-flows and by wind.

The red and brownish-red, predominantly oolitic, and often stratified bauxites of the upper part of the deposit with numerous structures and textures, were deposited in a shallow sea shelf near the coast. Oolitic bauxites of the upper part and the stratified bauxites were formed in a subtidal sea, and later the uppermost bauxitic breccias and conglomerates, as well as cross-bedded layers were formed in intertidal and supratidal environments.

The limestone breccia with calcite cement and bauxitic clay appearing locally at the base and at the top of the Nanos bauxite unit corresponds in part to the unit of Rovinj breccia and bauxite (TIŠLJAR & VELIĆ, 1988).

5.7. PALAEOGEOGRAPHY, TECTONICS AND SEDIMENTATION

The area investigated belongs to the Outer Dinarides. The unit of the Outer Dinarides was originally a relatively large, morphologically poorly differentiated area of shallow water carbonate deposition ranging from subtidal to supratidal. The carbonate rocks were continuously deposited from the Upper Triassic to the Upper Cretaceous periods. The platform consisted of a very thick carbonate succesion with an average thickness of about 4000 m to 5000 m.

Later the Outer Dinarides underwent a small differentiation due to the formation of the Slovene trench, and the originally uniform area was dissected into two minor platforms, the Julian and Dinaric platforms (BUSER, 1989). The examined bauxites occur in the Dinaric platform sedimentary succesion.

In the Nanos region, tectonics played an important role in the formation of the Jurassic bauxites. Palaeotectonic dislocations had special significance due to the origin, evolution and distribution of various depressions, where later bauxite substances were deposited and then accumulated.

The tectonic movements in the area investigated were the results of the Alpine tectonic cycles. These movements did not have any particular influence on the tectonic structure of this part of Slovenia, but they did have a very strong influence on the sedimentation during that time.

In the study area we may conclude that no orogenic movements in the Jurassic period occurred since no folding can be found there, nor are there any traces of thrusting or nappe-tectonic movement, volcanism or metasomatic changes of sedimentary rocks.

There are nowhere any tectonic-discordant contacts Indeed, in all cases one may observe concordance, or at most only slight discordance. It the area investigated, no thicker coarse-grained basal transgressive formations can be found, so that we may be correct in affirming that the continuity of sedimentation had only been disturbed by periodical interruptions as a reflection of weaker or stronger epeirogenic movements of the carbonate platform. These movements periodically created land in the Jurassic and the rest of Mesozoic period. They also affected the differentiation of the environment and thus had a considerable influence on sedimentation.

On the Dinaric platform, the Malm emersion phase had a different character. It was generally relatively short, but at some places - allowing for shorter and longer interruptions - it lasted through the greater part of the Upper Malm because of the late Kimmerian movements. So, at those places there is no clear boundary between the Late Kimmerian and the Dinaric tectonic phase (DOZET, 1989).

6. DISCUSSION

One of the most interesting and the most unanswered questions concerning the Nanos bauxites, and of the karstic type of bauxites in general, is that of the source material as well as of the origin of bauxites.

The major question we studied relates to whether the Nanos bauxite deposits were derived from the limestone residue. According to the residual theory of bauxite origin, the solution of limestones left an argillaceous residue which was subsequently altered to bauxite as a result of intense tropical weathering. In attempting to evaluate this theory we studied the composition of the Nanos bauxites and host limestone formation.

It was concluded that the footwall limestones are the parent material of the bauxites. The residual theory is taken into account to explain the close association of Nanos bauxites with carbonate rocks. The clayey micritic limestone which forms the basal calcareous breccia with bauxitic groundmass is not so pure as reef and oolitic limestones, as it contains only 80 % of carbonate, and consequently more insoluble residue. The main objection to the residuum theory of origin of the Nanos bauxites is the high purity of the footwall limestone succesion (96 % of carbonate).

An attempt was made to evaluate the accessory heavy mineral composition of the bauxites and to determine their contents. In the bauxite samples examined by Saša Orehek, opaque grains are predominant. The X-ray analyses showed that the opaque grains belong to boehmite, gibbsite, goethite and kaolinite. Among the transparent grains there also appear rare grains of rutile, titanite, zircon, tourmaline, epidote, amphibole, chlorite and muscovite. Likewise in the light fraction, opaque grains predominate. At some places rare grains of quartz were found. The main characteristic of the examined samples of bauxites and the footwall limestones is that they contain few transparent mineral grains. On account of the poor spectrum of the heavy minerals it is very difficult to conclude more about their origin or about the origin of bauxites and their parent rocks.

Similar heavy minerals in bauxites and the footwall limestones suggest that the Nanos bauxites could be the product of the host limestones. However, along two vertical profiles in the Logatec locality, not far from Nanos, a strong enrichment of the mobile trace elements (Ba, Ni, Co, Cu, Zn, Y, La, Pb) is exhibited towards the footwall limestone, indicating that the bauxitization process took place in situ (MAKSIMOVIĆ & BUSER, 1986).

On the basis of the present data, and owing to the high purity of the footwall carbonate succesion it could be concluded that the Nanos bauxites had their origin not only in the insoluble residue of the underlying Jurassic carbonates, but that important role in their genesis played aeolian and alluvial materials.

By comparing the Jurassic bauxites of western Istria (ŠINKOVEC, 1974) and those from Nanos, certain similarities of genesis, as well as certain differences, become evident. It appears that the near reef, reef and back-reef facies, emersion, and the bauxites of Nanos and of western Istria are not isochronous. The reef deposition at Nanos is of Upper Oxfordian - Lower Kimmeridgian age (TURNŠEK, 1966), and in western Istria of Upper Kimmeridgian age. The Upper Malm emersion took place at Nanos at the end of the Lower Kimmeridgian, and in western Istria during the Lower Tithonian (POLŠAK, 1965). Since the bauxites compared contain more than 25 % of clay minerals they belong to clayey bauxites. The mineral and chemical composition of the Nanos and western Istrian bauxites are quite similar. The difference lies in the main iron mineral, which is goethite at Nanos and haematite in western Istria, and in rare cases, in the main aluminium mineral. Both bauxites are characterized by a very low content of accessory heavy minerals. Paleogeographic and tectonic conditions were nearly identical in both areas with a difference in the environment of deposition i.e. mainland for the western Istria bauxites and land and shallow coastal sea for the Nanos bauxites. A peculiarity of the western Istrian bauxites is the introduction of a swamp regime at the final stage of bauxite formation, as has also been established in the Hrušica area (BUSER & LUKACS, 1966), not far from the Nanos bauxite occurrences. Finally, correlation permitted the identification of the highly similar depositional environments of beds underlying and overlying the bauxites of Nanos and of western Istria.

7. CONCLUSION

With the exception of the Lower Kimmeridgian-Upper Kimmeridgian emersion phase, when the bauxite deposits were accumulated on dry land, the upper part of the bauxites were deposited in shallow water. The cross section at Železni Klanec shows the following chronology of geologic events:

1. The depositon of lagoon limestones,

2. The deposition of bioclastic peri-reefal facies limestones, hydrozoan and coral limestones facies and oolitic facies,

3. Regression, fault tectonics, physical, chemical and biological weathering of carbonate rocks, formation of insoluble residues and shallow palaeokarstic depressions and their filling with residual, aeolian and alluvial material, bauxitization,

4. Transgression and deposition of the upper part of the bauxite deposit,

5. Locally (Hrušica) brackish water sedimentation of "Characea" marly limestones,

6. Weak and short-lasting local regression. The formation of limestone breccia and conglomerate with calcite cement and bauxitic clay groundmass,

7. At other places, uninterrupted shallow-water sedimentation, i.e. the continuous transition of the shallow

water bauxite layers into shallow-water "Characea" and "Clypeina" limestones and dolomites respectively, into peritidal fenestral limestone and facies of early and late diagenetic dolomites.

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