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ALTERATIONS IN THE BOR COPPER DEPOSIT AND THEIR SIGNIFICANCE FOR EXPLANATION OF THE ORE GENESIS

(Tabs. 3)

A b s t r a c t: In the area of the Bor copper deposit (East Serbia) existed during the first volcanic phase of the Timok igneous complex a large volcanic complex with the main vent in the vicinity of Bor.

This volcanic complex was not a regular stratovolcanic cone, but rather a deformed (by internal faulting and blocksubsidence) and composed (because of development of parasitic cones or vents) one. In late phases of volcanic activity andesite and quartzdiorite porphyry dikes intruded into deep levels of the volcano. In the same period hydrothermal solutions ascended, altering and mineralizing the volcanic rocks.

In the zone of the main vent or in the zone of the most important ascent of hydrotherms (the Tilva Roš column) zoned alteration originated. Later on during cooling of the whole complex the first high-temperature mineral associations were replaced by lower-temperature parageneses.

The hydrotherms which migrated laterally from the main vent or along parasitic chanale were mixed with descending waters and became sulphatic, very acid and mineral associations rich in sulphates originated. In such cases the horizontal zonality of alterations is well developed, but it is vertically leas expressed or even absent.

In some small lateral craters the rocks were alterated in a peculiar manner (near surface) and Cu-ores of a corresponding character were formed (i. e. ore body "H").

The origin of mineralization and related wall rock alterations are possible to explain only if these processes are connected with a long living big volcanic complex, intensively fractured and reactivated, which extended also laterally and vertically (to the extent of more than one kilometer) facies.

Р е з ю м е: В районе медного месторождения Бор (Восточная Сербия) за время первой вулканической фазы Тимочкой магматической области образован обширный вулканический комплекс с главными центрами в непосредственной близости Бора.

Этот вулканический комплекс не относится к нормальному стратовулканскому типу, а деформирован (внутренние разломы, опускания блоков) и усложнен паразитическими кратерами и каналами.

За время поздней фазы вулканической активности андезиты и дайки кварцдиоритпорфира внедрены в более глубокие горизонты вулкана. Состав гидротермальных восходящих растворов изменился в это время. Эти растворы минерализовали вулканические породы.

В зоне главных подводных каналов или в зоне самого активного действия гидротермальных растворов (Тильва Рош) появляются зональные вторичные изменения (альтерация). Позднее за время охлаждения целого комплекса первоначальная высокотемпературная ассоциация минералов заменена низкотемпературным парагенезисом.

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Латерально к направлению основных подводных или паразитических каналов гидротермы мешались с нисходящими водами и становились сульфатными. Так образовывались очень кислые минеральные ассоциации, богатые сульфатами. В таких случаях горизонтальная зональность вторичных изменений очень ярко проявляется, в то время как вертикальная зональность менее выражена или отсутствует.

В некоторых малых латеральных кратерах породы изменены особым образом (вблизи поверхности) и образованы медные руды, отличающиеся специфическими особенностями (например Рудное тело X).

Происхождение минерализации и соответствующие околорудные изменения можно объяснить только тем, что эти процессы связаны с длительным периодом существования огромного вулканического комплекса с интенсивными разломами и несколькими фазами гидротермальной активности. Таким образом формировались латеральные и вертикальные фации, распространенные на протяжении свыше 1 километра.

Introduction

Systematic and detailed investigations performed during the last years in the Bor copper deposit and its surroundings gave new data on the mode of ore occurrence and alterations of rocks, and enabled a new explanation of the origin of this ore deposit.

Long time ago Lazarević (1912) wrote that this ore deposit originated in a relatively shallow level. Cissarz (1956) was of a similar oppinion. When intrusive and dyke rocks were found in the neighbourhood of Krivelj (NW of Bor) the origin of the mineralisation in Bor was related to intrusive, or more preciously to shallow-intrusive rocks (Drovenik, 1961, 1968). The study of wall rock alterations in the Timok eruptive area has shown that there are two types of alterations, and that these related to the Majdanpek type mineralisations (which are related to shallow intrusions), and these related to Bor type mineralisations clearly differ (Karamata — Milenković, 1967, 1969). Mihajlović — Vlajić (1967, 1969) studied the rock alterations in the Bor mine, and concluded that this ore deposit originated in a volcanic complex near to the surface. Explorations performed during last years gave new evidence for a volcanogenic origin of mineralisations in the Bor area (Janković et al., 1980 a; Janković et al., 1980 b; Grujičić — Miličić, 1980).

During the last five years the rock alterations, their distribution and zonality in the Bor area have been studied systematically, especially because of their importance, as one of the criteria, for the explanation of the genesis of mineralisations. The investigations were concentrated to the open pit and the mine at Bor, the Borská reka area, and arround the ore body "H". In the Bor mine and the open pit the mineralisations are various, but it is possible to follow the vertical and horizontal distribution of alterations. The mineralisation at Borska reka is more uniform and it is possible to study in the drilling cores cutting it the alterations related to such a deeper seated mineralisation. Finally the alterations arround the ore body "H" exhibit many peculiarities, indicating a very shallow level of ore deposition.

Three types of wall rock alterations have been distinguished:

1. The principal alteration at the northern side of the Tilva Roš ore body

is silicification associated with sericitisation, grading by more intensive alteration and depth to the occurrence of diaspore, and finally of zunyite, andalusite, and corundum.

2. The ore bodies "I", "A", "B", and "Tilva Ronton" in the Bor mine are surrounded by a halo of silicified, sericitised and alunitised rocks. The same alterations occur associated with the Borska reka mineralisation.

3. The ore body "H" has an aureole of silicified and sericitised rocks, and further on of chloritised and calcitised ones. Characteristic are here breccious structures.

Kaolinite occurs together with other minerals, more abundatly in stronger altered zones. Anhydrite and gypsum are present almost everywhere, even at depths of few hundreds meters, but always as late phases.

The description of main features of each type of wall rock alterations follows in further text.

The alterations at the northern side of the Tilva Roš ore body

The wall rock alterations at the northern and northwestern side of the Tilva Roš ore body can be followed laterally only 200—250 meters, but their vertical distribution was studied for more than 200 meters, and if the original peak of Tilva Roš is considered the vertical column is about 500 m. The alterations are shown in the Table 1.

The full sequence of alterations at middle levels (open pit, + 134 m) is from weakly altered andesites with preserved biotite to intensively silicified rocks with sulphide impregnations. Very instructive is the succession of alterations from top to the deepest levels in the central part of the altered column:

— (+ 450 m) top of Tilva Roš (now removed), the characteristic mineral association was: quartz — sericite — kaolinite (the association was partly altered and leached by supergene solutions, but a reinterpretation of composition was possible):

— (+ 134 m) the main level of studies in the open pit, the characteristic mineral association is: quartz — sericite — diaspore — kaolinite +/— pyrophyllite in the very centrum:

— (— 78 m) the deepest studied level in the mine, the characteristic mineral association is: quartz — diaspore — andalusite — corundum (only in the centre of the column).

The type of alterations changes with depth: associations of higher temperatures occur, and the leaching of all compounds, except silica (alumina remains only as corundum) becomes more intensive.

It may be concluded that alterations were induced by high-temperature, acid, very active solutions, which cooled slowly by ascend. This points that here was one off the main vents along which the hydrotherms rose without reactions with descending waters.

After these alterations, because of the cooling of the area and changes in the character of hydrotherms corundum, andalusite and diaspore were altered to sericite and kaolinite, and alunite, followed much later by anhydrite and gypsum origin.

Table 1

Alterations at the northern side of the Tilva Roš ore body

Level	Approaching to the ore body ——————>				
Open pit (+ 134 m)	Chlorite-montmorillonite-sericite-biotite	Chlorite-montmorillonite-sericite	Quartz-sericite-kaolinite	Quartz-diaspore-sericite +/— pyrophyllite	Ore body
Mine (+ 46 m)	Chlorite-quartz-montmorillonite-kaolinite	Quartz-montmorillonite (sericite)	Quartz-kaolinite	Quartz pyrophyllite — kaolinite +/— alunite	Ore body
Mine (— 18 m)	Quartz — diaspore +/— alunite +/— zunyite +/— pyrophyllite +/— kaolinite				Ore body
Mine (— 78 m)	Quartz-diaspore +/— pyrophyllite +/— alunite +/— kaolinite	Quartz-diaspore sericite-kaolinite +/— pyrophyllite	Quartz-andalusite-diaspore +/— corundum	Quartz-diaspore-andalusite-corundum	Ore body

The distances at different levels are not comparable.

The alterations in Tilva Mika and arround analogous ore bodies

The alterations occuring arround the ore bodies "I", "A" and "B" in Tilva Mika, the ore body "Tilva Ronton", and in the boreholes B—2, B—5 and B—6 at Borska reka have been studied laterally (horizontally) in the open pit, and vertically in the open pit and in the mine, as well as in the boreholes. The alterations are presented in the Table 2.

The alterations show many similarities with the first described group, but there are two clear differences:

— alunite is always present in more intensively altered parts near to the ore bodies, and

— the high-temperature mineral associations are absent even in the deepest and most intensively altered parts.

The alterations in the Borska reka area exhibit some peculiarities, and approach in some aspects to the alterations of the Tilva Roš type. In this area diaspore occurs instead or along with alunite, but oppositely to the Tilva Roš alterations even after passing more than 500 meters through strongly altered rocks high-temperature mineral associations were not found. In these depths sometimes the chlorite contents increases only.

The alterations of this group are very intensive, they were induced by acid, sulphuric acid containing solutions. Characteristic is that the zonality of alterations is here much better expressed laterally then with depth.

The alterations arround the ore body "H"

The alterations around the ore body "H" are restricted to its close neighbourhood. The ore body is surrounded by a zone of very intensive silicification and sericitisation, but after a few meters the andesitic rocks are only weakly altered (chloritised, calcitised, weakly sericitised), even the biotite is preserved.

In the ore, as well as in the surrounding rocks a breccious structure is visible: unrounded fragments of intensively altered rocks occur in the ore or in the weakly altered material.

The alterations were performed here by the influence of very active solutions, but in a very limited space, contemporaneously with breaking and redeposition of mineral. These alterations occured at or very near to the surface.

Discussion of results and conclusion

Considering all the afore mentioned results and the existing data on the geology and ore deposits in the Bor area it is possible to propose the following succession of events.

In this area existed during the first phase of the volcanic activity in the Timok eruptive area a large volcanic complex with (according to the present knowledge) the centre in the neighbourhood of Bor. This volcanic complex is now exposed only as a NNW-SSE streaking zone: its northeastern part is downthrown along the Bor fault (where the Bor conglomerates occur), and at the southwest the rocks of the volcanic complex are covered by younger volcanics of the first volcanic phase an by psammitic and pelitic rocks (later only slightly laumontitised and calcitised). Inbetween the Bor conglomerates and the

Table 2

Alterations arround ore bodies at Tilva Mika and analogous ore bodies

1. Alterations arround the ore bodies at Tilva Mika "Tilva Ronton"

Level Open pit	Approaching to the ore body ——————>				
	Chlorite-montmorillonite-sericite-biotite	Chlorite-montmorillonite sericite	(Quartz-sericite-kaolinite)	Quartz-alunite-sericite-kaolinite	Ore body
Mine (+ 46 m)	Chlorite-quartz-montmorillonite-ilite-kaolinite		Quartz-montmorillonite-ilite (sericite)	Quartz-kaolinite	Ore body
Mine (— 78 m)			Quartz-alunite-kaolinite-sericite		Ore body

2. Alterations in the boreholes at Borska reka

Thickness of the zone and mineral association	B — 2	B — 5	B — 6
	Laumontitised and chloritised +/— calcitised andesites and andesitic pyroclastics		
	Fault at about 500 m depth About 400 m: quartz — sericite + — alunite-pirite etc.	Fault (?) at about 350 m depth About 200 m: quartz —sericite +/— calcite +/— chlorite-pyrite etc.	Fault (?) at about 400 m depth About 100 m: quartz — sericite — calcite-pyrite etc.
	More than 150 m: quartz — sericite — pyrite etc. The borehole stopped at about 1050 m	More than 400 m: quartz — sericite chlorite — pyrite etc. The borehole stopped at about 1000 m	About 100 m: quartz — sericite — diaspore — pyrite etc. About 250 m: quartz — sericite — pyrite etc. Fault at about 860 m depth Laumontitised andesites and andesitic pyroclastics

The distances at different levels in part (1) are not comparable, the correlation od depts in part (2) is approximative.

Table 3

Alterations around the ore body "H"

Approaching to the ore body ——————————>		
Chlorite — calcite Sericite — biotite	Quartz — sericite sulphides	Quartz + — sericite — ore (ore body)

slightly altered andesitic, psammitic and pelitic rocks is exposed only a elongated slice of the ancient volcanic complex, with its centre, or a part of it.

It is necessary to stress that this large volcanic complex should not be considered as a regular stratovolcanic cone, it was, as it is almost always the case in the nature, a volcanic complex deformed by faulting, subsidence of blocks, occurrence of parasitic cones and vents, volcanic explosions etc. Even when the volcanic activity began to clam, new small magma masses were intruded into andesites and pyroclastics, and andesite, andesiteporphyry and quartz diorite-porphyry dykes originated. Simultaneously new portions of hydrothermal solutions rose and altered the previously formed and more or less cooled volcanic rocks. The process of the growing as well as of calming of the volcano was a long lasting process with pulsations: intrusions or effusion of new magma /lava masses, ascend of hydrotherms and delivering of emanations.

In the middle of the exposed slice of the volcanic complex is the Tilva Roš, which represents one of the main volcanic channels, where the hydrotherms most easily ascended. Therefore in this zone, or in the zone of the main volcanic channel the vertical zonality of alterations is best developed, and the early sulphates (i. e. alunite) are scarce. Later on because of cooling of the whole volcanic system, and therefore of the hydrothermal too, the primary high-temperature mineral associations were replaced by younger associations stable at lower temperatures. In such parts of the volcanic complex massive to disseminated mineralisations may originate.

The hydrotherms ascending laterally from the main channel, as well as the hydrotherms ascending along smaller or less important fissures mixed probably with supergene waters, become sulphatic (slightly oxidised), very acid, and along with middle temperature alterations (silicification + sericitisation +/— diasporisation) deposited was alunite. The mainly lateral migration and slow ascend of solutions was the reason that lateral zonality is better expressed than the vertical one, and that the leaching in the deep parts is not extreme. In and arround some smaller volcanic vents, especially if closed, the alterations will be similar to the afore mentioned. In these cases stockwork — disseminated mineralisations may originate.

In small parasitic craters a special rock alteration/deposition of the ore, contemporaneous with breaking and redeposition of material occur, i. e. the deposits of the ore body "H" type originate.

The origin of ore deposits in the Bor area may be explained only if they are related to long lasting processes occuring in a large volcanic complex with different developments in the central and in the lateral parts along a depth interval from some tens of meters to more than one kilometer (for central parts

with roots). Finally, except the faulting and breaking associated with the volcanic activity, the different properties of rocks (especially of the argillitised zones) enable during the volcanic activity and later on by tectonic processes very irregular fragmentation and displacement of blocks, what masks or even destoys the primary relationships in the volcanic complex.

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