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METALLOGENY OF THE LJUBIJA ORE REGION

Abstract

The Ljubija ore region is a part of the Triassic, regional, internal metallogenetic zone of the Middle Dinarides. It is located approximately in the middle of this larger metallogenetic unit and has many characteristics in common with its other parts. After many wanderings in the interpretation of the genesis of iron ore in Ljubija, it was definitely determined that the metallogeny of iron is of the Triassic age, then, that it is associated with the deep rift dislocations, which allowed the circulation of hydrothermal solutions originating from the Upper mantle, that the primary economic concentrations of iron are found only in the Olistostromic member of the Javorik flysch formation and the secondary ones, redeposited in the Neogene-Quaternary lake sediments of the Prijedor-Omarska basin. Based on the distribution of mineralization in the Ljubija ore region, two ore subregions, one polymetallic ore zone and a group of ore fields with barite, were identified. All the above knowledge, along with the analysis of control factors of mineralization and the main prospective indications, enabled the division of entire region into areas with various categories of perspectives according to the justification of further research. Based on the results of many years of research, this work presents the results of metallogenetic analysis of the Ljubija ore region. All results of the future research should continuously supplement, correct and improve the metallogenetic and prognostic map and our metallogenetic knowledge about the region.

Keywords*: Ljubija ore region, Javorik flysch formation, Olistostrome member, metallogenetic analysis, metallogenetic map, metallogenetic regionalization, control factors*

1 INTRODUCTION

The Ljubija ore region covers the whole ore - bearing territory at the area of 1500 km^2, which represents part of the Dinaride metallogenetic province (as a major meta-llogenetic unit) and that is characterized by the same geological conditions and development of certain ore formations and types of economic deposits of iron and other minerals [1]. The Ljubija ore region is defined by the boundary of Sana-Una River nappe at the South, boundary of the Jurassic-Cretaceous formations on the east, the inner ophiolitic zone of Kozara Mountain on the north and tectonically defined riverbed of the Una River on the west, deeply carved into the terrain (Figure 1 and 3).

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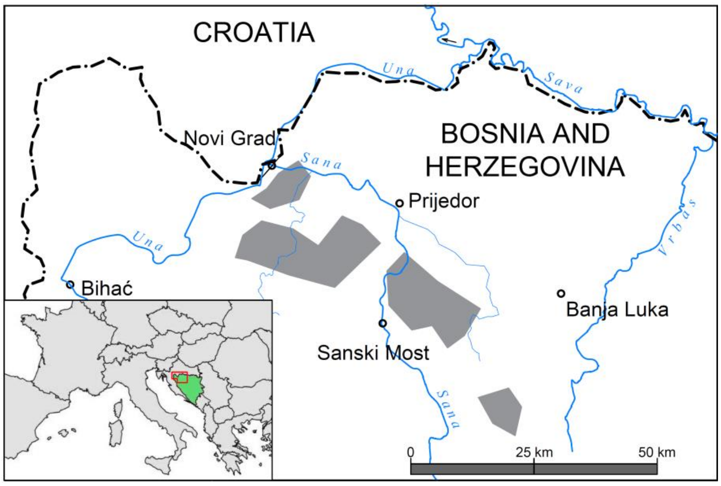

Figure 1. *Index maps with the location of the Ljubija ore mine. (a) Map od NW Bosnia and Herzegovina with marked areas od the Sana-Una Paleozoic complex (gray), (b) Geographic position of the area shown in Figure 1a; area of Bosnia and Herzegovna marked in green*

This work is the result of the Project of elaboration of Metallogenetic study of the Ljubija region. The Project was implemented in phases. In the first phase of the project implementation, the entire preparation for elaboration of the Metallogenetic Map of the Ljubija region was done. All existing data about exploration and mining works within the ore region were analyzed and based on that the Geological Background for Metallogenetic Map of the Ljubija Region M 1:50000 was developed. In the second phase, creation of the contracted maps started. Firstly, the mettalogenetic map was created, and then, based on that, the Perspective Projection Map of the Ljubija Region was developed in M 1: 50000.

2 LEVEL OF THE FIELD EXPLORATION

Generally, the level of exploration of the field is very good, according to the quantity of executed works and their diversity, but the density of exploration works is not equal. Their major concentration is usually in relation to the ore bodies and ore – bearing fields. Between them, the exploration works are reduced to minimum.

However, numerous explorations and analyzing the iron ore of the Ljubija region were carried out in different conditions and times, often uncompleted and nonsystematic, so the data about them are in most cases semi - usable. At the area of metallogenetic region, all in the total approximately 3500 drillholes were drilled. Most of them were "spent" in order to delineate the boundaries of known ore bodies and estimation of mineral resources/reserves because of the need for their distance to be less than 50 m and similar. There are about 600 regional drillholes. That implies that the information about high level of exploration of the field should be taken with reserve. The second problem is that the drill holes were limited upon exit from intersection with the ore body, because of unacquaintance with today's genetic model of ore forming.

The results of all exploration are registered in 300 different texts. Out of that, 130 are published papers, 170 are reports and elaborates of different volume. In 19 reports related to works executed 1987 to 1990, metallogenetic study has been given a special attention [2]. The three-volume study by M. Jurić on all phenomena of mineralization in the Sana Paleozoic is especially important [3].

3 STRATIGRAPHY

There are the following members of geologic column in the explored area: Carboniferous Javorik flysch formation, Formation of Perm - Triassic clastites, Terrigenous - Carbonate formation of Lower and Middle Triassic, Volcano - sedimentary formation, Triassic terrigenous and carbonate formation and Neogene – Quaternary formations [4] (Figure 3).

Javorik flysch formation

During earlier geological mapping, the Sana - Una Paleozoic was treated as a complex and unique whole in which no detailed dismembered is possible [3,5]. Recent geological works, however, have shown that such interpretation is not correct [6]. Carboniferous Javorik flysch formation is composed of three members, i.e., the Pre-flysch and Lower flysch, Olistostrome member and Upper flysch (Figure 2). All rocks of the Javorik Formation were epizonally metamorphosed maximum to the grade of greenschist facies.

The basal unit of the Javorik flysch formation is the Pre - flysch and Lower flysch member consisting of dark argillaceous schists with alternation of medium - grain sandstone [7]. It is well studied in the Adamuša opencast mine, in a core of large anticline structure. This member was probably formed in a deeper marine environment.

The Olistostrome member represents a middle part of the Javorik formation. Beneath it there is the Lower Flysch member which is exposed only in drill holes and, over it, there is the Upper Flysch member. It was formed under the deep marine conditions. This member is exposed in the middle parts of explored area and is built out of three types of rocks: flysch matrix, carbonate olistolithic blocks and mineralized bodies. The flysch matrix is made of two-member sequence of sandstones and black alevrolites with rare mechanoglyphs. Carbonate blocks are made of black micrites and grey organogenuous sparites and dolosparites. Within the Olistostrome member some authors distinguished more units, i.e. a Siderite – limonite member, and Wild – flysch and Middle flysch [6, 8]. Based on the fossils, it was concluded that the age of blocks is the Devon, Lower Devon or Middle Carboniferous age and whole member is of the Upper Carboniferous age [6]. This agrees with recent paleontological data according to which the carbonate blocks are of the Bashkirian age [7]. The mineralized bodies are siderite, ankerite, sideritic and ankeritic carbonates. Sometimes the entire olistolithic carbonate bodies were metasomatically replaced and some were only partially altered and then limonitized. Large stratiform mineralized bodies are specially notable, and their genesis was a subject of discussion for a long time. Thickness of this member is 100 to 300 m.

The Upper Flysch Member lies conformably over an Olistostrome member and unconformably below the Perm-Triassic Clastites Formation. It was formed under the deep marine conditions. Per superposition, it belongs to the Upper Carboniferous. It is built of the sandstone-siltstone two-member and three-member sequences with occurrences of gradation, parallel lamination and convolution [6]. There are the sporadic thinner siderite and limonite veins. Their thickness is up to 400 m.

Perm - Triassic Clastites Formation

This formation lies over the Javorik Formation unconformably and transgressively. It was developed and, because of erosion, kept only sporadically. It was formed in the continental, lagoon and sublittoral environments. Its age is supposed on the basis of superposition. This formation is built of different rocks: white and red quartz sandstones, conglomerates and shales [3]. The red rocks prevail. Sporadically, there are the cavernous dolomite and siderite veins up to 40 cm. Thickness of the formation is 150 m.

Terrigenous - Carbonate Formation of the Lower and Middle Triassic

This formation lies transgressively and unconformably over various Carboniferous and Perm - Triassic units. It is developed up to periphery of the researched area. Generally, it is compounded out of two parts. Its age is confidently proven on the basis of fossils. Lower part belongs to the Werfen and is composed of an alternation of sandstones, shales, marlstones and some limestone. Sporadically, there are the limonite veins. Thickness of this part of formation is up to 300 m. The Upper part of formation started to form in the Upper Campilian and takes hold of the Anisian. It is built out of the bedded limestone and dolomites. Numerous occurrences of limonite, lead sulphides, zinc and mercury, then barite and fluorite were registered. Its thickness is 300 to 400 m.

Volcano - Sedimentary Formation

This formation is conformable over the previous rock formation and its roof was destroyed by erosion. It is best developed in a wider area of the Volar. It is actually well known the Dinaridic porphyrite-chert formation of the Ladinian age. It was built mostly of cherts and volcanogenic materials. Volcanic rocks are represented with elements of spilite-keratophyric association in it. In addition, it also has marlstones and micritic limestones with cherts. The thickness of the formation, due to the lack of roof, is found only in a part and is approximately 500 m. This formation is of a great metallogenic importance because in the whole Dinarides polymetallic mineralization (with local mineralization specialization) they are associated with it.

Triassic Terrigenous and Carbonate Formations

It was developed on the eastern periphery of the explored field and only a small part is shown on a map. It was built in the lower part of the terrigenous sediments, which probably belong to the Werfen. Then, in a column, there is a thick series of well bedded dolomite. Its age is determined super positionally. The thickness is about 1400 m.

Neogene - Quaternary Lake Sediments

These young sediments have been developed only in the Prijedor basin on the north and Kamengrad basin on the south. In particular, stand out poorly rounded fragments originating from neighboring Paleozoic formations. There are significant quantities of redeposited iron ore, which are largely exploited. Clastic material filled large pre - Neogene relief indentations in which the sediment thickness reaches up to 200 m [9].

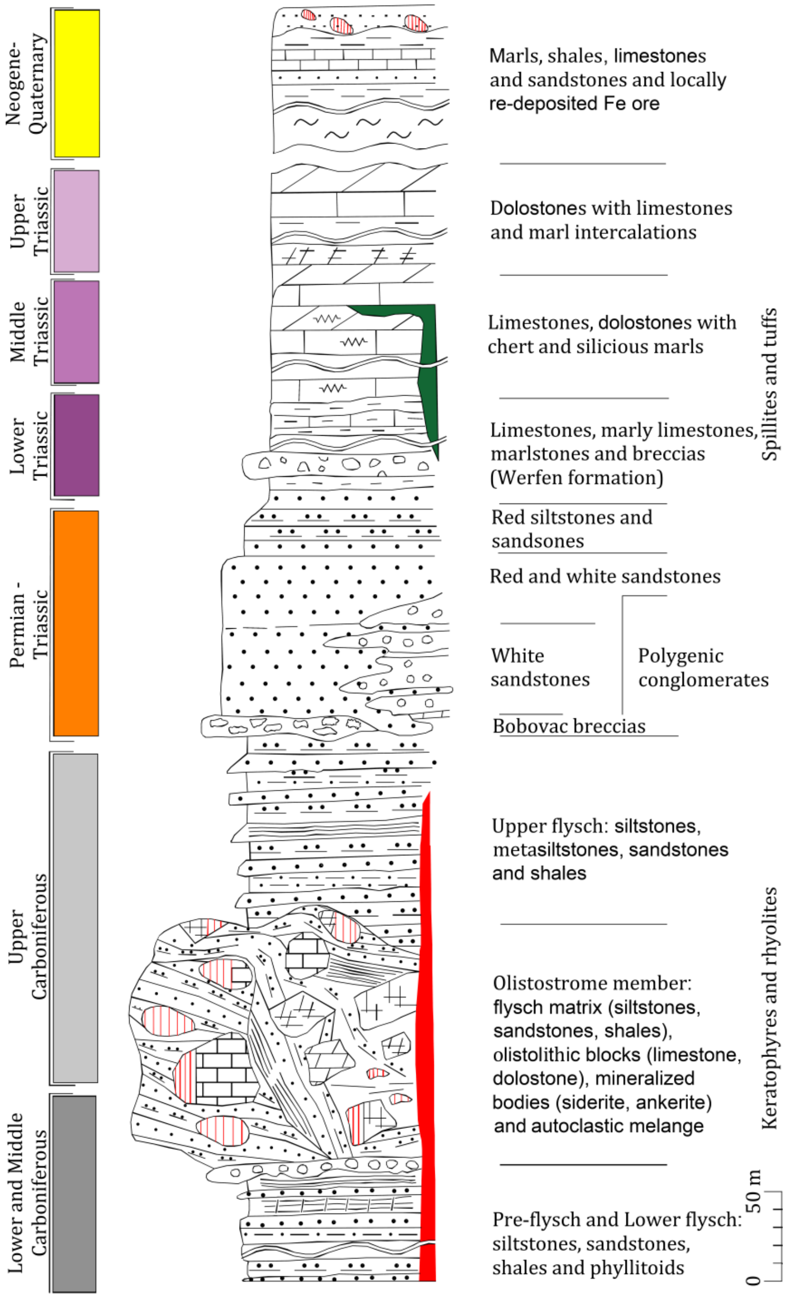

Figure 2 *Schematic lithostratigraphic column of the Ljubija ore region[7]*

3.1. Stratgraphic and Lithological Control Factors

In the geologic column of the Ljubija ore region, there are two ore - bearing formations: Javorik formation with their olistostrome members and Neogene - Quaternary formation in the Prijedor basin. The first contains primary siderite and ankerite ore bodies partly oxidized into limonite; in the second, there are only redeposited limonite [10]. Iron ore occurrences are also found in the other formations, but these are veins that have no significance for economic exploitation.

Regarding to lithology, the iron ore is associated with carbonate olistolithic blocks. Siderite and limonite are associated with limestone and, in dolomites, there are ankerite and limonite. Whole olistoliths or a portion could be replaced by the iron ore. Stratiform morphology of deposits are derived from the lensoid carbonate bodies, what were the confusing facts for hypothesis of iron ore genesis in this region.

4 MAGMATISM

Magmatic rocks have no wide distribution in the field. They occure in the wider area of Volar, in the north, and at Trnava, in the south. They are separately shown on the map although they are actually part of Triassic ie. Ladinian Volcano - sedimentary formation.

There are indentified: spilite, diabase, keratophyres and rhyolite - volcanic members that make Porphyrite - chert formation. Based on the analysis of their isotopic age (114 million years), the rocks are Cretaceous, which is not in accordance with the geological facts from the field. Therefore, it is assumed that this terrain in the middle of the Cretaceous was exposed to temperatures above 350^0C for a long time and that complete homogenization was achieved, ie "ideal rejuvenation" [11]. Magmatism in this zone of the Dinarides, based on the isotopic age of the rocks, took place from the Upper Permian to the Upper Triassic, but was still the strongest during the Ladinnian [12]. In Dinarides this Formation is an important magmatic control factor for polymetallic mineralization with specialization on mercury, iron, lead - zinc and manganese.

5. TECTONICS

Tectonics of studied terrain is very complex because it is the result of Hercynian, Kimmerian and Alpine deformation phases. Hercynian events have left their mark only on the Javorik formation as folds whose B - axis have azimuth from 10 to 40 ^{0} [6,13]. This dissipation of the B - axis is due to the Alpine folds, that is clearly identified by the Schmidt net of bedding with triclinic symmetry [6].

Of Kimmerian age is Sana dislocation, which was created during rifting in peripheral areas of the Apulia. As per its direction NW - SE Sana dislocation belongs to the south - west, supporting faults of rifting and opening of Dinaric ophiolitic belt. It cut through the entire lithosphere to mantle and were accompanied by ruptures of the lateral systems. It left her mark on the Javorik as well as younger formations. Through subsequent events it significantly influenced the change of Hercynian structural plan in Alpine terrain.

In Alpine tectogenesis were created fold structures with B - axis direction NW - SE (130 -140 degrees) and the corresponding longitudinal, transverse and diagonal ruptures. Sana dislocation was by the reverse transport turned into a nappe. Hercynian and Kimmerian structures are pre – ore - bearing structures and Alpine are post – ore – bearing.

5.1. Tectonic control factor

At the end of the Permian and in the Lower Triassic Sana dislocation cut the lithosphere to the mantle and became the supply channel for magmatism and circulation of hydrothermal fluids. So, it was a decisive impact on the orientation of Ljubija ore region, in a NW - SE direction, as a part of discontinued Triassic "metallogenetic zone of Central Dinarides"

Associated ruptures of the lateral systems at the studied terrain have predominantly NE - SW direction. They are well expressed in the field and in the metallogeny they had the role of distribution channels, which were significant for the circulation of hydrothermal fluids and today's distribution of ore deposits and mineral occurrences in the form of ore knots and ore fields.

This Cimmerian regional mega - framework made his mark in the meters field of view. In Adamuša and Southern Tomašica paleo splits of decimetere in size, filled with siderite and siderite with quartz, has exactly the same orientation. Their two conjugated systems that extends in NW - SE and NE - SW direction are also recorded. Alpine fault and split systems opened the pathways for descending meteoric waters that were rich with oxygen and over time gradually oxidized siderite and ankerite.

6 METALLOGENY

The first scientific researcher of the iron ore in the Ljubija ore region, F. Katzer, was of opinion that the iron ore was mostly of the hydrothermal - metasomatic origin and there was a possibility that some occurrence was of synsedimentary origin [5]. After him, all the authors supported the hydrothermal - metasomatic genesis. In the early sixties, M. Jurković suggested that all iron ore in this region were exclusively of synsedimentary origin [14]. He presented a variety of evidence for it. After him, such opinion on genesis were also shared by the authors of two doctoral dissertations, M. Jurić and M. Šarac [15].

During the nineties, after detailed studies of Adamusa and Southern Tomasica, A. Grubic and Lj. Protic assumed that there are two metallogenies in the region. The older one, the Carboniferous hydrothermal - sedimentary, sideritic, and the younger one, Triassic hydrothermal - metasomatic, ankeritic and polymetallic accompanied with sulphides [5].

It was not possible to do more with field, sedimentology, petrographic and ore-microscopic methods. For more reliable judgment, there had to be done very detailed and complex geochemical analysis and interpretation. That was done, at the end of the first decade of this century, by the Croatian geochemists for their own needs.

S. Strmic - Palinkas and others analyzed in the Swiss laboratories, sixty samples from the Adamusa, Southern Tomasica and other mines on: common elements, rare elements, isotopes of oxygen, sulphur and carbon, and hydrocarbons. All results and, in particular, the content of rare elements shown the hydrothermal metasomatic genesis of iron. In this regard, particularly indicative are the cerium (Ce) negative and europium (Eu) positive anomalies, which indicate that the ore could not be of the sedimentary origin [16]. These results were confirmed by V. Garasic and I. Jurkovic, but they left the question on genesis of threstratiform deposits opened [8].

After the first phase of this study, it was concluded that the first and main task in the next work was to check the geochemical characteristics of real (based on other geological features) stratiform siderite ore bodies. At the very beginning of work on the second phase of the study, samples were collected from the Adamusa and South Mines. The spectrochemical analysis of samples of the representative, verified stratiform body in Adamusa, showed an identical composition of rare elements that every hydrothermal - metasomatic deposits have. This was crucial evidence on the basis of which was completely abandoned working hypothesis about consedimentary and sedimentary, marine, Carboniferous origin of siderite and ankerite.

In the Ljubija ore region, there are the primary carbonate iron ore (siderite and ankerite) and the secondary oxidized (limonites). The limonite ore was formed from the first by long - term oxidation under hypergenetic conditions to depths of about 300 m. Apart from the iron ore, there are sulphides Pb, Zn, Cu, Hg, Ag and Au then, fluorite and considerable amount of barite in the region. It is a unique "siderite - polysulphide – barite ore formations", which consists of three sub-formations: a) siderite - ankeritic, partly limonitised; b) polysulfide and c) barite-fluoritic. Based on the mutual relations of members of mentioned sub-formations in the field, they should be formed in the following phases. In the first phase, siderite and ankerite were formed by the hydrothermal metasomatism of carbonate olistolithic blocks at moderate depths and at temperatures around 246 ^{o}C. In the second phase, sulphides in the form of veins were generated in almost all parts of geologic column. As it seems, in parallel with them, siderite veins were created too (at temperatures around 186 ^{o}C). Finally, in the third phase, barite was created in several places in the region in all formations except in the Neogene formations [16]. These were the fundamental data on the basis of which the Metallogenetic map of Ljubija Ore Region 1: 50.000 was made.

7 METALLOGENETIC REGIONALISATION AND CLASSIFICATION THE PERSPECTIVE AREAS OF THE LJUBIJA REGION

The all iron deposits are genetically related and close in age and have been developed in the framework of distribution the major, medium and minor deposits, and a large number of ore occurrences and widespread mineralization. Metallogenetic regionalization of the Ljubija area was carried outd. Smaller ore-bearing areas with the identified ore and mineralization, and favorable geological conditions for finding the other ones have been isolated and contoured. Smaller metallogenetic units are characterized not just by the individual geological position in the main structures of the Ljubija ore region and separation by smaller or bigger areas without ore, but also by different conditions of localization their ore formations and mineralization, and their affiliation to different ore formations. Smaller metallogenetic units within the Ljubija ore region are the ore zone, ore knot and ore field (Figure 3).

A prognostic map represents ranging of areas in the present level of exploration. Before current map, two - three accurate maps, similar to these maps of this area, were published. One of them was made by M. Šarac where the iron occurrences and deposits were plotted inside by his opinion, the overall ore - bearing Carboniferous rock layers of Sana - Una Paleozoic. According to this author, those are the prospective surfaces, and non-prospective would be all peripheral areas which are built of other stratigraphic units [5].

The different areas are marked on the Prognostic map of this study, according to the prospectivity, taking into account the quantitative (appearance and size of the ore bodies, excavated mass, potential resources...) and qualitative indicators (primarily chemical composition of the ore), followed by the control factors (stratigraphic, lithological, structural) and indications of mineralization (ore outcrops, alteration around the ore, indicator elements). In general, there are three major categories on the map as follows: prospective areas where exploration is justified with four groups of fields from the first instance fields to the insufficiently explored, followed by the are as where the additional exploration is not required at the present moment with two groups of fields and third non-prospective areas out of the ore zones and nodes. Isolated surface areas, most commonly, represent the geological units or units by the exploration level. They can be reclassified into the units of different prospectivity then they are at this stage of knowledge.

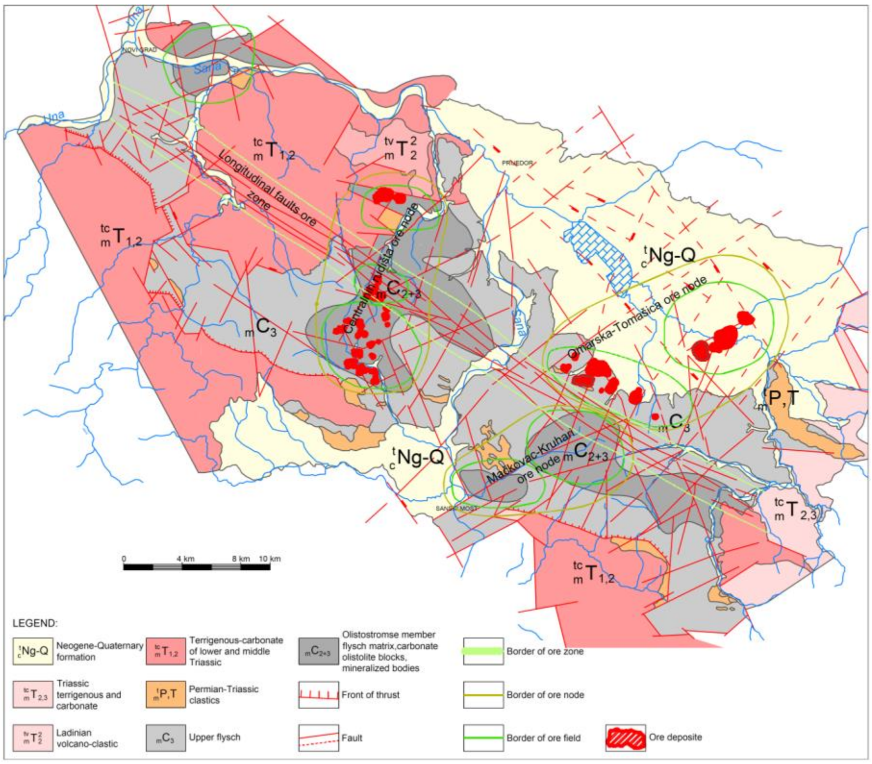

Figure 3 *Formation - geological map of the Ljubija ore region [4]*

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