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Izvorni znanstveni članak

The Zinc Deposit Agios Elefterios (Glyka Nera) South-East of Athens in Greece

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In this paper the author reports the results of a survey of the Agios Elefterios (Glyka Nera) zinc deposit south-east of Athens in Greece. On the basis of chemical analyses of numerous systematically sampled ore specimens in the underground mine workings the author maintains the hypothesis that the deposit is of magmatic origin.

U ovom radu autor iznosi rezultate proučavanja ležišta cinka Agios Elefterios (Glyka Nera) jugoistočno od Atene u Grčkoj. Na temelju kemijskih analiza brojnih, sistematski uzetih uzo-raka rude u podzemnim rudarskim radovima autor podržava hipotezu magmatskog porijekla ležišta.

INTRODUCTION

The zinc deposit of Agios Elefterios (Glyka Nera) is part of the wider lead-zinc area represented by the Laurium ore district located on the peninsula of Athica southeast of Athens (Fig. 1). The Laurium ore deposits have the following paragenesis: galena, sphalerite and pyrite are the main ore minerals, the gangue minerals are fluorite, barite, ankerite and calcite. Small quantities of Mn, Ag, Cu, Bi, As, Ni, Co and Au are very often present in these ores. The content of metals (Pb + Zn) is low, the ore is low-grade. The greater part of the ore deposits is oxidized into anglesite, cerussite, smithsonite (calamine) and hydrozincite. The Laurium ore district is built up of Mesozoic marbles and schists. The mineralization is related genetically to stocks, sills and dykes of granodiorites and granodiorite-porphyrates of young Tertiary age. (Marinos, 1982). In Hellenic times (from the 10th to the 5th century B. C.) the silver-bearing ores were exploited and silver coinage manufactured. The mines were reopened in the 19th century, but recently suspended.

GEOGRAPHIC POSITION

The ore deposit of Agios Elefterios occurs some ten kilometers south-east of the city of Athens, and is situated in the immediate vicinity of the asphalted road Athens—Koropi. The ore deposit stretches on gentle

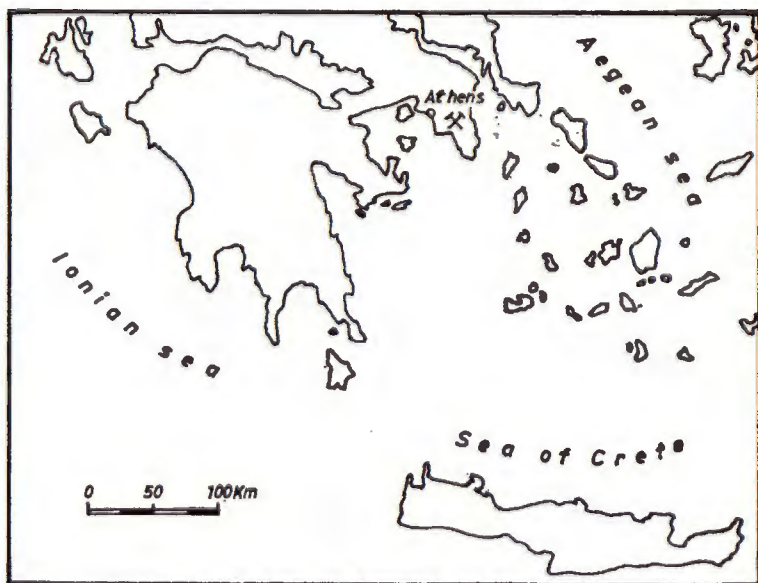


Fig.(Sl.) 1 X Ore deposit (ležište cinka) Agios Elefterios

slopes, which rise out of the Koropi valley in the direction of the west. The underground water-table is situated at about 8—10 meters beneath the valley surface, or at about 50 meters beneath the ore outcrops.

GEOLOGY OF AREA

According to the data of the »Geological map of Greece« (1954) on the scale 1 : 500.000 issued by the Institute for Geology and Subsurface Research, the Koropi valley is built up from laky or continental diluvial (Pleistocene) sediments. The western and northwestern slopes and hills are built up of metamorphosed rocks: marbles (more or less metamorphosed limestones) and crystalline schists (mainly micaschists, sometimes marbles, as well as gneisses).

Our microscopic investigations of the rock specimens proved that the zinc ore occurrences are placed in a series of metamorphosed limestones, or finegrained marbles. In the marbles, local intercalations of schists are noticeable. The marbles are laminated or as slabs. The extension of the marble series in the northeast part of the ore area is NE—SW, with a very steep dip (65—75°) to SE, and in the southwest part, the extension changes to the south in the shape of an arrow, thus forming an obliquely shaped anticlinal. At several places, tectonic disturbances such as faults, differential shifting of blocks, etc. have been surveyed.

MINERALIZATION

The ore bodies are inserted in parallel (concordantly) in series of marbled limestones. The ore bearing zone is shaped like an oblique anti-

clinal, with the extension axis NE—SW. So far, only the northwest flank of the saddle of the anticlinal is known, while the southeastern flank of the saddle, as well as the southeast wing of the anticlinal ore bearing zone, is not sufficiently known, although on the site there are outcrops of ores on the presumed territory. The saddle of the anticlinal and its flanks extend to a length of 150 meters, from which it may be concluded that the anticlinal is slightly arched.

The saddle of the anticlinal with its slightly bent flanks, is mineralized to the maximum. The local thicknesses of the ore body are of several meters, even up to more than 5 meters. In that part of the ore bearing zone, very little mining prospecting has been carried out by means of shallow trenches.

The northwest wing of the anticlinal is known in more detail, having been investigated by mining. The extreme northeast part of this wing of the anticlinal has been opened up by underground mining works to a length of 150 meters, and a depth of 30 meters. A vein-like ore body has been discovered, the thickness of which varies from 1 to 2,5 meters, the average being 1,5—2,5 meters. Further to the SW, the ore outcrops have been followed by means of shallow pits and trenches to a distance of 100 meters. In the part of the ore bearing zone, hitherto opened up to a total length of 400 meters, several tectonic disturbances have been noticed, this tectonic being epigenetic.

UNDERGROUND MINING WORKS

From the attached map (Fig. 2) on the scale of 1 : 500, the scope and nature of mining works in the extreme northeastern part of the northwest wing of the anticlinal may be seen in the ground-plan and crosssection plan. By means of these underground works the ore bearing zone is opened up to a length of about 150 meters and to a maximum depth of 30 meters below the surface. On the ground-plan, the thickness of the ore body is indicated. The thicknesses vary from 1,05—2,40 meters, but the thicknesses generally recorded are between 1,5—2,5 meters. In the middle part of the mine, the thicknesses are greatest and amount to about two meters, or even more.

CHEMICAL CHARACTERISTICS OF THE ORES

The first 31 partial quantitative chemical analyses of calamine (silica, zinc, lost of ignition) presented in Table 1, received from the owner of the mine (Georges Alexandridis, Athens), were carried out in the chemical laboratory of Dr. S. Vrahamis, Athens in 1962.

At our disposal were also three complete quantitative chemical analyses made by the State commercial enterprise, Rudmetal in Sophia (Bulgaria). The first was taken from the best oxidized ore, the second one from the ore of second quality, and the third from zinc ore concentrate. The results are presented in Table 2.

Our first visit (Jurković, 1963) to the underground mine workings and a survey of the open parts and outcrops of the ore deposit at Glyka Nera convinced us that the above mentioned analyses refer to selected

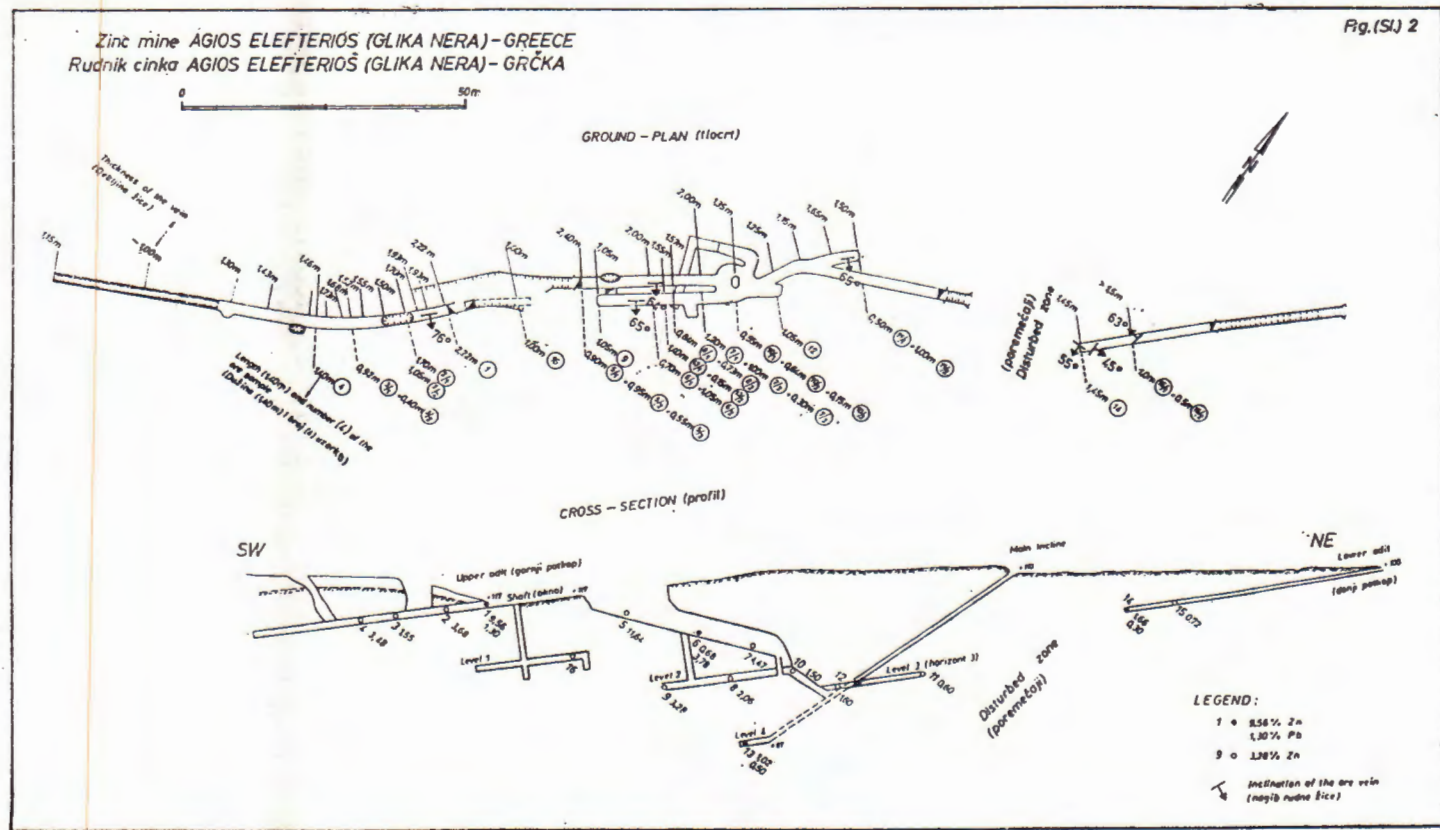


Table (tabela) 1
 Partial chemical analyses of the zinc ore
 Parcijalne kemijske analize cinkove rude

No	SiO ₂	Zn	lost of ignit.	No	SiO ₂	Zn	lost of ignit.	No	SiO ₂	Zn	lost of ignit.
1	50,00	4,50	19,10	11	4,60	18,50	20,70	21	6,80	26,50	10,50
2	13,40	4,80	31,60	12	2,60	18,50	29,30	22	2,60	27,50	36,45
3	2,20	6,00	3,80	13	7,00	19,00	35,80	23	7,30	32,00	15,10
4	10,70	7,00	26,05	14	1,90	22,00	34,80	24	5,85	36,25	30,40
5	3,00	7,00	28,10	15	9,00	22,50	27,80	25	2,00	38,50	36,90
6	7,80	8,00	32,70	16	2,40	24,00	35,70	26	6,00	43,50	32,35
7	6,20	8,75	33,80	17	9,40	25,00	15,70	27	1,30	45,50	35,00
8	2,80	10,00	29,15	18	12,80	26,00	13,00	28	1,20	46,50	34,80
9	2,45	12,10	28,10	19	11,60	26,00	3,70	29	2,60	47,70	13,70
10	23,10	15,25	34,80	20	3,10	26,50	17,90	30	1,05	47,50	35,50
								31	5,70	53,50	1,45

pieces of zinc ore, and that the ore occurrence in this main part consists of a considerably lower metal content. Because of the very strong limonitization of the ore body in the oxidation zone, which has been only opened up by mining works, it was not possible without chemical analyses to evaluate the actual zinc content of the opened part of the deposit.

Table (tabela) 2
 Complete chemical analyses of the zinc ore
 Kompletne kemijske analize cinkove rude

	I	II	III		I	II	III
SiO ₂	4,00	1,85	1,32	Zn	37,10	35,20	49,00
Al ₂ O ₃	1,84	0,86		Pb	0,52	0,38	0,47
CaO	7,80	16,20	20,00	Cd	0,15	0,13	0,17
MgO	0,14	0,19	0,20	Cu	0,02	0,015	0,007
Fe ₂ O ₃	—	—	1,34	As	0,07	0,11	0,05
Fe	4,00	0,90	0,66	Sb	0,002	—	trace
Mn	0,20	0,08	0,014	Co	0,005	0,002	0,003
CO ₂	36,37	37,00	17,61	Sn	—	—	trace

In order to obtain a correct sampling of the ore body, a method involving channel samples taken perpendicularly to the ore body thickness was employed. Where possible, we cropped out a channel either at the bottom or at the roof of the ore vein. The part of the vein left in the flank of the gallery was sampled by underground drilling. In

some positions, we were able to sample only by channels, in other positions by a combination of channel and bore holes, or by drilling alone. 16 positions were selected in the underground works for sampling, arranged according to extension and the dip in the ore body in a way which permitted the most accurate disposition of the samples, as far as the actual mining works allowed this.

It was observed that the ore vein is of varying quality, and even of different consistency in its bottom, or in its roofy part. In 10 positions therefore we took two, or even three channel samples, or boreholes and analysed them separately. Chemical analyses confirmed our presumption that the bottom part of the ore body is of better quality.

The material obtained by sampling, was reduced by quartering and analysed in the Institute for Analytical Chemistry of the Technological Faculty at the University in Zagreb (analysts Hlavaty Miroslav and Mažuranić Karmen).

On the attached mining map, scale 1 : 500, all the sampled positions are designated (Fig. 2). On the cross-section plan of the mine at each numbered sample, the percentage zinc content has been given, and in some samples the contents of zinc and lead. On the ground-plan of the mine, the positions of the samples taken are recorded and designated by number, as also are the channel and bore hole lengths.

RESULTS OF THE CHEMICAL ANALYSES

In Table 3 the results of all the analyses have been given. 26 partial quantitative chemical analyses were carried out on three components (H_2O^{+105} , lost of ignition and zinc) taken at 15 different positions in the mine.

One sample of zinc concentrate, obtained by roasting the ore, has also been analysed. This analysis was performed in the Institute for Mining Chemistry of the Faculty for Mining, Geology and Oil Engineering at the University of Zagreb (analyst Dubravko Siftar).

The five samples recorded as numbers 1, 7/1, 7/2, 13/1 and 14 were submitted to a complete quantitative chemical analysis performed in the Institute for Mining Chemistry of the Faculty for Mining, Geology and Oil Engineering, University of Zagreb (analyst Dubravko Siftar). The results are given in Table 4.

To determine the trace elements (oligoelements), especially of cadmium, six semi-quantitative spectrographic analyses were carried out in the Institute of Nuclear Raw Material in Belgrade (Table 5, samples 1, 7/1, 7/2, 13/1, 17 and 18).

From the chemical analyses we obtained the following results: (a) the zinc content is distributed within the deposit very irregularly, the zinc values vary from 0,6 % to 11,64 %. The computed weighed average is 3,82 % Zn; (b) the Pb content is less irregular than the zinc content. The Pb values vary from 0,30 % Pb to 1,30 % Pb. The weighed average is 0,76 % Pb; (c) the parts of ore closer to the surface contain a higher metal content (Pb + Zn) than the lower parts of the deposit; (d) the footwall part of the ore body (vein), which is harder, more compact and

Table (tabela) 3

Partial chemical analyses of the zinc ore taken by sampling in the underground mine workings

Djelomične kemijske analize cinkove rude uzorkovane u podzemnim rudarskim radovima

Sam- ple	H ₂ O ^{+105°}	Zn	lost of ignit.	Sam- ple	H ₂ O ^{+105°}	Zn	lost of ignit.	Sam- ple	H ₂ O ^{+105°}	Zn	lost of ignit.
1	3,30	9,56	16,20	6/1	0,35	5,51	28,20	10/2	0,70	1,68	16,40
2/1	0,98	3,68	11,40	6/2	0,66	2,63	16,30	11/1	0,87	0,60	27,60
2/2	1,04	1,76	10,60	7/1	0,70	6,75	29,90	11/2	3,30	0,60	18,20
3/1	2,30	1,81	15,00	7/2	0,26	2,43	13,50	12	2,60	1,60	20,90
3/2	1,50	0,95	22,59	7/3	0,94	2,11	20,20	13/1	1,40	1,02	20,80
4	0,50	3,48	18,81	8/1	0,42	1,23	21,23	14	0,47	1,66	29,40
5/1	1,60	11,35	21,50	8/2	0,47	3,02	29,81	15/1	0,80	0,93	26,80
5/2	4,60	11,86	13,80	9	3,30	3,28	18,30	15/2	0,60	0,31	21,30
5/3	0,53	1,27	24,80	10/1	0,45	1,29	27,81	17	1,59	12,78	17,91

Table (tabela) 4

Complete quantitative chemical analyses
Kompletne kvantitativne kemijske analize

Components	1	7/1	7/2	13/1	14
SiO ₂	16,6	4,9	12,8	13,7	5,1
Al ₂ O ₃	4,6	1,8	6,5	5,5	1,6
Fe ₂ O ₃	33,8	23,7	52,9	27,3	24,2
MnO	0,2	0,2	0,3	0,2	0,2
CaO	8,1	23,4	4,0	21,9	26,3
MgO	1,4	2,0	0,5	1,1	5,5
BaO	1,8	0,5	0,9	1,1	0,3
SO ₃	0,9	0,3	0,5	0,5	0,2
ZnO	9,2	9,7	3,2	1,4	3,1
PbO	1,4	0,6	1,0	0,6	0,3
H ₂ O-110°	0,9	0,9	1,6	0,8	0,9
lost of ignit.	17,6	29,7	12,6	22,2	31,4

massive is usually of better quality (higher Zn content) than the hanging wall portion of the vein, which is softer, banded and more limonitized; (e) the hanging wall portions of the ore body contain a higher percentage of Fe_2O_3 , BaSO_4 , Pb, SiO_2 , Al_2O_3 while the footwall parts contain more CaO, MgO, CO_2 , lost of ignition, Zn; (f) the mining works that have been carried out are situated at those points within ore body, where, according to our sampling, the best chemical results were obtained. The adjacent satellitic ore veins contain high grade ore with a relatively high Zn content; but the veins are no more than 5—15 cm thick.

Table (tabela) 5
Semi-quantitative spectrographic analyses
Semikvantitativna spektrografska analiza

Samples	1	7/1	7/2	13/1	17+	18++
Elements						
Pb	1%	>3160 ppm	3160 ppm	3160 ppm	1%	400 ppm
Cd	563 ppm	1100 ppm	nd	470 ppm	1800 ppm	
Cu				16 ppm		5 ppm
Ni				28 ppm		8 ppm
Mn				563 ppm		502 ppm
Ba				> 1%		nd
not detectable (nd)				Sn, As, Sb, In, Tl	As, Sb	Sn, As, Sb, In

Sample (uzorak) 17+ = concentrate (koncentrat); sample (uzorak) 18++ = pure zinc ore (čista cinkova ruda)

THE GENESIS OF THE LAURIUM ORE DEPOSITS

Schneiderhöhn (1941) considers that the Laurium lead-zinc deposits are metasomatic, located in tectonic zones of the underlying crystalline Attic mountain range which consists of several series of marbles with intercalations of mica schists. Individual ore deposits are situated in the marbles at the interfaces with other rocks. Marinov and Petrascheck (1956) consider that these deposits are hydrothermally metasomatic and linked to a granitic stock, zonally distributed round it according to the temperature at which they were formed. Jurković (1963) describing the Agios Elefterios deposit, writes that the hydrothermal metasomatic deposition of the primary ore (sulfides) was accompanied by processes of silification, ankeritization, dolomitization and baritization. The open part of the deposit is in the oxidization zone, with lead, zinc and iron as secondary minerals. Leleu (1966) and Bernard-Leleu (1967) put forward an exogenic-descendent hypothesis for the origin of the Laurium deposits. The primary metallic content derives from volcanogenic-sedimentary deposits laid down in mica schists, from which it was carried and deposited in the karstified spaces of the marbles via a descendent route. Petrascheck (1982)

favours the hydrothermal hypothesis which he had already described in a joint publication with Marinovs (l. c.). The deposits are zonally distributed round a granitic stock about ten million years old, with which they are genetically linked, just as numerous granite-porphry veins are linked with it. Ascending hydrothermal solutions took advantage of the penetration of these eruptive veins in order to spread and to deposit their metallic content. Overlying mica schists and phyllites acted as a screen in the localisation of the ore-bearing zones. Marinovs (1982) writes that the lead-zinc deposits of Laurium are of meso-to epithermal origin. The mineral solutions were constituted during the crystallization of the eastern Laurium granite massif, which dates back to the Miocene period. The numerous occurrences of stocks, sills and dykes of granodiorites and granite-porphryes indicates the existence of deeply emplaced granites. The most intensive mineralisation came about in the eastern Laurium in the vertices of an asymmetrical meridionally situated anticline. The deposits are in the form of lodes, layers or massive metasomatic bodies in the marbles at interfaces with schists or porphyres. In his most recent textbook (Petraschek-Pohl, 1982) W. E. Petraschek deploys both hypotheses concerning the origin of the Laurium deposits, the exogenic-descendent and the hydrothermal, but is personally inclined to favour the latter. In his studies of the tectonic-metallogenic units of the Mediterranean area, and hence of the Laurium deposits, the same author connects the lead-zinc deposits of the Aegean Sea with a zone of neogene activation saying »the lead and zinc appears to have been inherited from the Pb-Zn enriched Hercynian crust, rejuvenated by palingenesis«.

HYPOGENIC AND HYPERGENIC PROCESSES

Mine workings on the Agios Elefterios (Glyka Nera) deposit merely opened up the oxidization zone, because they are located some ten meters above the underground water-table. The primary (hypogenic) zone of the ore occurrences was not discovered, but the numerous chemical analyses given in Tables 1, 2 and 4 indicate that the deposits concerned are hydrothermal. Thermal springs used tectonically disturbed zones in the marbles, as well as diastatic planes and the interfaces of marble and thin strata of mica schists in order to ascend, leaving deposits in them and simultaneously extending them by metasomatism. The deposition of primary sulfides, principally pyrite, sphalerite and galena was accompanied by other hydrothermal processes of alteration: silification, dolomitization, ferro-dolomitization, ankeritization and barytization (see Table 4). In the metasomatic process the marble yielded a certain amount of non-soluble residue (clay-like substance), and there was a partial decomposition of the thin schists intercalations.

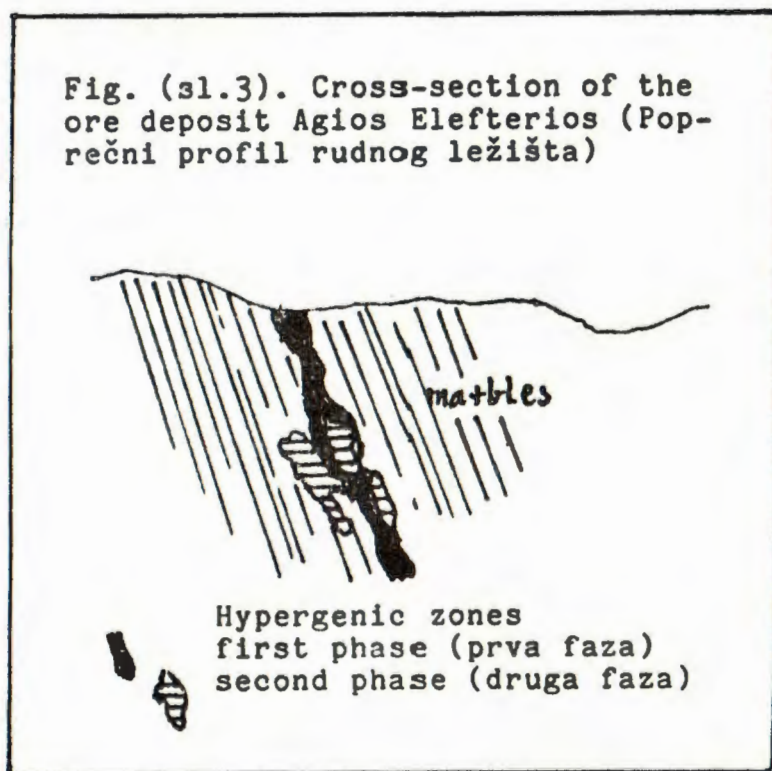
In the hypergenic phase a major geochemical and spatial separation of lead and zinc took place. The author is of the opinion that hypergenesis developed in two phases. In the first phase sulfate solutions of lead, zinc and iron were formed by the oxidation of sulfides, while goethite (»limonite«) was formed by the oxidation of ferrodolomite and ankerite. Ferrosulfate is very rapidly oxidised into ferrisulfate, and then

hydrolised, being precipitated as goethite and lepidocrocite. Lead sulfate, which is not readily soluble and only slightly mobile reacted with percolating vadose water enriched with CO_2 by its passage through carbonate rocks, and was precipitated practically »in situ« as insoluble cerussite. Because of its high degree of solubility in water, and its consequent greater potential for migration, zinc sulfate penetrated descendantly through the ore-bearing zone into its lower regions, separating out from the lead and reacting mainly with percolating carbonic acid and only partially with silicic acid, giving smithsonite and hydrozincite (calamine). Conversion of the chemical analyses under numbers 1, 7/1, 7/2, 13 and 14 from Table 4 into possible minerals as shown in Table 6 indicates that the calculated quantitative loss in heating best corresponds when the zinc is entirely or mostly recomputed into hydrozincite. We have represented the clay-like component as illite. The oxidation ore of the first phase of hypergenesis which occupies the major part of the ore body in the oxidation zone is of poor quality on account of the very low lead content, a relatively low zinc content, a considerable

Table (tabela) 6
Conversion of the chemical analyses into possible minerals
Preračunavanje kemijskih analiza na mineralni sastav

	I	II	1a	1b	7/1a	7/1b	7/2a	7/2b	13a	13b	14a	14b
Q	1,83	0,84	11,20	7,76	2,77	0,99	5,12	3,95	7,20	6,69	3,21	2,06
II	5,03	2,39	12,60	12,60	4,91	4,91	17,75	17,75	15,02	15,02	4,37	4,37
Cc	6,32	26,85	10,97	10,97	36,80	36,80	5,78	5,78	36,33	36,33	33,23	33,23
Dol	0,61	0,81	6,40	6,40	9,20	9,20	2,30	2,30	5,10	5,10	25,30	25,30
Ank	15,65	3,47	—	—	—	—	—	—	—	—	—	—
Smt	71,10	67,50	—	—	—	—	—	—	—	—	—	—
Cer	0,67	0,50	1,68	1,68	0,65	0,65	1,16	1,16	0,65	0,65	0,39	0,39
Hyd	—	—	11,75	—	13,10	—	4,37	—	1,85	—	4,20	—
Hem	—	—	—	13,62	—	14,36	—	4,74	—	2,07	—	4,59
Rod	0,42	0,17	0,32	0,32	0,32	0,32	0,48	0,48	0,32	0,32	0,32	0,32
Gth	—	—	38,19	38,19	26,38	26,38	58,88	58,88	30,38	30,38	26,93	26,93
Ba	—	—	2,70	2,70	0,80	0,80	1,40	1,40	1,60	1,60	0,50	0,50
$\text{H}_2\text{O}-110^\circ$	—	—	0,90	0,90	0,90	0,90	1,60	1,60	0,80	0,80	0,90	0,90
Σ	101,63	102,53	96,71	96,14	95,83	94,41	98,84	98,04	99,25	98,96	99,35	98,59
L. of ign.	36,37	37,00	17,60	17,60	29,70	29,70	12,60	12,60	22,20	22,20	31,40	31,40
(T-2,4) (calc.)	35,24	37,74	16,55	14,53	28,13	25,81	13,02	12,25	23,84	23,51	31,20	30,46

Legend: Q = quartz, II = illite, Cc = calcite, Dol = dolomite, Ank = ankerite, Smt = smithsonite, Cer = cerussite, Hyd = hydrozincite, Hem = hemimorphite, Rod = rodochrosite, Gth = goethite, Ba = barite, l. of ign. = lost of ignition, T-2,4 = Tables 2, 4, calc. = calculated (computed)



quantity of clay component and a high percentage proportion of »limonite«. In the second phase of hypergenesis, a proportion of the dissolved zinc sulfate used for its descent the satellite planes of the »litage«, diaclasis and the previously formed cavities in the marble on the flanks of the ore body. In these areas a descendent metasomatism of the marble took place, during which high quality smithsonite (possibly also to some extent ferro-smithosonite-nonheimite) was deposited. The analyses under nos. I and II in Table 2, converted to the possible mineral composition shown in Table 6, clearly indicate the qualitative difference between this ore in the satellite veins and nests (Fig. 3) and the ore in the main part of the oxidation zone of the deposit.

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Ležište cinkove rude Agios Elefterios (Glyka Nera) jugoistočno od Atene u Grčkoj

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Ležište cinka Agios Elefterios je dio šire olovno-cinkane oblasti Lauriona koja se nalazi na poluotoku Atika SE od Atene (sl. 1). U tim ležištima glavni su rudni minerali galenit, sfalerit i pirit, a od minerala jalovine fluorit, barit, ankerit i kalcit. Sadržaj olova i cinka je nizak. Ruda sadrži male količine (često samo u tragovima) Mn, Ag, Cu, Bi, As, Ni, Co, Au. Veći dio tih ležišta je oksidiran u hipergene (sekundarne) minerale od kojih su najvažniji smitsonit, ceruzit i »limonit«, a ima i kalamine i hidrocinkita, te anglezita. Mineralizacija je prostorno vezana za poremećajne zone u seriji mezozojskih mramora i tinjčastih škriljaca, a genetski na granitske štokove te silove i dajkove granodiorita i granodiorit-porfira miocenske starosti (Marinos, 1982). U helensko doba vadilo se srebronosni galenit i iz srebra kovao novac. Rudnici su danas u mirovanju.

Ležište Agios Elefterios se nalazi oko 15 km SE od grada Atene, na zapadnim obroncima doline Koropi koji su izgrađeni od serije pločasto razvijenih mramora s tanjim ulošcima tinjčastih škriljaca. Pružanje serije u sjeveroistočnom dijelu zone mineralizacije je NE—SW sa strmim padom od 65—75° ka SE, a u jugozapadnom dijelu N—S izgrađujući tako koso položenu antiklinalu. Rudna pojava je konkordantna slojevitosti (litažu) mramora i slijedi zonu tektonskog poremećaja. Podzemnim rudarskim radovima otkrivena je na NE križu antiklinale slojna žica promjenljive debljine od 1,0 do 2,5 m na dužini od 150 i do dubine od 30 m. Orudnjenje je praćeno po izdancima daljnjih 100 m na SW. Ostali dijelovi rudne zone istraživani su samo manjim raskopima i nisu dovoljno poznati (sl. 2.).

Prije nego što smo pregledali rudarske radove raspolagali smo sa 31 parcijalnom analizom uzoraka rude izrađenim u Ateni, kao i s dvije kompletne analize na glavne komponente i neke mikroelemente izrađene u Sofiji (tabele 1 i 2). Srednji ponderirani sadržaj cinka parcijalnih analiza iznosio je 24,4% Zn, a kompletnih 36,15% Zn. Kao što smo to kasnije dokazali, te izuzetno visoke vrijednosti dobivene su na uzorcima rude u dijelovima ležišta koji su nastali descendentnom metasomatozom (sl. 3.).

Detaljnim pregledom svih rudarskih radova (sl. 2.) potvrđena je naša pretpostavka da se glavnina oksidacione zone sastoji od rude znatno nižeg kvaliteta te smo prišli sistematskom uzorkovanju dostupnih dijelova rudnog tijela. Uzorkovanje je izvršeno na 16 pozicija, pretežno izbijanjem brazdi, rjeđe točkasto, a u nepristupačnim dijelovima u bokovima, krovini i podini podzemnim bušenjem rudarskom bušilicom. Rezultati analiza prikazani su na tabelama 3, 4 i 5.

Iz analiza zaključujemo: (a) da je sadržaj cinka vrlo nepravilno raspoređen u rudnom tijelu i po padu i po pružanju s time da su plići dijelovi oksidacione zone bogatiji od onih dubljih. Srednji sadržaj za cijelo, podzemnim radovima otvoreno rudno tijelo, iznosio je 3,82% Zn. (b) vrijednosti sadržaja olova su pravilnije ras-

poređene, ali je sadržaj vrlo nizak, srednja vrijednost je 0,76% Pb; (c) podini bliži dijelovi rudnog tijela su tvrdi, kompaktniji, s višim sadržajem cinka, CO₂, gubitka žarenja, CaO i MgO, krovini bliži dijelovi su siromašniji na cinku, sadrže više SiO₂, Al₂O₃, BaSO₄, limonitske supstance; (d) povadeni dijelovi ležišta nalaze se oko pozicija kvalitetnijih kemijskih analiza što upućuje na džepove, satelitske žice i gnijezda bolje smitsonitske rude iz kojih potječu i rezultati analiza navedeni u tabelama 1 i 2; (e) od elemenata u tragovima dokazana je prisutnost Ni, Co, Cu, As, Sb, Cd i Mn što je karakteristično za laurionska ležišta olova i cinka.

Rezultati kemijskih analiza potvrđuju da je hipogena mineralizacija ascendentna, hidrotermalnog postanka, da su terme koristile tektonske poremećaje duž litaža mramora proširujući ih metasomatozom. Proces odlaganja rude bio je praćen slabijom ili jačom silifikacijom, dolomitizacijom (ferodolomit), ankeritizacijom i baritizacijom. U toku tih procesa hidrotermalnim potiskivanjem mramora zaostao je glinoviti talog netopivog ostatka stijene, a izvršena je u manjem opsegu i macerizacija škriljaca.

U toku hipergeneze izvršena je vrlo značajna geokemijska preraspodjela i separacija olova od cinka. Autor je mišljenja da se hipergeneza vršila u dvije faze. U prvoj fazi odvijala se oksidacija sulfida u sulfate, a ferodolomita i ankerita u getit («limonit»). Ferosulfat nastao iz pirita vrlo brzo je prešao u ferisulfat i zatim hidrolizom u getit i lepidokrokit. Olovni sulfat kao teško topiv reagirao je s perkolirajućim vadoznim vodama obogaćenim na CO₂ taložeci se praktički »in situ« u netopivi ceruzit. Cinkov sulfat kao jako topiv u vodi i migrativan prodirao je kroz rudno tijelo u niže dijelove reagirajući s perkolirajućim vodama formirajući smitsonit i hidrocinkit, a sa silicijskom kiselinom i manje količine kalamine (hemimorfita) (Tabela 6).

Dio cinkovog sulfata izvršio je descendentnu metasomatozu relikata mramora unutar rudnog tijela kao i u salbandima duž satelitskih prlina, pukotina, po plohama slojevitosti ili površina karstifikacijom nastalih šupljina stvarajući bogate karbo-natne rude u vidu satelitskih tanjih žica te manjih ili većih gnijezda (Tabela 6 i sl. 3).