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Geochemical haloes of gold in the Lece ore field (southern Serbia)

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Abstract. In the area of the Lece base–metal ore field in the SE part of the Radana Tertiary volcanic complex, prospecting researches, lasting several years, was done during the last decade of the last century. In the paper some results are presented and analyzed, especially those concerning the distribution of gold relative to trace elements in the secondary lithogeochemical dispersion haloes. In the assemblage of 8 analyzed trace elements of the Lece lithogeochemical field, Au, Pb, Zn, Ag and Sb show expressive, contrasting and mutually well correlated secondary dispersion haloes. The presented results of geochemical prospecting are considered not to be clearly indicative for epithermal gold mineralization in the polymetallic ore field Lece.

Keywords: gold mineralization, secondary geochemical haloes of gold in soil, southern Serbia, ore field Lece.

Апстракт. У циљу проучавања и проналажења потенцијалних епитермалних минерализација и орудњења злата, у домену југоисточног дела терцијарног вулканогеног комплеса Радана, у ареалу полиметаличног рудног поља Леце, извршена вишегодишња проспекцијска испитивања током последње деценије прошлог века. У раду се приказују и анализирају неки резултати посебно они који се тичу расподеле злата и његовог односа према пратећим микроелементима у секундарним литогеохемијским ореолима расејавања. У скупу од 8 анализираних микроелемената литогеохемијског поља Леце, изражајне, контрасне и међусобно добро корелисане секударне геохемијске ореоле расејавања имају Au, Pb, Zn и Sb. Презентирани резултати мултиелементне геохемијске проспекције не дају јасна уверавања о постојању епитермалног типа орудњења злата у склопу испитиваног дела терцијарног андезитског комплекса Лецке вулканске калдере.

Кључне речи: минерализације злата, секундарни литогеохемијски ореоли злата, Јужна Србија, рудно поље Леце.

Introduction

During the nineties of the twentieth century, geological studies were undertaken in Serbia, aimed at discovering areas bearing primary gold deposits, especially epithermal ones, which in both the past and present have represented the leading geological-economical type. Segments of the Lece volcanic complex, including the tract of land in Serbia, harmonized with previous predictions, based, first of all, on the works of Janković *et al.* (1992a, 1992b), are thus classified as the most important priorities. The initial steps in the search of these deposits was concentrated in the area covered by the Lece base-metal ore field, where during a durable period of time, from 1992 to 1998, field work was performed. The aim of these studies, both through the amounts of ore, related to geochemical prospecting for gold mineralization and indicative trace elements, was to delineate a closer tract of land for further investigations. The project of these investigations was realized by "Geozavod–IMS", Belgrade, whereas the author of this paper interpreted the analytical data of lithogeochemical prospecting, based on both secondary and primary dispersion haloes. A part of the obtained information is presented in this paper.

General Geological Data

The Lece magmatic complex is the most individual and the most completed volcanic and geological product of the Tertiary intermediate magmatic activity in the

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Serbo–Macedonian metallogenic province. The mass occupies an area of more than 700 km^2, located on the line traced by the sub-meridional abyssal fractures, separating the central Vardar subzone from the Serbo–Macedonian mass (delineated by the Propolac–Medveda and Tupala dislocation in southern Serbia; see Fig. 1). The mass is essentially built up of products of complex extrusive-explosive volcanic activity, andesitic in composition, being later affected by endogen hydrothermal alterations, especially in the domain of volcanic centers and linear structures unfilled with hydrothermal breccias. These influences resulted in definite base-metal mineralizing activity, particularly in individual volcanic centers, located in the linear rupture structures. The Lece ore field is the most important environment, not only for zinc and lead mineralization but also as a potential for the discovery the gold epithermal deposits. The metallogenic-geological specifics of the Lece ore field derive from its structural-geological setting, evidently favorable for mineralizing activity. It is characterized by numerous smaller magmatic centers of both volcanic and post-volcanic hydrothermal activity, developed along favorable volcanic-tectonic and tectonic rupture systems. The mentioned processes resulted in the creation of a complex, very remarkable, several kilometers long zone of silicification (PEŠUT, 1976), known as the "quartzose-brecciated Suta–Resovaca zone" – hydrothermal breccias, as the chief bearer of a low-temperature base-metal ore complex, including also deposits with augmented gold concentrations in the domain of the Majdan–Lece mines (Fig. 2). In addition, previous studies and analyses of the composition and setting of the hydrothermally altered volcanites and volcanic clastites in the Lece ore field, indicated the terrains with effects of both low and high sulfidization-alunitization and silicification (KARAMATA, 1970; STAJEVIĆ, 2002). The central part of the Lece ore field was covered by geochemical prospecting, evidently exhibiting these indications for the discovery of gold epithermal mineralization in all similar volcanic complexes.

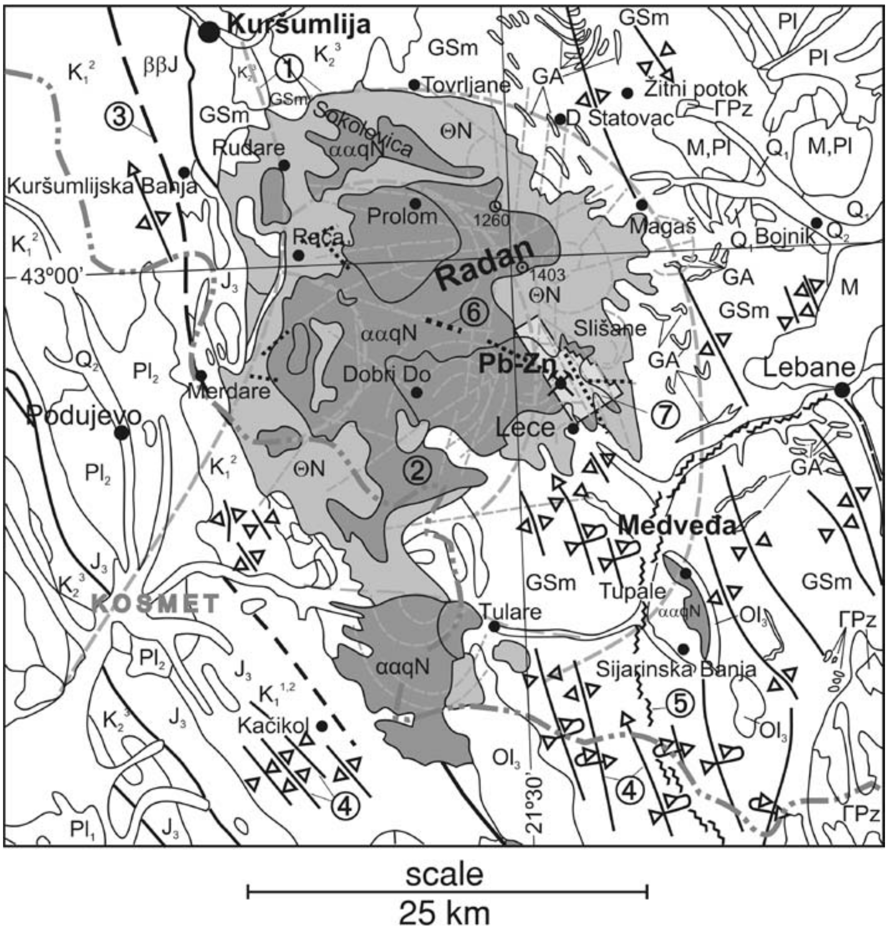

Fig. 1. Overview geological map of the volcanogenic complex Lece, southern Serbia (Geological Map of SFR Yugoslavia 1:500 000, Federal Geological Institute, Belgrade, 1970; upgrade). Legend: $Q_{1,2}$ = unconsolidated sediments, Pleistocene–Holocene age; Pl = clastites and limestones of Pliocene in general; Pl_2 = clays, sands and graves, middle Pliocene ages; MPl = clastites, limestones and coal of Miocene–Pliocene; Ol_3 = clastites of upper Oligocene; $\alpha\alpha\theta N$ = andesite–dacites Neogene age; θN = pyroclastites of Neogene; K_2^3 = flysch Senonian age; $K_1^{3,4}$ = flysh Baremian-Aptian; $\beta\beta J$ = diabases and spyllites of Jurassic; GSm = gneisses, leptinolites and mica schist of Proterozic; G = gneisses of Proterozic; GA = gneisses with amphibolites of Proterozoic age; G = granitoides of indeterminate age. Structural marks: 1 and 2 = volcano-tectonic elements upper and lower range (after SERAFIMOVSKI, 1993; STAJEVIĆ, 2002); 3 = tectonic faults; 4 = tectonic folds; 5 = tectonic faults zones; 6 = quarz–breccia zones; 7 = area of geochemical prospecting for Au.

The geochemical prospecting was aimed at registering and defining geochemical features, such as element-indicators, producing dispersion haloes characteristic for gold epithermal mineralization, in addition to the already known evidences indicating base-metal mineralization of the Lece type-outcrops, alterations and mining prospects.

The Work Methodology

In this work, the metallometric method or lithogeochemical prospecting of the secondary dispersion haloes

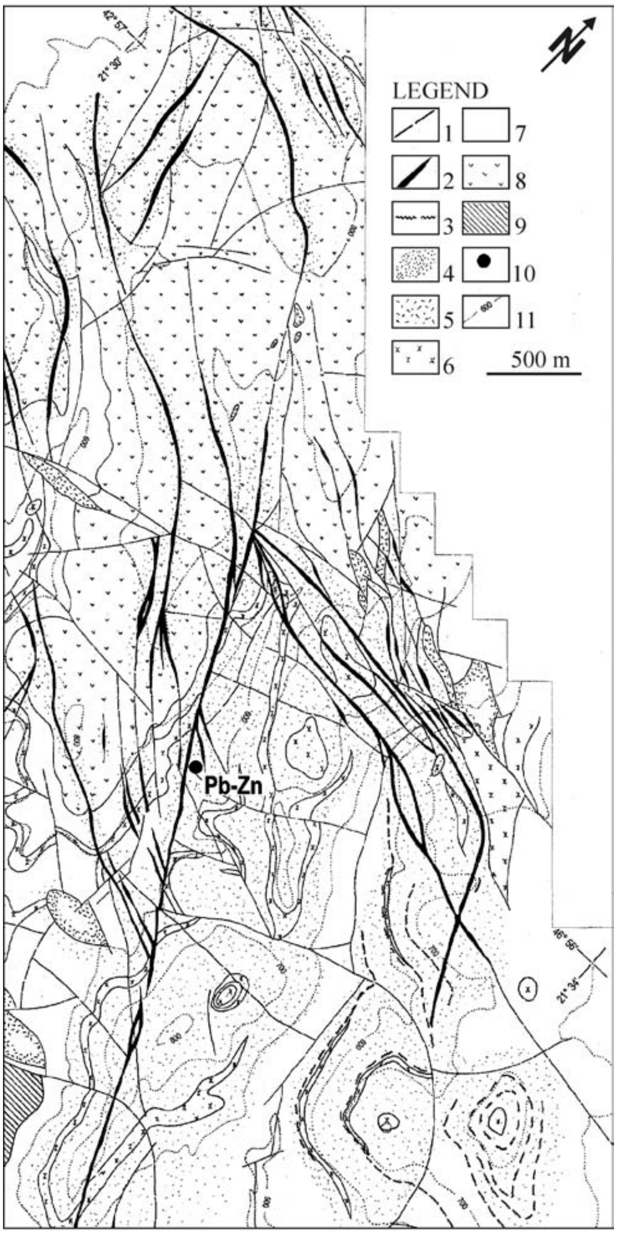

Fig. 2. Geological map of part of the ore field Lece enclosed geochemical prospecting (after data of the geological map 1:10 000, from Geozavod–Belgrade, modified). Legend: 1 = trace of fracture; 2 = quartz-breccia zone; 3 = opal–chalcedonized volcanic rocks; 4 = hydrothermal alterations in volcanic and volcanoclastic rocks (propylization, sericitzation, chloritization, kaolinization, silification, adulariazition and alunitization); 5 = pyroxene andesite; 6 = pyroxene-amphybole andesite; 7 = pyroclastic rocks (tuff, agglomerate and breccias); 8 = amphybole-pyroxene andesite; 9 = gneiss of SMM; 10 = Pb/Zn ore deposit of Lece; 11 = topographical contour line of land surface.

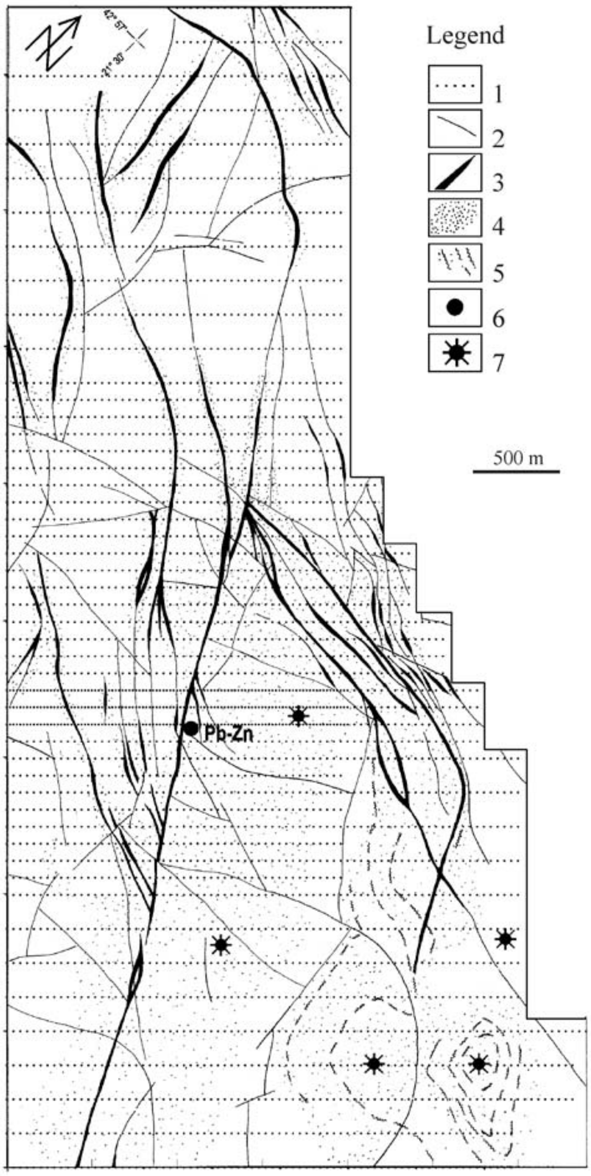

Fig. 3. Map of the grid of geochemical sample stations in the soil haloes of the ore field Lece. Legend: 1 = places of sample–collection; 2 = trace of fracture; 3 = quartz–breccia zone; 4 = hydrothermal alterations of surrounding volcanic rocks (argilitzation, adulatitization, propylization, sericitzation, chloritization, kaolinization, silification); 5 = opal–chalcedonized volcanic rocks, 6 = Pb/Zn ore deposit of Lece; 7 = supposed volcanic vent.

was applied. This is detailed prospecting covering an area of about 17 km^2 by use of a basic 200 $\times$ 40 m sampling grid, on the elluvial-dilluvial cover. The direction and density of the grid coincides with relevant features of the geological setting of the field. The grid profiles trend 225°, dipping 45°, showing average dispersion of density 56.25 samples per 1 km^2. In the middle part of the grid, covering 40% of the total grid area, the profile lines were doubly close, making in such a way a grid 100 $\times$ 40 m over an area of about 7.5 km^2 and a grid 100 $\times$ 20 m on about 0.8 km^2. Altogether, 3162 samples were collected (Fig. 3).

The gold and silver concentrations were analyzed by atomic absorption flame spectroscopy and a group of 6 potentially indicative elements – Pb, Zn, As, Sb, Cu and Tl by semi-quantitative emission spectral analyses, using a high selective spectrograph DFS–13. The analyses were performed in the chemical and geochemical laboratory of "Geozavod IMS". The lower sensitivity limits of the mentioned methods for the individual elements are: gold 8×10^{-3} ppm; lead 2 ppm; zinc 10 ppm; copper 1 ppm; silver 10^{-1} ppm; arsenic 100 ppm; antimony < 10 ppm and thallium 2 ppm.

Calculation of statistical indicators was performed by the methods of basic statistics, nonparametric statistics and cluster analysis. With the aim of providing the most real indices and indicators of individual constituents by use of statistical treatment of the analytical results, the minimum values are considered to be the amount represented by half of the values of the lower sensitivity limit of the corresponding chemical element. The results are presented first as plots for each individual element and then by secondary lithodeochemical haloes, delineated by isolines of the contents. The isoline spread coincides with the variation spread for the corresponding element and equidistance with the class frequency.

Interpretation of analytical data was made by kriging treatments throughout the variogram model with regulated anisotropy. Interpretation of results is based on the comparative analysis of the treated geochemical data and the relevant features of the geological setting.

The Results Review and Interpretation

The analytical results of the to 3162 investigated samples have been statistically treated (basic and nonparametric statistics) and plotted as mono-element dispersion haloes of the indicative elements (Au, Pb, Zn, Cu, Ag, As, Sb and Tl).

Table 1. Descriptive statistics of trace elements in the secondary lithogeochemical haloes of the ore field Lece.

Element	Au	Pb	Zn	Cu	Ag	As	Ti	Sb
Valid samples	3162	3162	3162	3162	3162	3162	3162	3162
Mean*	0.03	78.03	102.47	8.55	1.62	68.79	2.93	12.54
Median*	0.004	22.00	40.00	3.00	0.75	50.00	3.00	0.5
Mode*	0.004	10.00	30.00	3.00	0.60	50.00	1.50	0.5
Std. deviation	0.19	476.41	506.31	37.56	4.65	77.43	1.973	40.83
Coeff. variation	633	610	494	439	287	113	67	325
Stand. error	0.003	8.4722	9.004	0.668	0.083	1.377	0.351	0726
Minimum*	0.004	1	5	0.5	0.05	50	1	0.5
Maximum*	5.030	10010	10010	1500	120	3000	50	1200
Clarke**	0.004	16	47	55	0.07	1.7	0.5	0.2

*/ units: ppm (10 %)
**/ units: ppm

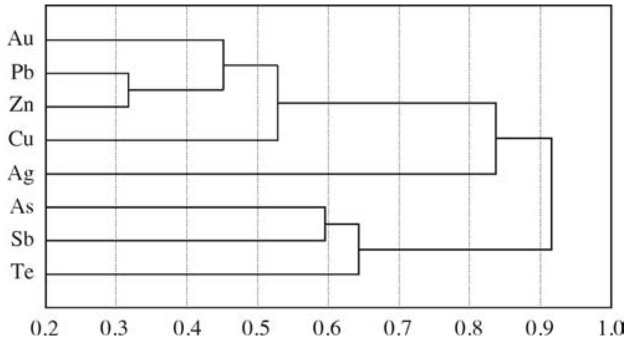

Fig. 4. Cluster diagram-dendrogram for eight trace elements in the soil halos of the ore field Lece

The statistical indicators and mutual links of all of the 7 analyzed elements in the area of the Lece ore field, are presented in Table 1 and Figure 4, respectively.

The values of the mode and arithmetical mean or their tripled values could be arbitarily chosen as quantitative geochemical indicators, of, for example, the background and threshold value of the anomaly. This was applied only to those elements the Clarke value of which was either at the level or above the lower sensitivity limits (Au, Pb, Zn, Cu and partly Ag and Sb). The concentration ranges for gold and the other trace elements in the secondary lithogeochemical haloes in the Lece ore field are presented in Fig. 5.

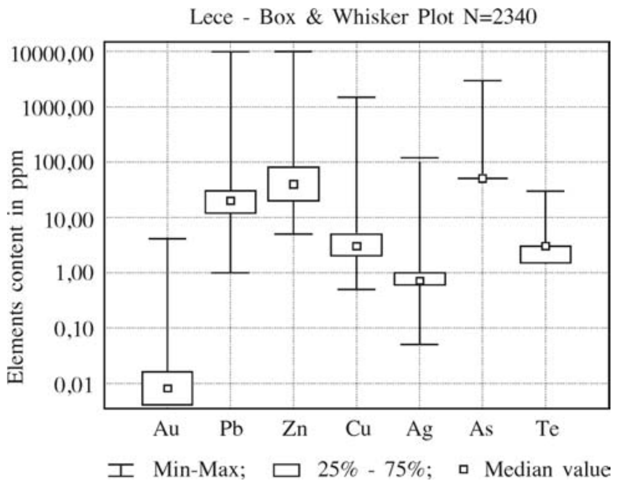

Fig. 5. Plot of ranks concentration and variation contents of Au and other microelements in the Lece ore field.

From the above presented results, it can be seen that the group of 6 elements, including Au, Pb, Zn, Cu, Sb and Ag, shows considerable irregularities and variability in the aerial distribution, which is characteristic for an anomalous geochemical field. In some field segments these elements are anomalous, exhibiting augmented background values. They show higher mutual correlation, except antimony, and could be classified into a common geochemical parageneting association, exhibiting typomorphism toward polymetallic, but not disseminated gold epithermal mineralization. On the other hand it is not advisable to make conclusions on the background and threshold anomalies of As, Sb and Tl, the minimum values of which are over Clarke (Sb not over 25 times, As about 30 times and Tl 4 times). In any case, these elements cannot be considered indicative for gold mineralization, not being in correlation with the "base metals" association, having meager mutual correlations (Pearson's coefficient: r = 0.4) and relatively uniform distributions.

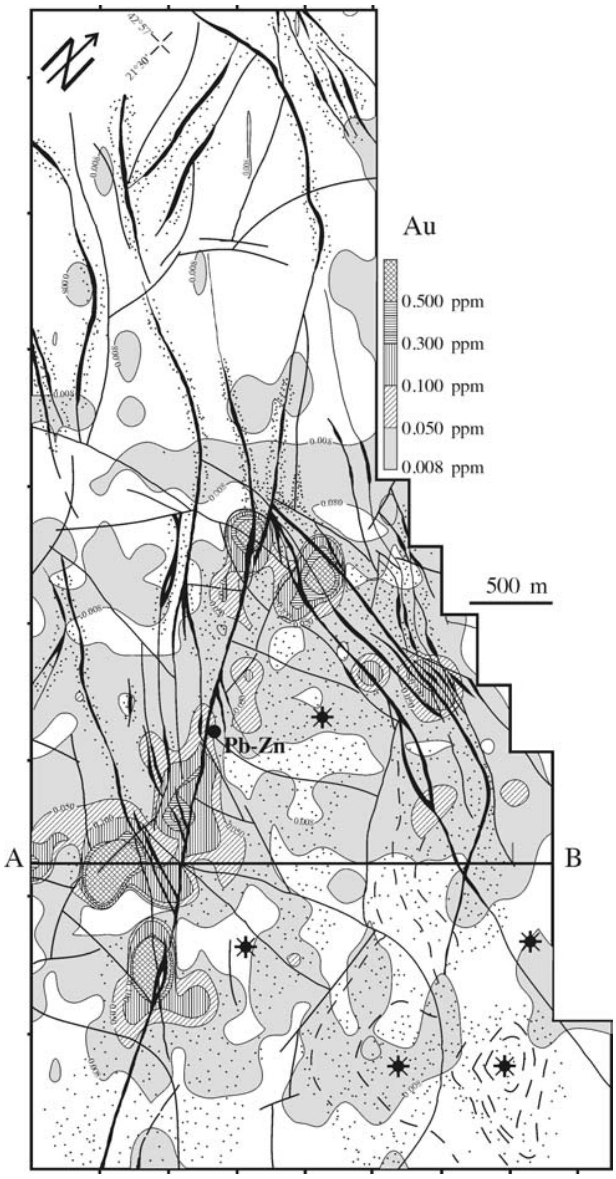

Fig. 6. Simplified geological and geochemical soil map of gold in the central area of the Lece ore field.

The secondary gold dispersion haloes, plotted in the form of content contours, together with the structures and position of the gold geochemical field in the central part of the Lece ore field are presented in Fig. 6. Inspite of the secondary haloes, the gold distribution is the product of endogen gold mineralization in the field as well. Orogenic-denudation processes resulted in the accumulations of the material, in which the mineral material is bonded with mechanically disintegrated, shortly dispersed fragments, so that the secondary haloes are similar to the primary ones, which are thus sufficiently representative.

The characteristic relation of the gold distribution and the associated paragenetic trace elements in the secondary dispersion haloes, relative to the geological setting in the domain of the Rasovaca anomalous lithogeochemical field are presented in Fig. 7.

Discussion and conclusions

The essential features of the geochemical field – secondary gold geochemical dispersion haloes in the Lece ore field were aquired by comparative analysis of the geochemical distribution of gold and the geological setting. Gold, as an essential constituent of gold mineralization in the Tertiary Lece volcanic complex, is actually the basic indicative element of base–metal mineralization. The high frequency of populations at the minimum concentration level, which coincides with Clarke, give the background at the Clarke level. On the basis of this statement, it could be concluded that this is not an anomalous but a normal geochemical field. On the other hand, however, the extremely high dispersion of the values, which are of very low frequencies, indicates anomalous segments in the geochemical field, which is clearly visible in the plots of the secondary geochemical gold haloes (Figs. 4, 5).

The rough topography of the terrain is visible in sectors delineated by the contour lines (in ppm): 0.008; 0.05; 0.1; 0.3; 0.5 and > 0.5). The correlation with the examined trace elements ranges from close with Pb, Zn and Cu to slightly low with Ag. Relative to the geological fundament, anomalous areas are restricted to the silicified volcanites as a part of the quartzose–brecciated zones (hydrothermal, partly phreaticmagmatic breccias) or along fault–fractured systems. From the standpoint of ore–bearing appearance in the Lece ore field, two essential ore–controlling tectonic–magmatic structural systems, marked by the several kilometers long quartz–breccias zone, are remarkable. One of them is linked to the dominating Rasovaca–Majdan–Vrtopska Cuka–Maligot quartz–breccias zone running 150°–320° and the other is related to the Jezerina structure in the 2.5 to 3 km long Donji Gajtan–Ponta zone, running east-west (280°–100°). Most conspicuous are gold anom-

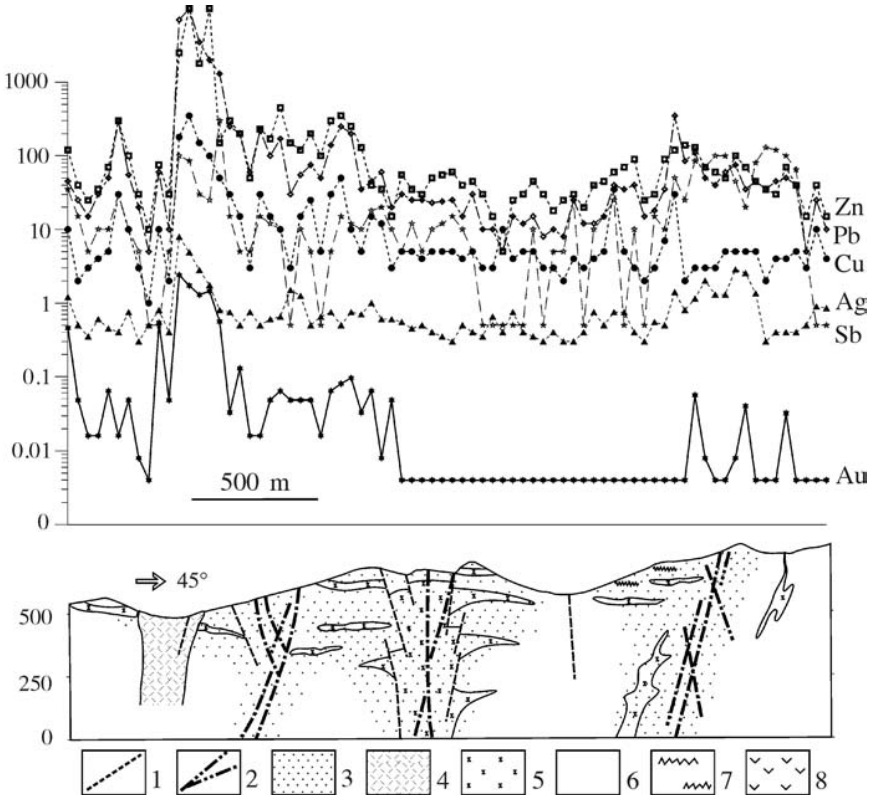

Fig. 7. Major and trace element distribution across the andesyte complex of the ore field Lece–Profile AB. 1 = trace of fracture; 2 = quartz–breccia zone; 3 = hydrothermal alterations in volcanic rocks (propylitization, sercitzation, chloritization, kaolinization, silicification); 4 = pyroxene andesite; 5 = pyroxene–amphybole andesite; 6 = pyroclastic rocks (tuff, agglomerate and breccias); 7 = opal–chalcedonies volcanic rocks; 8 = amphybol–pyroxene andesite.

alies, grading 0.05- > 0.5 ppm Au, located in intersecting sectors of the quartz-breccias zones. In the analyzed Gajtan ore field, two anomalous gold geochemical fields, linked to secondary lithogeochemical haloes, are generally present. One is restricted to the closer area of the Lece–Rasovaca lead-zinc deposit and the other is somewhat more to the north, in the Vrtopska Cuka-Donji Gajtan–Kamenica-Ponta zone.

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Резиме

Геохемијски ореоли злата рудног поља Леце (јужна Србија)

У циљу проучавања и проналажења потенцијалних епитермалних минерализација и орудњења злата, у домену југоисточног дела терцијарног вулканогеног комплеса Радана, у ареалу полиметаличног рудног поља Леце, извшена вишегодишња проспекцијска испитивања током последње деценије прошлог века. У раду се приказију и анализирају неки резултати посебно они који се тичу расподеле злата и његовог односа према пратећим микроелементима у секундарним литогеохемијским ореолима расејавања. У скупу од 8 анализираних микроелемената литогеохемијског поља Леце, изражајне, контрасне и међусобно добро корелисане секударне геохемијске ореоле расејавања имају Au, Pb, Zn, Ag и Sb. Иако се и ореоли бакра добро корелишу са са оре-

олима Au, Pb и Zn, то је елемент који не показује својства аномалности, чак што више коцентрисан је испод кларка. Ова група релативно повезаних микрокомпоненти— Au, Pb, Zn, Ag и Sb може се сматрати геохемијском парагенетском асоцијацијом типоморфном за полиметаличне хидротермалне рудне комплексе. Узајамно добро корелисане геохемијске аномалије групе полиметаличних компоненти покривају оне делове у вулканском комплексу Лецког масива, где су присутне појаве силицијских алтерација, хидротермалних силицијских бреча, полиметаличних минерализација локализованих дуж раседно-пукотинских структура и старих рударских радова. У томе смислу аномално геохемијско поље већине анализираних елемената лоцирано је у оквиру структура хидротермалних кварцно–бречастих зона, у оквиру којих су и концентрасна раније позната орудњења Гајтанске калдере. Арсен је елеменат без посебне асоцијативности и контрасности и нема карактеристике индикаторне компоненте. Антимон има карактеристике аномалне компоненте, али без индикативности према злату, цинку или олову. Његова асоцијативност је најизраженија према арсену, донекле талијуму и сребру у југоисточној половини терена. Талијум је екстензивно присутан са повишеним фоном, али без знатније корелативности са другим анализираним елементима. Обзиром да, поред арсена, антимона и сребра, нису анализирани и неки други елементи индикатори епитермалних орудњења злата, као што су жива и баријум, сматрамо да приказани резултати не дају јасна уверавања о постојању епитермалног типа орудњења злата у склопу испитиваног дела терцијарног андезитског комплекса Лецке вулканске калдере.