ROŞIA MONTANĂ

GEO-MECHANIC STUDY FOR THE DETERMINATION OF THE BLASTING EFFECTS ON THE PROTECTED ZONE STRUCTURES

Completed by:

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INTRODUCTION

Under the redevelopment strategy of the Rosia Montana Mining Project located in the Alba County and based on the results of the exploration programme there were several investment projects designed in order to explore the gold and silver resource identified in the area.

Open pit mining method will be used to mine the resource, a method that is also currently used in the Cetate pit.

The Rosia Montana Project is located within the southern part of the Apuseni Mountains, which are located north of the Southern Carpathian Mountains and west of the Transylvanian Basin. The site's setting is therefore hilly in character, comprising alternating valleys and ridges and includes the gold and silver deposits outlined and partly mined in the Orlea, Văidoaia, Cîrnic, Cîrnicel, Cetate and Carpeni massifs.

The open pits were designed based on economic efficiency and rational mineral resources exploitation criteria as per the provisions of the Mining Law 85/2003 however also considering the implementation as from the design stage of the adequate measures to preserve and ensure integrity of the historic monuments and heritage structures existing in the Rosia Montana protected zone.

The mining programme of the gold-silver resources/reserves in the Rosia Montana mining district considers extraction of ore in four open pits, i.e. Cetate, Carnic, Jig and Orlea pits, located on both sides of the Rosia valley.

The mining technology to be employed further in the Rosia Montana mining district involves breaking of rock using explosives emplaced in blast holes, loading by high tonnage excavators and truck haulage of excavated rock.

Without the implementation of certain special measures, the use of blasting technologies in areas adjacent to the Rosia Montana protected zone or to the heritage structures may cause damage or degradation of the existing structures especially given that many of the heritage structures are very old and in an advanced state of wear, which increases their sensitivity.

The use of explosives in engineering works or the quantification of the effects of the blasting on residential or industrial buildings located within the area of influence of the blasting has been the object of numerous studies and researches developed in order to adopt certain standards or technical rules to regulate this activity.

Specific research to determine the effects of the rock blasting technology were conducted for the Rosia Montana mining district in the 80's which research resulted in a report titled ”*Study regarding the open pit mining*

technology in the NAPOLEON and CORHURI sectors and influence of blasting on adjacent area and buildings".

The data and conclusions of this study that was developed over 20 years ago were used in the present study also in conjunction with new data resulting from site investigations conducted in the early months of 2006 and from the assessment of the Rosia Montana structures.

The technological progress made in terms of using explosives in engineering works were also taken account of since the new technologies allow for an efficient control of the energy of the blast.

SCOPE AND PURPOSE OF THE STUDY

This study was developed in order to quantify the effects of excavation technologies to be employed in the Rosia Montana mining district and identify the methods that ensure the protection of the structures from the protected zone or of other heritage constructions.

Employing the technology for breaking of rock using explosives emplaced in blast holes also generates a number of side effects that may cause damage to the structures located in the impact area or occurrence of accidents.

Of these effects, the ground vibration, i.e. the seismic effect generated by blasting and the blast air wave pressure constitute major elements that may cause damage/degradation to the structures.

The side effects generated by blasting have different sizes subject to a large variety of factors, with the most significant being the following:

- ✳ explosive quantity and type;
- ✳ employed technology;
- ✳ distance from the blast centre to the investigated structure;
- ✳ geological structure.

In the engineering practice, the side effects generated by the use of explosives are assessed by adopting limit values for the particle vibration velocity measured in proximity of the protected structure.

The permissible limits for vibration velocity differ subject to several factors, of which the most important are the structure type and its technical status and the social use of the respective structure. These limits are normally set out by specialised technical rules.

Because there is no such rule in Romania to regulate the structural protection against seismic effect on blasting, the analysis done in this study used the limits recommended by the specialised rules applied in GERMANY (DIN 4150/83) which currently is the most stringent in EUROPE.

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To protect heritage structures and historic monuments, as per DIN 4150/83 recommendations, the maximum permissible particle vibration velocity is 0.2 cm/s which ensures negligible effects to the respective structures and does not result in damaging or deteriorating the same.

To estimate the effects of blasting to the structures in the protected zone or to other heritage structures, this study adopted a maximum permissible limit for particle vibration velocity of 0.2 cm/s.

Geomorphologic Data

The Rosia Montana Project is located within the southern part of the Apuseni Mountains, which are located north of the Southern Carpathian Mountains and west of the Transylvanian Basin. The site's setting is therefore hilly in character, comprising alternating valleys and ridges and includes the gold and silver deposits outlined and partly mined in the Orlea, Văidoaia, Cîrnic, Cîrnicel, Cetate and Carpeni massifs.

From an administrative perspective, the investigated mining license is part of the communes of Rosia Montana and Abrud administrative districts of Alba county, approximately 80 km north – west of the capital of the county, i.e. the city of Alba Iulia.

From a geomorphologic perspective, the region where the Rosia Montana mining district lies is part of the Southern Apuseni mountains, the Metaliferi Mountains group, located between the Gaina and Drocea mountains on the west and Vintiului and Trascau mountains on the east.

The Rosia Montana region is characterised by a highly differentiated relief, separated by deep valleys.

Streams radiate from the highest ridge tops, which are concentrated to the east of the proposed site and flow west and north into the Abrud and Aries rivers, respectively.

The Rosia Montana site is, therefore, bisected by the west-flowing Rosia stream, which drains east-west trending linear ridges. The southern ridgeline also drains west and southwest into the adjacent Salistei and Corna valleys, respectively. The ridgeline to the northeast is dominated by Rotund Hill (1091 m), which is the western-most of the higher ridges and peaks to the east of the site.

Much of the Rosia valley has been modified by mining activity and this is most evident in the west of the concession area with some 20 ha of land affected by open pit mining and dumping of rock waste.

The climate in the Rosia Montana area is temperate continental and the higher areas have an alpine microclimate with cold winters and significant snowfall.

The air temperature regime is characterised by annual, monthly and seasonal fluctuations. The annual average air temperature is 5.4^0C. The highest monthly average temperatures are recorded during July – August (15.4^0C) and the maximum absolute temperature is 27.3^0C. The lowest monthly average temperature is recorded during December - February (-3.0^0C) and the minimum absolute temperature recorded was -19.4^0C.

The precipitation regime varies largely throughout the year with the annual average value being in excess of 800 mm.

During the warmer months of the year (April - September) the precipitation amount represents 2/3 of the annual amount.

The 24 hour maximum precipitation amount exceeds 245 mm.

The total annual average precipitation for the last 10 years varied between 600 mm and 883 mm. The lowest precipitation month is February (30 mm) and the maximum precipitation month is June (102 mm). Snow pack stays from November (sometimes even as from late October) until March or April.

The maximum snow cover thickness is recorded in January and February.

In terms of the relative air humidity, the annual average is 77% however it varies during the year from 83-85% in January and December down to 72% in July and August.

Potential annual evapo-transpiration has relatively high values i.e. about 516 mm/year and is less than the atmospheric precipitation amount characteristic for mountain areas.

The predominant wind direction is south-west with an average speed of 2.3 - 4.0 m/s.

In terms of the seismic potential of the area, according to the „Rules P100/92 regarding anti-seismic engineering of residential and industrial buildings" the Rosia Montana area is located in Zone F, which is characterised by a coefficient K_s = 0.08 and corner period T_c = 0.7sec.

Administrative Location

The ROSIA MONTANA gold-silver deposit is located outside the built-up area and partially within the built-up area of Rosia Montana and Abrud, Alba county.

The commune of Rosia Montana is located 7 km away from the Alba – Iulia – Abrud - Campeni – Turda road and Turda – Abrud narrow gauge railway and is accessed from the upgraded communal road, about 7 km from Abrud.

The nearest normal train station is at Zlatna and is located on the Alba Iulia – Zlatna section.

CHAPTER 1 REGIONAL GEOLOGY

1.1 Geological and Structural Data

From a geologic perspective, the Rosia Montana region is part of the morpho-structural unit of the Metaliferi Mountains and is located very close to the northern rim of the crystalline that constitutes the structural core of the Apuseni Mountains.

The geologic composition of the region is due to the crystalline schists, Jurassic, Cretaceous, Miocene deposits and Neogene eruptive rocks.

The basement of the region is constituted of crystalline schists outcropping in the northern part, close to Musca and Baia de Aries. The crystalline schists are formed of a lower metamorphosed series such as quartz - bearing schist with chlorite and garnet, black quartzite with biotite and amphibolite, paraschists and injection gneiss and an upper series formed of crystalline limestone, quartzite, black phyllite and sericite-chlorite schists

On top of the crystalline basement lie sedimentary deposits of Lower, Medium and Upper Cretaceous which are covered – in abnormal position under the form of klippe – the Upper Jurassic deposits.

Miocene deposits forming a completely isolated basin in the middle of the Upper Cretaceous are encountered indicating sedimentation continuity. This basin has a prolonged oval shape and is intersected by a series of rhyolite and andesite eruptions with gold-silver mineralisations.

The sediments belonging to the Cretaceous in the Rosia Montana region are constituted of dark coloured schists, black or violet-blue, sandy and clayey, sandstone and grey or yellowish conglomerate, as well as marl and limestone.

The <u>Valanginian and Hauterivian</u> indicate the beginning of the Cretaceous sea by way of a marly calcareous complex with lithographic limestone intercalations. These formations are in close contact with the central zone of the crystalline schists and are similar with the *apticus* layers from the Eastern Carpathians.

The <u>Baremian</u> is represented by black schistous sandstone which could represent the Cabesti layers facies ((T. P. Ghiţulescu and V. Socolescu).

The <u>Aptian</u> is represented by satiny schists, marl and dark grey limestone intersected by calcite veins.

The <u>Cenomian</u> is represented by hieroglyphic sandstone and calcareous sandstone. The Cenomian conglomerate occurs in a single point located south-east of the Piciorului Peak and has a limited development.

The Senonian has the largest development in the region and is represented by sandstone, grey or yellowish micaceous gritty schist, conglomerate, marl and marly schists.

The sedimentary formations in the Rosia Montana area belong to a great extent to the Upper, Medium and Lower Cretaceous, outcropping along the Corna valley and being covered in the north-east side, in the east and north-east side along the Sesei valley and even on the ridge separating the Sesei valley and the upper part of the Abrudel valley by the Tortonian deposits of the Rosia basin. The Medium Cretaceous and Bozes strata facies occur in the area that lies north and south-west of the eruptive zone.

The Upper Cretaceous formations cover discordantly older formations, are less consolidated and are characterised by their richness in mica and in reshaped crystalline schist and flysch elements.

Following the tectonic sinking occurred at the beginning of the Tertiary in the Rosia Montana region, a small size intra-mountain basin filled with Tortonian deposits comprising a detritus series mixed with rhyolite pyroclastic material was formed.

The main occurrence of the Tortonian formations begins approximately along the eastern line of the Rosia Montana village and extends southward up to the Corna village.

The main Tertiary effusive rocks that are found spread in the Rosia Montana region are: rhyolite, andesite and dacite. They cover large areas, are in shape of circular or oval necks and are surrounded by a large lava blanket.

The eruptive in the Rosia Montana region is situated in area covered by the Tortonian rock, constituting the main Cetate and Carnic massifs, both massifs being represented by unitary bodies. The contour of these bodies is largely followed by the underground workings. Thus, in the case of the Cetate eruptive rocks, the contact surfaces with the north and south sedimentary material dips in the same direction. The Carnic eruptive body is rooted normally however towards the top its contours are complicated by subsequent processes.

The Carnicel massif located approximately 100 m south-west of Carnic, was formed as a result of the lava overflowing Carnic.

The eruptive rocks are white or light grey in colour due to the overall kaolinisation they suffered. Bi-pyramidal quartz phenocrystals and finely disseminated cubic-shaped pyrite crystals either uniformly spread or concentrated in nests may be observed in their mass.

The andesite in the Rosia Montana region occurred as a result of subsequent rhyolite and dacite eruptions and constitute an actual effusive belt delineating in the north and east side the Neogene basin of their lower formations.

The andesite are placed first in terms of the area covered by effusive rocks and form the Ghergheleu, Rotundu, Curmatura and Vars massifs.

Breccia shows significant development in the eruptive rock area and is related to the volcanic apparatus that functioned in the active phase of the volcanism.

1.2 Region Tectonics

The latest research regarding the volcanic apparatus in the Rosia Montana basin indicates that its structure and evolution is complex. The study titled "Geological evolution of the Metaliferi Mountains" outlines a few main stages of the volcanic activity.

The first stage corresponds to the occurrence of a predominantly explosive phase of which products are comprised in what may be seen today in the volcanogenic – sedimentary formation initially named "Lockalsediment" by Fr. Posepny (1867). Activity in this stage occurred with the overall sinking of the north-east side of the Metaliferi Mountains and local tectonic collapse

which outlines the configuration of this basin and at the same time explains the significant thickness of the formation which, right on the edge of the basin, on contact with the Cretaceous deposits, reaches an average thickness of about 200 m. The rhyolite elements in the volcanogenic - sedimentary formation constitute the only witness of this initial activity. It is possible that the craterial area or the feed channel to have collapsed before the activity was resumed or maybe, which seems more likely, to have been fully destroyed by the activity in the second stage, which was the most important anyway.

The second stage, marked by dacite effusions gave rise to two central volcanoes in the Carnic and Cetate hills. Their lava overflowed covering relatively delineated areas, rested exclusively on the volcanogenic – sedimentary formation in thickness that sometimes reaches 200 m and constitutes the surface edifice of this volcanic structure. Erosion destroyed to a great extent the architecture of this edifice in which composition there seems to be no explosion products.

The presence of breccia at the periphery of the two dacitic bodies reflects the effect of magma's ascending mechanical effort which displaced some of the less cohesive material of the volcanogenic – sedimentary formation.

The two pillars are largely covered in a muddy-looking pelitic formation which includes fragments of the Pre-Tertiary basement of volcanogenic – sedimentary formation and dacite rocks under formation. This material called "glam" enters irregularly both in the brecciated areas as well as in the adjacent fault cracks.

Glam is a muddy material accumulated on the basin bottom, fine fraction not diagenised which falls or infiltrates with large amounts of water in the cracks of the faults system created by the movement effect of the magma subsequently released by these ways through large dacite effusions. Some of the poorly consolidated rocks of the volcanogenic - sedimentary formation was in this way demolished and carried away along with the mud torrent in proximity of the faults. Subsequently, this material is to a great extent brought back to the surface along with the arrivals of dacites. They was infiltrated under pressure both in the brecciated zones of the dacite mass or at its contact with the adjacent rocks as well as in the fault cracks at various levels up to the current erosion level. In other cases, they interlard the spaces between the roots of the two pillars and also accumulate depending on the movement direction in other spaces created by the morphology of their surfaces.

The beginning of the dacitic phase corresponds to the overall rising movements of the land and probably those of the basin also which made it that only the first dacitic lava eruptions to have occurred in aquatic environment.

The third stage, which in fact develops in continuation of the previous stage, is predominantly eruptive. This gave rise to eruptive pipes filled with breccia which include basement and dacite elements. The explosive potential of this stage caused brecciation and fissuring processes in the entire structure which are more frequently developed in immediate proximity of these pipes. The time lagging of these processes created these tubular shapes, especially in brecciated areas of different age. Thus appeared the main access ways for hydrothermal solutions in conjunction with the most spectacular metallogenic phenomena, which were proved to have taken place in several stages.

The muddy material keeps being carried away during the metallogenesis in the upper parts of the structure.   This is massively impregnated with silica generating compact rocks, typically poorly mineralised.

CHAPTER 2 GEOLOGY OF THE DEPOSIT

The Rosia Montana deposit is interpreted as a maar complex emplaced into Cretaceous sediments, predominantly black shales with fine to medium sediments and Tortonian (Miocene) tuffaceous grits.

The Rosia Montana gold - silver deposit is located in the NE side of the Metaliferi Mountains.   In the Metaliferi Mountains, the volcanic activity represents the most important period of the volcanism (late Badedian, Sarmatian and Pannonian).

An intra-mountain basin occurred during the effusive phase in which deposits with mixed detritic-volcanogenic composition accumulated. Rhyolite necks crossed the Mesosoic metamorphic basement and Tertiary deposits.

The gold / silver mineralisations are localised in the sedimentary and pyroclastic deposits and in the eruptive material that intruded them. The mineralisations that are spatially associated with rhyolite are present under the form of veins.

Hydrothermalism occurred with great intensity and consisted of silicifiation, sericitiation and mineralization.

Generally, the veins are thin (1-50 cm); gold is present in native form.

Stratigraphic Data

Lithology inside the maar complex is dominated by breccia intruded by a series of porphyritic dacitic sub-volcanic intrusions. The dacitic intrusions are interpreted as Neogene age and are informally named the Cetate Dacite and Cârnic Dacite. The dacite complex is interpreted to have intruded vertically into the maar breccias and to have spread laterally at shallower levels.

A breccia, locally termed the **'Black Breccia'**, forms a sub-vertical pipe in the centre of the diatreme, between the Cetate and Cârnic dacites. The black breccia consists of Cretaceous black shale of the sedimentary sequence incorporated in the eruptive deposits from the centre of the maar complex.

The maar complex and particularly the black breccia are found at the intersection of two regional faults oriented north-west and north-east.

The andesitic extrusive rocks have been mapped as mantling the northern and eastern parts of the area forming a cover over the maar complex.

The types of breccia that have been mapped inside the diatreme complex are the following:

⇒ *dacitic breccia*, strongly hydrothermally altered with breccia fragments constituted predominantly of porphyritic dacite.

⇒ *vent breccia* representing mixed lithology breccias containing a high proportion of dacite, located in proximity of the intrusions. The size of the rock fragments, degree of rounding and the proportion of matrix varies largely. Both massive breccia as well as breccia with gradual stratification were observed. The vent breccia may contain dacitic intrusions as well as in Carnic area sub-vertical structures NE-SW trending, inside the dacite, called "internal vent breccia".

⇒ *black breccia*, brown-black diatreme breccia which predominantly includes black shale fragments and also fragments of all lithologic types in the area. This lithologic type does not contain gold - silver mineralisation with significant grades.

An extensive zone of hydrothermal alteration is associated with the Roşia Montană deposits. The distribution of alteration assemblages is complex.
However, it can be simplified to three key groupings:

⇒ *Clay-sericite-pyrite ("argillic")* assemblages that generally occur peripheral to the core zones of gold-silver mineralisation;

⇒ *Silica-adularia-pyrite-sericite ("silicic/potassic")* assemblages, which usually represent the core zones of the various deposits at Rosia Montana;

⇒ *chlorite-carbonate-pyrite (propylitic)* alteration assemblages that regionally developed within the andesites.

Mineralisation within the Golden Quadrilateral district includes mesothermal porphyry intrusive-related gold-silver, copper-gold and copper deposit types associated with Tertiary (Neogene age) volcanic rocks.

The major regional structure that controls the mineralisation in the volcanic belt is interpreted as being the major west-northwest trending fault which overlaps older faults. Breccia, intrusions and mineralisations at Rosia Montana are interpreted as being localised on an east-west trending dilational discontinuity from a structure intersected by north-east trending faults.

The mineralisation types identified up to now at Rosia Montana are the following:

⇒ *disseminated gold-silver mineralisation;*

⇒ *gold-silver mineralisation localised in veins and sometimes accompanied by low grade polymetallic mineralisation.*

The gold-silver mineralisation at Rosia Montana is interpreted as a mid- to shallow-level, low to intermediate sulphidation epithermal system that may be associated with a porphyry-style system at depth.

The geometry of the mineralised zones and lithology of the host rocks identified at Rosia Montana includes:

⇒ *Sub-vertical breccia zones crosscutting dacite intrusive bodies - breccias are commonly of mixed lithology and are considered to represent structurally controlled phreatomagmatic breccias. Mineralisation occurs within strongly, to intensely silicified alteration zones and contains low to moderate amounts of disseminated fine grained sulphide within both the matrix and breccia clasts This mineralisation type has been mined extensively as from the Roman times.*

⇒ *Disseminated dacite-hosted gold-silver mineralization - is characterised by wide zones of finely disseminated sulphide (pyrite) hosted within dacite porphyry. Significant gold mineralisation of this type occurs at Cetate, Carnic, Carpeni, Gauri, Letiu - Cos and partially at Vadoaia.*

⇒ *Mineralisation hosted in vent breccia and dacite – Gold mineralisation of this type occurs in Carnic massif where there are numerous old exploration and mining workings (Cantaliste, Corhuri, Napoleon-Corhuri, Napoleon, Piatra Corbului).*

⇒ *Quartz vein hosted mineralisation within dacite – silicified veins, steeply dipping, gold and silver mineralised, hosted in dacitic intrusions up to 1 m thick in the upper part of the dacite and thinner but more frequent at depth. These veins were intensely mined in the Austro-Hungarian Empire times.*

⇒ *Disseminated and vein hosted gold-silver mineralisation within vent breccia - significant gold-silver mineralisation is hosted by the vent breccia surrounding the dacitic intrusions and less frequent in the Cretaceous black shale. Examples of this mineralisation type are known in Carnicel, Vadoaia, Jig, Igre, Orlea and Tarina.*

⇒ *Quartz vein hosted mineralisation within vent breccia – a series of steeply dipping quartz veins, generally narrow (less than 1 m) are hosted in the volcanogenic sediment and are fine to medium grained. This mineralization type has been mined as from the Roman times at Orlea and Tarina.*

CHAPTER 3 PHYSICAL - MECHANICAL PROPERTIES OF THE ROCKS

One of the main factors that have a direct influence on determining the cutting - excavation technology is the physical - mechanical properties of the rocks.

The size of the dynamic parameters generated by the extraction activity (cutting, crushing, haulage equipment and blasting operations) is influenced by the physical-mechanical characteristics, geophysical properties, joint systems (density, orientation, characteristics of the joint fill material), sequence, orientation and extent of the geological formations.

The mineralogy, structure, texture, nature of the bond material and alteration degree determine a large range of physical - mechanical properties which we present in Tables No. 1 and 2.

Table No. 1

No.	Rock Name	Apparent Specific Gravity γ_a [tf/m^3]	Angle of Internal Friction ϕ [^{0}]	Sample Cohesion c [tf/m^2]
1.	Tuffaceous gritty micro-conglomerate	2.2	28	130
2.	Black breccia	2.4-2.5	27-28	5.7-20
3.	Altered breccia	2.31-2.44	32-33	300-800
4.	Silicified compact breccia	2.42-2.52	33-36	1100-2000
5.	Altered dacite	2.31-2.46	30-35	480-900
6.	Silicifed dacite	2.32-2.52	36-37	1150-1500

The mineralogy and structure led to a large variation range of the sample cohesion and angle of internal friction.

Mechanical strengths (compression, tensile and double shear) are shown in Table 2.

Table No. 2

No.	Rock Name	Value	Strength		
			Compression σ_{rc} [kgf/cm^2]	Tensile σ_{rt} [kgf/cm^2]	Double shear σ_{rf} [kgf/cm^2]
1.	Tuffaceous gritty micro-	min.	51	2.7	5.9
		med.	66	5.3	9.4

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	conglomerate	max.	86	8	13
2.	Altered breccia	min.	209		71
		med.	234	20	75
		max.	255		80
3.	Altered breccia	min.	261	29	105
		med.	456	54	118
		max.	632	71	159
4.	Altered breccia	min.	122	-	29
		med.	157	12	36
		max.	295	17	45
5.	Silicified compact breccia	min.	280	40	102
		med.	368	64	125
		max.	560	84	149
6.	Silicified compact breccia	min.	713	20	170
		med.	817	26	182
		max.	927	55	202
7.	Compact breccia with coarse elements	min.	368	49	183
		med.	542	71	207
		max.	726	100	223
8.	Silicified breccia with fine elements	min.	1023	51	182
		med.	1229	67	198
		max.	1406	83	232
9.	Hard silicified compact breccia	min.	712	57	127
		med.	787	71	175
		max.	899	81	225
10.	Hard compact breccia with coarse elements	min.	525	88	116
		med.	612	105	120
		max.	718	128	123
11.	Silicified compact breccia with fine elements	min.	1090	63	228
		med.	1550	90	334
		max.	2167	109	372
12.	Fissured altered dacite	min.	265	41	92
		med.	338	54	106
		max.	428	62	127
13.	Altered dacite	min.	204	16	53
		med.	313	25	74
		max.	453	38	95
14.	Altered dacite	min.	149	22	55
		med.	182	29	58
		max.	235	49	62
15.	Silicified dacite	min.	759	85	123
		med.	1230	92	147
		max.	1640	97	193
16.	Silicified dacite	min.	466	29	87

		med.	604	58	111
		max.	930	94	211
17.	Silicified dacite	min.	866	43	140
		med.	898	61	168
		max.	934	72	226

Table No. 2 shows the significant influence of the alteration, fissure and especially silicification and grain size on the strength properties and the resulting large variation range of the mechanical strengths.

The vulcanic activity in several phases result in the occurrence of rhyolite in phase I, dacite in phase II and brecciation and fissuring in the entire structure.

Tectonisation, faults, fissuring and fracturing occurred during the phase 2 of eruption when the dacitic body was emplaced and as it would cool.

The fissures and fractures in the eruptive rock mass have high frequency of up to 10 fissures/m distributed in 4-5 systems of which 2-3 are main systems.

Table 3 gives an indicative classification of the rocks by degree of fissuring.

Table No. 3

Degree of fissuring	Average extent of natural separation [m]	Content (%) of natural separation in massif		
		+300 mm	+700 mm	+1000 mm
Highly fissured	0.1÷0.5	10÷70	30	5
Medium fissured	0.5÷0.8	70÷100	30÷80	5÷40
Low fissured	0.8	10	80÷100	40÷100

The approximate rock proportions by degree of fissuring are: highly fissured rocks 15-20%, medium fissured 25-40%, low fissured 50%.

The above mentioned indicative proportions will be valid for formations encountered below the oxidation-alteration zone.

The average values of the formations that are most spread in the RMGC Project area – breccia and dacite will be considered in selecting the excavation - blasting technology.

The sound propagation speed varies from 1000-1500 m/s in sand, gravel, saturated loam, 2000-3000 m/s in marl, andesite and 4500-6000 m/s in quartz sandstone, granite, diabase. The vibration propagation speed also depends on the rock type and increases with their strength.

CHAPTER 4 MINING METHOD AND BLASTING TECHNOLOGY

Cost-effective capitalisation of the gold-silver ore resource is possible only by using high capacity mining methods and state of the art equipment.

This mining method includes conventional open pit mining with 10m high benches. The 10 m high bench and equipment suitable for the open pit mining flowsheet were considered, i.e. rotary drill rigs, 19,9 m^3 backhoe loaders, 12m^3, front-end loaders, 425 and 358 kW bulldozers and 146 t haul trucks.

A total of 4 main areas were identified based on the spatial distribution of the gold and silver resources where is possible to develop open pits i.e. Cetate (Cetate and Carpeni), Carnic (Carnic and Carnicel), Orlea and Jig.

FINAL CETATE PIT
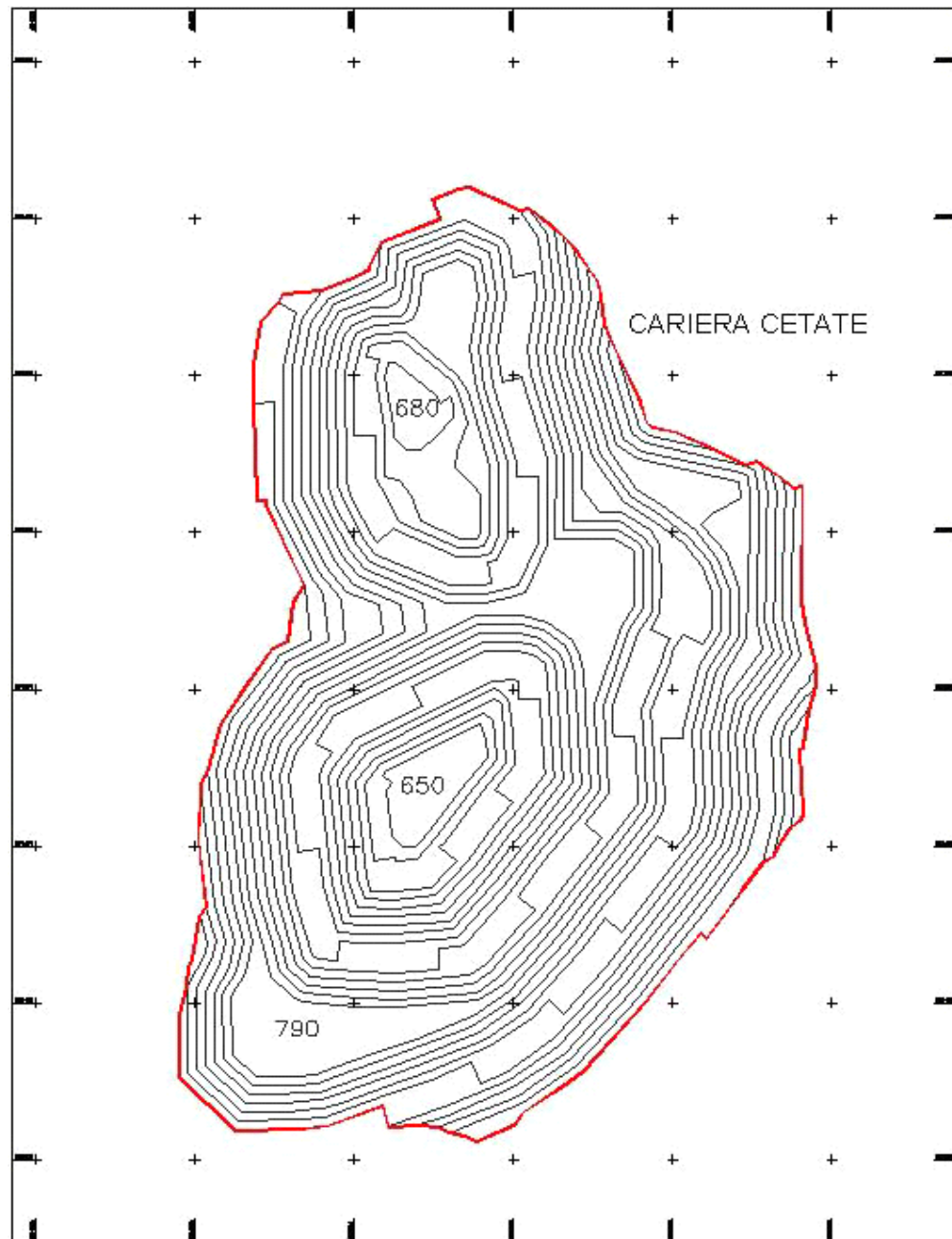
Cetate pit covers an area of 69ha. This pit will be oval in shape with length of 1100 m along the NE-SW alignment and width of 600 m along the SE-NW alignment.

The pit benches are constructed between the highest elevation +930 m and the two pit floors located in the northern area (Carpeni) at elevation +680 m and southern area (Cetate) at elevation +650 m, respectively.

FINAL CARNIC PIT
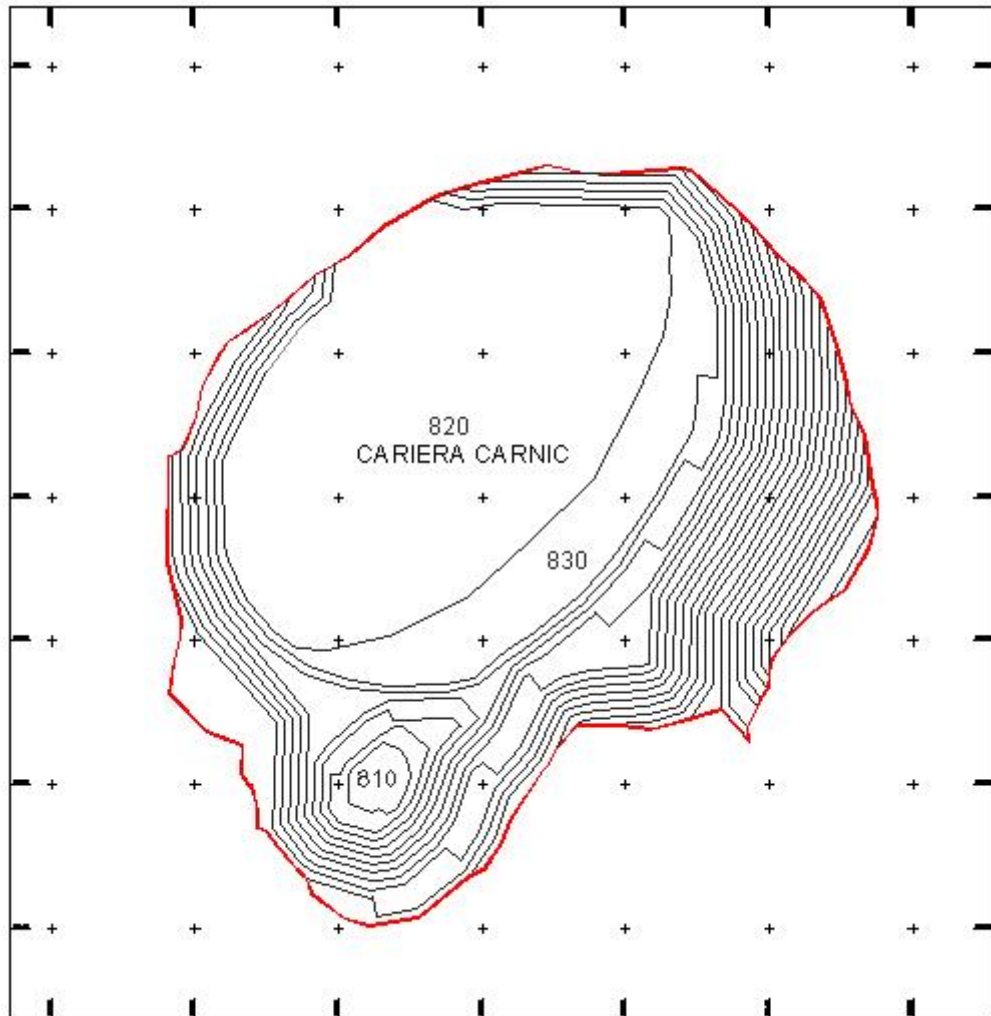
Carnic pit covers an area of 73 ha, is almost circular in shape extending E-W for 900 m and N-S for 1000 m.

The pit benches are constructed between the highest elevation +1080 m and the two pit floors located in the northern area at elevation +660 m and southern area at elevation +810 m, respectively.

FINAL ORLEA PIT
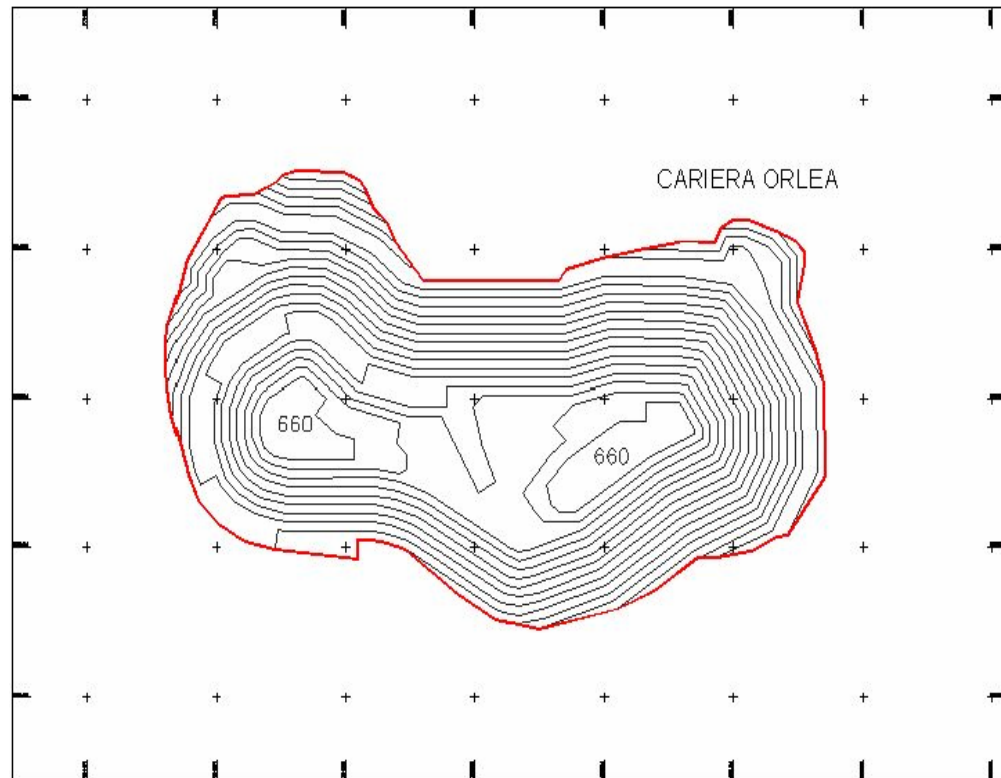
Orlea pit covers an area of 45 ha. This is partly a slope pit which deepens with an oval shaped pit developed below the ground level. It has a length of 1000 m along the E-W alignment and width of 500 m along the N-S alignment. The slope works include removal of the E-W side of a hill at the top elevation +880 m down to elevation +750 m. The pit will be deepened below the ground level and will eventually have two floors at elevation +660 m.

FINAL JIG PIT
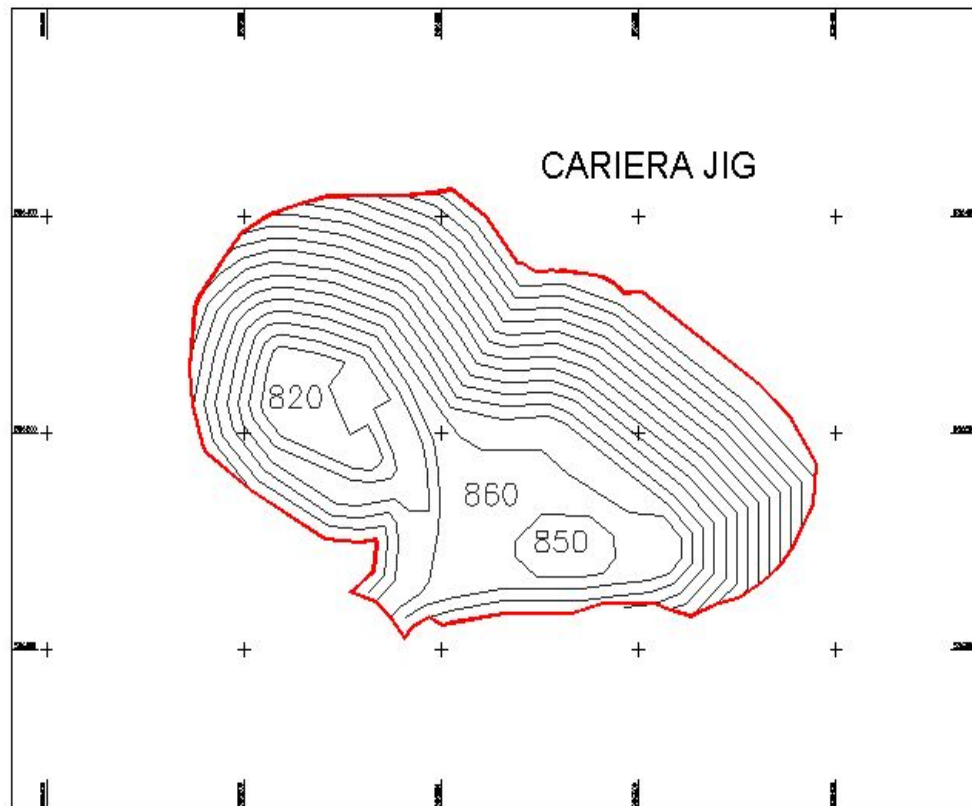
Jig pit covers an area of 18 ha and is also a slope pit (consists mainly of excavation works in a hill slope). It has a length of 850 m along the E-W alignment and width of 350 m along the N-S alignment. The top elevation is +1000 m. The slope works extend between elevations +1000 m and +820 m/850m.

4.1. Deposit Opening and Preparatory Works

Open pit mining involves prior opening and preparation of the deposit.

Opening involves providing access to the deposit and stripping works and as preparatory works defining the benches, establishing the haulage ways and work sites.

Access to the deposit for benches located above the general level is provided by a network of roads linked to the main haulage road. For benches located below the general level opening will be done by trenches. The trench will have the bottom width L = R_{exc} + 3 m, namely 25m.

The geological formations within the pit sites belong 98% to the hard and very hard rock category of which breaking requires blasting. The

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remaining 2% are oxidation – alteration rocks and topsoil which may be extracted by mechanical cutting.

4.2. Displacement Capacity

The annual displacement capacity (ore + waste rock) is almost constant during year 1 through to year 9, i.e. 35,000,000 tones and decreasing in years 10 – 14. The average annual displacement capacity is 35,000,000 tones which means 98600 t of material mined per day.

These quantities will be obtained by operating simultaneously in two pits. In each of the two operational pits work will be conducted on several benches. Each pit will be developed both in depth as well as horizontally. The minimum metal content in the material to be processed will be thus ensured. Pit mining will be carried out selectively: waste rock and ore in two sorts, i.e. high grade and low grade ore. The high grade ore will be hauled to the processing plant while the low grade ore will be stockpiled separately to be processed in years 14 – 16.

The rocks within the 4 pit sites (Carnic, Cetate, Orlea and Jig) are of the hard and very hard type and can only be displaced by blasting.

The rock will be broken using explosives emplaced in blast holes.

The rock displacement method that uses explosives emplaced in blasting chambers is not economic being comparable with the blast hole method only where the bench height is greater than 25-30 m.

4.3. Blasting Technology

4.3.1. Geometric parameters of drilling works

Diameter of blast hole corresponding to the selected equipment (19.9 m^3 backhoe loader and 150 t haul truck) that ensures the daily output of 98600 tonnes considering 355 work days is 210 mm.

The blast holes will be drilled descending and dipping at 75^0.

Depth will be 11.5 m of which the length of blast hole extension is 1.2 m.

$lsad = K_1 D$ (1)

D – 210 mm diameter of blast hole

K_1 – coefficient with value 6

Anticipating (minimum resistance line)

$W = K_2 D$ (2)

where K_2 = 25-30 for breccia; K_2= 20-25 for dacite.

Resulting

W = 6.3 m in breccia; W = 5.75 m in dacite

The holes will be placed horizontally according to a square pattern in 3 or 4 rows (fig. 1).

Distance between blast holes and hole rows is a = b = 6 m for breccia and a = b = 5.3 m for dacite.

4.3.2. Parameters of the explosive loading – blasting works

The explosive charge will be continuous (columnar) (fig. 2).

The primary blasting agent will be NITRAMON (ANFO) and the blasting initiator will be dynamite II type explosive which will represent 5% of the primary charge.

Gel type explosive or Nitramon watergel cartridge explosive will be used where there is water in the blast hole.

The amount of explosive load was determined taken into calculation the specific consumption.

- 0,23 kg/t for dacite blasting,
- 0,15 kg/t for altered breccia blasting (the weakest).

The load in a blast hole will be 160 kg TNT in dacite and 145 kg TNT in altered breccia of which 8 kg of initiator in dacite and 7 kg in breccia, respectively.

The load length in the blast hole will be 6 m in dacite and 5.6 m in altered breccia and the stemming length will be 5.5 m in dacite and 5.9 m in breccia, respectively.

4.3.3. Blast grid

The blast grid comprises a circuit of electric caps (with millisecond-delay) fixed onto the blasting fuse from the blast holes (fig. 3).

The load in a blast hole will be initiated in two points: at the bottom of the hole and underneath the stemming. The initiator load from the two points will be half the total initiator load.   A blasting fuse corresponds to each initiator load. The P12 blasting fuse length will be 27 m. An electric cap with millisecond delay will be fitted on each of the two fuses. The two fuse caps that ensure the detonation of the charge in a hole will be set to the same delay time. The electric caps with millisecond delay will be connected in series.

The optimal delay ranges between 17 - 30 milliseconds.

The number of delay levels was determined such that the seismic wave to be minimal. According to the normal practice, the seismic wave is minimum when the number of delay levels is maximum.

The delay levels will ensure the breaking of material with a core which can be achieved at one of the panel ends or in the middle of it depending on the bench conditions (fig. 4).

4.4. Estimated blasting results

4.4.1 Indicators

Indicators:
- blast hole output: 700 t in dacite and 864 t in breccia
- blast hole efficiency: 60 t/m in dacite and 63 t/m in breccia

Consumptions:

- explosive consumption: 0.23 kg/t TNT equivalent in dacite and 0.15 kg/t in breccia
- detonators consumption: 2.8 pcs/1000 t in dacite and 2.3 pcs/1000 t in breccia
- P12 blasting fuse consumption: 3.3 ÷ 3.8 m/1000 t
- drill bits consumption : 1 drill bit/1000 m blast hole, i.e. 700,000 t in dacite and 846,000 t in breccia, respectively
- drill rods consumption – 1 rod / 10,000 m blast hole, i.e. 7,000 thousand tonnes in dacite and 8,640 thousand tonnes in breccia, respectively

4.4.2 Particle size of material resulting from blasting

Particle size depends on the natural fissuring of the massif of rocks subjected to blasting. Particle size for the three categories of natural fissuring is shown in table 4.

Table No. 4

Rock Category	Particle Size Class [cm]											Average Size [cm]
	0-20	20-40	40-60	60-80	80-90	80-100	100-120	120-140	140-160	160-180	+180	
Highly fissured	58	13	11	13	5							32.5
Medium fissured	47	14	17	5	7	2	4	4				38.6
Low fissured	28	17	15	16		6	5	3	4	4	2	43.4

4.4.3 Placement of broken material

- Height of material broken by blasting: $h_1 = 7-8$ m
- Distance (placement width)

$$L = A\left(2k\inf\frac{h1}{h} - 1\right) \qquad \textbf{(3)}$$

A – width of panel subjected to blasting which depends on the number of hole rows (3 or 4)

$$\textbf{A= W + (n-1)b} \qquad \textbf{(4)}, \quad unde$$

n – number of rows of holes, 3 or 4;

b – distance between the rows f blast holes (5.3 for dacite breakage and 6 m for altered breccia breakage);

k_{inf} – coefficient of swelling of broken material: kinf = 1.4

h – bench height: h = 10 m

As a result, we have the following material placement widths:

- dacite – 3 rows of blast holes 16 m
- dacite – 4 rows of blast holes 21 m
- altered breccia – 3 rows of blast holes 18 m
- altered breccia – 4 rows of blast holes 24 m

4.4.4 Distance of throw of material

Throw of material broken by blasting occurs when the geometrical parameters for explosive charge placement and the blasting technique are not complied with.   This distance was calculated based on the following equation:

$$\textbf{D}_{ar} = \textbf{20 n}^2 \textbf{*W} \qquad \textbf{(5)}$$

where n is the throw factor. For blasting n = 1

Distance of throw will be maximum 106 m for blasting in dacite and maximum 120 m for blasting in altered breccia.

4.4.5 Seismic effect of blasting – particle vibration velocity

The seismic effect of blasting is characterized by the particle vibration velocity.

Vibration velocity depends on a number of factors listed in the previous chapters, i.e. physical – mechanical properties of the formations traversed by the seismic wave, their sequence and extent, structural disturbance of the

rocks (size, sequence and orientation), distance covered by the seismic wave (distance between the blast centre and measurement point), blasting technology and blast load distribution and size.

Velocity is determined by onsite measurements or by using the equations provided by the specialist literature.

The size of the blast load depends on: displacement capacity, blasting frequency (daily, weekly, monthly).

The high displacement capacity and local conditions require that blasting be conducted daily in several working faces in the operational pits.

The volume of ore to be broken daily will be about 98,600 tonnes at an average explosive consumption of 0.21 kg/t, which means a daily quantity of explosive of 20,600 kg in TNT equivalent to be used within at least 3 panels, i.e. 6,860 kg/working face.

Measurements have been conducted within the Rosia Montana mining district as from 1985 in order to assess the seismic effect of the underground and surface blasting.

The aim of the measurements was the seismic protection of the residential and industrial facilities located in proximity of the mining operation.

An important facility in terms of the local seismic protection is the Roman – Catholic Church.

The seismic waves generated by the blasting activities were measured for this facility in 1985 and 2006.

Seismic measurements were conducted in 1985 (by IPROMIN Bucharest) for three blasting operations in CARNIC massif and in 2006 the seismic wave generated by a blasting operation conducted in CETATE pit was recorded (by UTC Bucharest).

The results of these measurements are presented in the table below.

Table No. 5

Blasting No.	Quantity of explosive kg (TNT)	Distance (m)	Coefficient of correlation (k)	Vibration velocity (mm/s)
1/85	500	480	15	0.32
2/85	800	528	14	0.32
3/85	1000	520	27	0.73
4/06	1900	939	51	0.78

Coefficient of correlation, k (table no. 5) was determined based on the equation:

$$V = k(Q/R^3)^{1/2} \qquad\qquad (6)$$

The average value of the coefficient, k = 30, was used to calculate the maximum permissible loads.

Consequently, the formula for calculating the vibration velocity in case of blasting operations at Rosia Montana will be:

$$V(cm/s) = 30(Q/R^3)^{1/2} \qquad\qquad (7)$$

In Romania there isn't a regulatory standard for the protection of constructions against the seismic effect of blasting.

In light of the above, the provisions of the German standard DIN 4150/83 (table no. 6) were adopted in terms of the seismic protection of the heritage structures at Rosia Montana.

Limit values of vibration velocity (mm/s) as per DIN 4150/83

Table No. 6

Type of Building	Velocity (mm/s)		
	< 10 Hz	10-50 Hz	50-100 Hz
Industrial facilities	20	20-40	40-50
Residential buildings	5	5-15	15-20
Historical monuments	3	3-8	8-10

It should be noted that the 3 mm/s velocity is the maximum permissible velocity for protecting historical monument.

With formula (7) were calculated the maximum permissible loads, detonated instantaneously in the future pit, to ensure seismic protection of the local heritage structures for which maximum vibration velocity limits of 0.2 cm/s and 0.4 cm/s are permitted.

For blasting with millisecond delays the formula was adjusted with a function related to the total delay time.

The following formulas were used for these cases:

$$V = \frac{K\sqrt{\theta}}{R\sqrt{R}} f(n) \text{ for blasting with millisecond delay} \qquad (8)$$

$$f(n) = 1 - 12.9(n\Delta t)2 \text{ for blasting time >140 millisecond} \qquad (9)$$

$$f(n) = \frac{0.275}{n\Delta t} \quad \text{for blasting time < 140 millisecond} \quad (10)$$

The following calculation situations will be adopted for blasting with millisecond delay:

$$n\Delta t = 0.140 \, \text{sec}$$
$$n\Delta t = 0.600 \, \text{sec}$$

The vibration velocity at distance of 100 m, 200 m and 300 m to the structured requiring protection was calculated using the above formulas in case of blasting 6,860 kg TNT per blasting operation, as provided in the designed blasting technology.

The following particle vibration velocities are obtained (table no. 7).

Table No. 7

Blasting Type	Distance to blasting centre				
	100 m	200 m	300 m	400 m	500 m
	Vibration velocity [mm/s]				
Instantaneous	24.8	9.1	4.7	3.0	2.2
With millisecond delay n∆t = 0.140 s	17.6	6.5	3.3	2.2	1.6
With millisecond delay n∆t = 0.600 s	14.6	5.4	2.8	1.7	1.3

The data presented in table no. 7 indicates that the 6860 kg load may be used at distances to the protected structures exceeding 300 m under millisecond delay conditions.

4.4.6. Gas volume and air blast overpressure

Toxic gases which spread in the atmosphere occur as a result of blasting. The spread distance depends on the gas volume and direction and speed of air currents.

By blasting 6,860 kg of explosive in one operation the gas volume is about 150,920 l of toxic gas equivalent CO.

Blast wave overpressure depends on the quantity of explosive to be blasted. This overpressure is determined with formula:

$$P = 0.87A + 2.7 A^2 + 7A^3 \qquad (11)$$

where:

$$A = \frac{\sqrt[3]{Q}}{R} \qquad (12)$$

R - distance [m], Q - blast load, Kg TNT.

The calculation considered distances of 100, 200, 300, 400 and 500 m to the blast centre and the results are as follows:

Distance [m]	100	200	300	400	500
Pressure P [kgf/cm^2]	0.2792	0.1024	0.0972	0.044	0.036

Pressures were determined considering a surface explosives storage protected by earth walls.

4.5. Scope of the blast hole technology

The blast holes will be used to break the rocks in benches of height ranging between 4 and 10 m. Short blast hole technology involving sub-benches with 2 m maximum height will be employed for heights less than 4 m.

125 mm diameter blast holes may be used for excavation heights ranging between 4 and 8 m.

The 98600t average displacement capacity may be achieved depending on the position of the dacite or breccia blocks from the following working face lengths.

Table No. 8

Location of working face	Working face length, m	
	Number of rows of holes	
	4	3
Dacite	227	251
Altered breccia	187	222

The annual lengths of the working face are shown in table no. 7.

Working face lengths mean the length of all the faces/year corresponding to the emplacement of 3 or 4 rows of holes.

Table No. 9

Year	Excavations		Annual lengths of working face [m]			
	Dacite [thousand tone]	Breccia [thousand tone]	Dacite		Breccia	
Number of rows of blast holes			3	4	3	4
0	6,898	1,879	17,610	13,394	4,270	3,185
1	27,105	6,689	69,500	52,631	15,202	11,337
2	24,592	16,411	63,050	47,751	3,736	2,786

3	26,914	8,085	69,010	52,260	18,375	15,699
4	26,425	8,576	67,756	49,369	19,491	14,536
5	22,724	12,275	58,267	44,124	27,898	20,805
6	22,243	12,756	57,033	43,190	28,991	21,620
7	19,021	15,981	48,772	36,934	36,320	27,086
8	11,498	23,502	29,482	22,326	53,414	39,834
9	22,154	12,844	56,805	43,017	29,191	21,769
10	12,240	22,759	31,385	23,697	51,725	38,575
11	21,752	13,249	57,774	42,237	30,111	22,456
12	3,992	23,408	10,236	7,751	53,200	39,675
13	18,728	4,449	48,021	36,365	10,111	7,541
14	22,574	8,714	58,277	43,833	19,805	14,769

The special conditions at Rosia Montana – Carnic, Cetate, Jig and Orlea pits are in immediate proximity of the Rosia Montana village.

In Rosia Montana village there are heritage structures and a protection zone has been established. These structures are in an advanced state of wear and their protection requires a technology generating minimal dynamic loads.

Operational restrictions include reducing the explosive load per blasting operation and employing a millisecond delay method with a high number of delay levels. These restrictions will be applied in all the pits at Rosia Montana.

CHAPTER 5 USE OF BLASTING TECHNOLOGIES IN PROXIMITY OF ROSIA MONTANA PROTECTED ZONE

5.1 Rationale criteria for open pit zoning

The technology for breaking the rock using explosives emplaced in blast holes has a number of side effects such as ground vibration, blast wave, fly rock – effects with different extent depending on the distance to the blast centre and measurement points.

To protect the heritage structures, the above mentioned parameters exceed the permissible limits at distances less than 300 m.

These criteria led to the following zoning of the mining areas:

Zone I – zone where the basic designed technology may be employed.

Zone II – zone where the blasting technology will be changed in order to meet the permissible dynamic parameters.

At the current level of knowledge and measurement of the side effects of blasting on the protected areas, this zoning has a provisional character and will be permanently adapted in accordance with the practical results obtained during the mining operations.

Starting from this zoning, we estimate that the volume of ore displaced using the basic technology will represent about 85% of the total volume while for the remaining 15% the technology will involve emplacement of explosives in 125 mm diameter blast holes or in short blast holes.

The blasting side effects such as vibration velocity and blast wave overpressure may be controlled and mitigated by a number of technical and management measures.

Shock wave overpressure is influenced by the explosive load amount and blasting technique (electric or non-electric, instantaneous or millisecond delay). It is hazardous for people and structures that are in an advanced state of wear. The effect of the shock wave overpressure may be mitigated by the same procedures as for the distance of throw (orientation of the working faces and compliance with the load emplacement geometrical parameters).

The seismic wave (particle vibration) represents the most significant side effect on ground and constructions. It is evaluated according to velocity, acceleration or particle movement. The most used parameter where the protection of constructions is concerned is the velocity.

The particle vibration velocity was adopted as parameter on delineating the two large pit zones and the condition laid down is that the velocity should not exceed 0.2 cm/s for the construction which is nearest the blast centre.

5.2 Permissible limit of particle vibration velocity

5.2.1. Characterisation of local constructions

The constructions in the protection zone are divided in classes according to the following criteria: local natural seismicity (maximum ground acceleration, composition and frequency of seismic movement), local conditions (geological - technical and hydrogeological), importance and social use category of the construction.

Under P-100-92 Standard, the area includes constructions falling under all classes of which the most important ones that need to be protected - class I: heritage constructions and some of class II.

These constructions are concentrated in the central part of Rosia Montana village, in the protection zone.

From a seismic perspective, the zone is characterised by values of the coefficient Ks of 0.08 and corner period Tc of 0.7.

Equivalence between the seismic intensity recorded in MKS degrees is VI – VII for Rosia Montana.

In addition to the special importance of some of the constructions, their advanced state of wear must also be considered.

5.3 Calculation of the blasting parameters in the restricted zone regarding the amount of explosive load as a function of the vibration velocity.

5.3.1. Amount of explosive load

The permissible amount of explosive per blast and blast bench is determined with the above mentioned formulas.

Calculations are done considering distances of 100, 200, 300 and 400 m between the blast centre and measurement point. The measurement point will be at the boundary of the protection zone or of the nearest heritage structure.

The calculation results for instantaneous blasts (permissible velocities of 0.2 and 0.4 cm/sec) and millisecond delay blasts with total blasting time nΔt of 140 millisecond and 600 millisecond are shown in the table below.

Table No. 10

BLAST	DISTANCE BEWEEN BLAST CENTRE AND PROTECTED STRUCTURE									
	100 m		200 m		300 m		400 m		500 m	
	VIBRATION VELOCITY [cm/s]									
	0.2	0.4	0.2	0.4	0.2	0.4	0.2	0.4	0.2	0.4
	LOAD AMOUNT [kg TNT]									
Instantaneous	45	177	355	1,420	1,200	4,760	2,845	11,385	5,560	22,200
Millisecond delay nΔt ≤ 0.14	78	325	630	2,530	2,130	8,528	5,056	20,164	8,700	39,200
Millisecond delay nΔt = 0.14	352	1,407	2,820	11,236	9,500	37,947	22,500	90,000	40,000	175,790

Calculations were done using formulas (7), (8) and (9) determined following instrument measurements.

In addition, calculations were made for 0.4 cm/s permissible velocity assuming that the specialists will also consider this value given the actual distance of the protected structures located within the protected zone.

The analysis of the design data indicates as follows:

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- instantaneous blasting is not recommended for distances less than 500 m to the blast centre and at a permissible velocity of 0.2 cm/s; millisecond delay blasting with numerous delay levels and high blasting time are recommended for distances less than 200 m;
- the conventional blasting technology (with 10 m benches and 210 mm diameter blast hole) will require no changes for a distance of up to 200 m.

5.3.2. Blasting options in the restricted zone

The blasting options are mainly dependant on the amount of explosive load.

A. Instantaneous blasting

Permissible velocity - 0.2 cm/s
Distances up to 200 m -short blast holes in 2 m high benches - 5 benches
Between 200 – 400 m – 125 mm diameter blast holes in 5 m and 10 m high benches.

Between 400 – 500 m – 210 mm diameter blast holes.

Permissible velocity - 0.4 cm/s
Distances up to 100 m – short blast holes in 2 m high sub-benches.
Between 100 – 200 m – 125 mm diameter blast holes.
Above 200 m – 210 mm diameter blast holes (as per zone I).

B. Millisecond delay blasting n∆t ≤ 0.14 s

Permissible velocity - 0.2 cm/s
Distances up to 100 m - short blast holes in 2 m high sub-benches.
Between 100 – 200 m – 125 mm diameter blast holes in 5 m and 10 m high benches.
Above 200 m – 125 mm diameter blast holes in 10 m high benches.

Permissible velocity - 0.4 cm/s
Distances up to 100 m - short blast holes in 2 m high sub-benches.
Above 100 m – 125 – 200 mm diameter blast holes.

C. Millisecond delay blasting nΔt ≤ 0.6 s

<u>Permissible velocity - 0.2 cm/s</u>
Distances up to 100 m - 125 mm diameter blast holes in 5 m and 10 m high benches.
Above 100 m – 125 and 210 mm diameter blast holes in 10 m high benches.

<u>Permissible velocity - 0.4 cm/s</u>
Distances up to 100 m – 125 mm diameter blast holes.
Above 100 m – 210 mm diameter blast holes in 10 m high benches.

5.4 Details on the blasting technologies in areas close to constructions

5.4.1 Short blast hole technology

It is employed for distances up to 100 m to the blast centre. Depending on the blast time (instantaneous or millisecond delay) the permissible amount of explosive that would generate 0.2 cm/s velocity, ranges between 45 - 352 kg TNT or 177-352 kg TNT in case of 0.4 cm/s permitted velocity, respectively. Technology will be used by dividing the 10 m bench in 2 m sub-benches. The short blast holes will be drilled descending according to a square pattern. There are areas of the benches where the height is not 10 m and the short blast holes will be shorter.

The geometrical parameters and the loading-blasting parameters are given in table no. 11.

Table No. 11

Blast hole length [m]	1.2	1.4	1.6	1.8	2.0
Holes row spacing [m]	1	1	1	1	1
Distance between hole rows [m]	1	1	1	1	1
Explosive load, kg/hole	0.6	0.8	1.0	1.2	1.4
Stemming length [m/hole]	0.6	0.6	0.6	0.6	0.6
Maximum number of hole rows	3	3	3	3	3

For the short blast hole technology, the quantities of explosive are relatively high requiring a significant number of short blast holes which makes blasting difficult (loading, stemming, etc). In light of this, the drilling and loading-blasting operations will be done in several panels with sizes adapted

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to the site and equipment – management conditions. Sub-bench blasting may be conducted from the bench bottom or on all sub-benches.

Technology is of little efficiency and requires high labour and material consumption, i.e. explosive consumption - 0.21-0.22 kg/t, detonator consumption - 0.4 pcs/t, hole efficiency - below 2.4 t/m of hole. The only advantage is the possibility to achieve low particle vibration velocity.

A maximum load per blasting operation of about 126 kg of explosive is obtained by 90 short blast holes panel division. The same quantity of ore may be obtained by using the 125 mm diameter blast hole in 10 m high bench technology or by dividing the bench in 5 m sub-benches in the case of millisecond delay blasting with 0.6 sec blast time when permissible velocity is 0.4 cm/s.

5.4.2. 125 mm diameter blast hole technology

This technology may be employed by instantaneous blasting at distances above 200 m from the blast centre ((V_{ad}=0.2 cm/s) and at distances above 100 m (V_{ad}=0.4 cm/s). The millisecond delay blasting may be used to break the rock at distances above 100 m (V_{ad}=0.2 cm/s) provided blast time is 0.14 s and at distances less than 100 m provided blast time is 0.6 s however with approximately 20-30 delay levels.

Using 125 mm diameter blast holes allows for using explosive loads per hole lower than in the case of 210 mm diameter blast holes in detriment to the efficiency per meter of blast hole. Reduction of the blast hole load is also achieved by dividing the bench in 2 x 5 m high sub-benches (fig. 5) which doubles the loads per blast and gives the possibility to increase the number of delay levels and blast time.

The load emplacement geometrical parameters and the loading-blasting parameters for 125 mm diameter blast holes are shown in table no. 12.

Table no. 12

Blast hole length, m	5,85	11,5
Holes row spacing "a", m	3,2	3,2
Distance between hole rows "b", m	3,3	3,3
Explosive load, kg/m	10	10
Încărcătura de exploziv, kg/gaură	29	60
Stemming length, m/hole	2,9	5,5
Number of rows of holes	2	2
Initiator load, kg/hole in TNT equivalent	1,5	3,0
Number of electric caps	1	2
Number of blasting fuses	1	2

Blasting fuse length, m/hole		8	20
Blast grid: combined (blasting fuse + electric caps at surface)			

The blast hole load will be of columnar type. Initiation will be done with an explosive stronger than NITRAMON, preferably water resistant cartridge explosive of DINAMITA II type. A combined blasting grid will be employed, i.e. blasting fuse in blast hole and electric detonation with millisecond delay at surface. One P12 type blasting fuse will be inserted in the 5.85 m long blast holes and two fuses in the 11.5 m long blast holes. The initiator load will be emplaced in the blast hole at the middle of the primary load (5.85 m hole) or in two points at the bottom of the load and under the stemming (11.5 m hole). The two initiator loads (upper and lower) will be of the same amount.

The number of blast holes corresponding to 0.2 and 0.4 cm/s velocities in case of instantaneous and millisecond delay (0.14 and 0.6 sec blast time) blasting in 5 and 10 m high benches and the loads discussed in table no. 8 are shown in the table below.

Table No. 13

SPECIFICATION	Distance to blasting centre			
	100 m	200 m	300 m	400 m
	Number of blast holes with d = 125 mm			
A. Vibration velocity 0.2 cm/s				
A1. Instantaneous blasting:				
5 m high benches		12	43	101
10 m high benches		6	20	47
A2. Millisecond delay blasting with blast time of 0.14 s:				
5 m high benches	approx. 3	23	76	210 mm holes
10 m high benches	1	6	36	210 mm holes
A3. Millisecond delay blasting with blast time of 0.6 s:				
5 m high benches	13	79	d = 210 mm blast holes	
10 m high benches	6	47	d = 210 mm blast holes	
Vibration velocity 0.4 cm/s				
A1. Instantaneous blasting:				
5 m high benches		50	d = 210 mm blast holes	
10 m high benches	-	23	d = 210 mm blast holes	
B2. Millisecond delay blasting with blast time of 0.14 s:				
5 m high benches	12	90	d = 210 mm blast holes	
10 m high benches	5	42	d = 210 mm blast holes	
B3. Millisecond delay blasting with blast time of 0.6 s:				
5 m high benches	50		d = 210 mm blast holes	
10 m high benches	23		d = 210 mm blast holes	

S.C. IPROMIN S.A.

The 125 mm diameter blast hole operation with division of the bench in 5 m sub-benches may be conducted independently in each sub-bench however this involves setting up the access to the work platforms at each sub-bench or simultaneously on the two sub-benches. The width of the work platforms must ensure conditions to drill two rows of blast holes plus allow for another 2 m for the caving slope – in total 8.6 m.

This width ensures haulage of over 80% of the broken material to the bench bottom. Displacement will be done in a descending way – from sub-bench 2 to sub-bench 1.

The results of the 125 mm diameter blast hole operation involving 10 m benches or 5 m high sub-benches are given in the table below:

Particle size of material resulting from breaking rocks with different degree of fissuring.

Highly fissured rocks	class 0-40 cm	67%	40-60 cm	14%	60-80 cm	14%	80-100 cm	5%
Medium fissured rocks	class 0-20 cm	56%	20-40 cm	19%	40-60 cm	13%	60-80 cm	12%
Low fissured rocks	class 0-20 cm	45%	20-40 cm	15%	40-60 cm	15%	60-80 cm	13%

- Distance of throw of material

10 m – 20 m Height

5 m – 9 m Height

- Distance of throw - $D_{ar} = 20 n^2 W \approx 70$ m, the 10 m bench;
- Distance of throw - $D_{ar} = 20 n^2 W \approx 40$ m, the 5 m bench;
- The blast wave is smaller than that determined previously which corresponded to a load of 6,860 kg TNT equivalent per blasting operation.

The particle vibration velocity will be either 0.2 or 0.4 m/s and on its basis were determined the explosive loads for the two blasting techniques (i.e. instantaneous and millisecond delay).

Specific consumptions:
– explosive in TNT equivalent: 0.23 kg/t;
– detonators: 7 pcs/1000t;
– blasting fuse: 59 m/1000t (5 m bench) and 77m/1000t (10 m bench).

The output of one hole is 250 t for 10 m bench and 125 t for 5 m bench, respectively.

5.4.3 Conclusions regarding blasting technologies and techniques to be employed at Rosia Montana

Mining of the gold – silver resource/reserve within the Rosia Montana mining district by breaking the rock using explosives emplaced in blast holes given the presence of heritage structures in proximity of the Project site, in the area where the vibration velocity should not exceed 0.2 cm/s, is possible only provided certain special technologies are employed, namely:

- the short blast holes technology will be employed only where the permissible load is 50 kg TNT equivalent.
- the 125 mm diameter blast hole technology will be employed where the explosive load per operation exceeds 50 kg TNT using the option involving division of the bench in sub-benches where the load is up to 600 kg TNT equivalent and without division in sub-benches where the load exceeds 600 kg of explosive.

CHAPTER 6 DELINEATION OF THE PIT ZONES DEPENDING ON THE BLASTING TECHNOLOGY EMPLOYED

6.1 Criteria for delineating the blasting zones according to the technology

The aim of the protected zone established at Rosia Montana is to protect the historic centre of the village and any works that would change the zone are prohibited. There will be mining works (excavation, stockpiling, backfill, etc) conducted either in this zone or in the buffer zone.

The seismic protection aims not to cause any damage to the heritage structures as a result of the mining works conducted outside the protected and buffer zones.

To ensure seismic protection, maximum dynamic parameters were included in the design, i.e. 0.2 cm/s velocity which as per the MKS scale corresponds to natural earthquakes of degree I and II.

Basically, these velocities should ensure the integrity of the most sensitive and worn out heritage structures existing at Rosia Montana.

6.2 Presentation of the Rosia Montana heritage structures

The 42 structures that are classified as heritage structures are grouped in the Rosia Montana historical centre. The Technical University of Civil Engineering Bucharest made a detailed analysis. The situation of these structures is summarised in table 14.

The data review indicates as follows:

I – 2 structures are in good condition and only require some construction works;

II – 14 structures are in satisfactory condition but require a number of works;

III – 10 structures are affected by medium structural, foundation, wall, cornice, etc damage.

IV – 11 structures are affected by numerous and diverse damage;

V – 4 structures are in an advanced state of structural, wall, cornice, displacement, subsidence, etc related damage.

VI – 1 structure appear to require reconstruction in order to be protected.

In addition to the structural system the table also presents the evaluation of the condition of the construction.

Of these structures there will be discussed in detail only those located in the historical centre and near the Carnic, Cetate, Orlea and Jig pits.

Given its location, the Carnic pit is the nearest to the Rosia Montana historical centre. This area includes the majority of the old buildings listed as heritage buildings. They are located at various distances to the protection zone boundary and buffer zone.

The protection of the structure that is nearest the pit boundary will be ensured with this structure being the Roman – Catholic Church which has a slenderness ratio higher than that of all the other structures in Rosia Montana.

Roman – Catholic Church has the following structural system:
- it is a construction with foundation of natural rock
- the ground floor walls are of 100 cm thick natural rock masonry.

- the floors have timber structures
- roof is timber support type with metal sheet roof covering.

The church has an 8 – 10 m high steeple. Having ensured stability for this structure it is ensured for the other constructions located farther from the pit.

This structure served as centre for delineating the Carnic pit operational zones.

House No. 372 has the following structural system:
- construction with basement, ground floor and attic
- natural rock foundation
- 80 cm thick basement walls made of natural rock
- 50 cm thick ground floor walls made of wood
- wood floors
- wood veranda propped on natural rock foundation
- roof is timber support type with metal sheet roof covering.

The damage and degradation are the result of construction defects (no waterproofing) and lack of ongoing or overall repair works.

This building served to delineate the operational protection zones as it is the nearest to the Jig pit.

Town Hall Building No. 460 is the heritage structure nearest the Cetate pit. It was constructed in 1935 and has the following structural system:
- construction with basement, ground floor, first floor and attic
- natural rock foundation
- 50 cm thick basement walls made of natural rock
- 50 cm thick ground floor walls made of brick and rock

- roof is timber support type with grooved tile roof covering.

The damage and degradation are the result of construction defects (no waterproofing) and lack of maintenance work (advanced biodegradation process of the roof frame).

The cinema theatre was the second centre taken into consideration when delineating the operational protection zones for the Orlea pit.

The structure was constructed at the beginning of the 20th century (1900-1918).

- It consists of ground floor and attic with natural rock foundation, 85 cm thick brick and rock walls.
- roof is timber support type with grooved tile roof covering.

It is in an advanced state of wear and the causes for it are age, design and construction faults and lack of maintenance work.

6.3. Delineation of zones with different blasting technologies.

In order to delineate these zones, the vibration velocity variation graph as a function of the distance to the protected structure for a maximum load per blasting operation of 7000 kg TNT detonated instantaneously was calculated using formula (7).

Distance between the blasting center and the
protected building
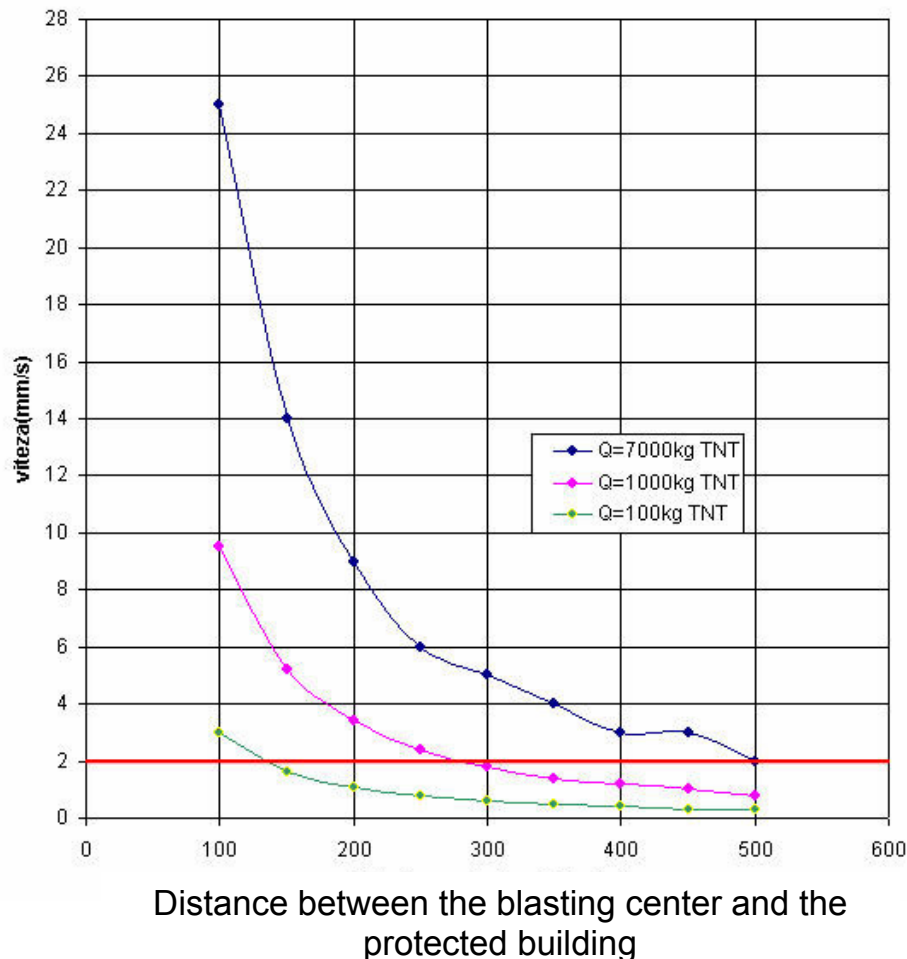
Thus, there were two large zones delineated as follows:

- zone I where the technology provided in the design report (210 mm diameter blast holes in 10 m bench) without restrictions on the load per blasting operation will be employed;

- zone II with technological blasting options involving restrictions on the explosive load imposed by the generated seismic effect.

Using adequate technologies in each of the listed zones will ensure that the maximum vibration velocity generated in proximity of the nearest structure does not exceed 0.2 cm/s.

The zoning presented in drawing 3 was done on this basis with the quantities of explosives that may be detonated without posing hazard to the protected structures being noted on the drawing.

Zone II is located within 0 – 300 m from the structure that is nearest the blast centre.

In this zone will be employed variants of the technology with elongated load, short blasting holes, 125 mm diameter blasting holes or the technology provided in the design report which involves reducing the load per blasting operation.

This zone was divided in three sub-zones according to the distance to the protected structure, namely:

Subzone II A – 100 m distance – where the technology involving 125 mm diameter blast holes in 5 m sub-benches and longer duration of the millisecond delay blasting or in 10 m benches will be employed. Explosive load will be 78-352 kg.

Zone II B – 200 m distance – where both the 125 mm and 210 mm diameter blast hole technologies may be employed. Explosive load per blasting will be 630 - 2820 kg.

Zone II C - 300 m distance – 125 mm diameter blast holes (Q = 2130 kg) are recommended or 210 mm diameter blast holes (Q = 6860 kg).

In all blasting options the working faces will be oriented such that the minimum resistance line to be oriented at 90-180^0 to the protected structure. The vibration velocity is thus reduced and also the fly rock hazard, while the blast wave and toxic gases will not affect the residential area.

Blasting operations will be conducted only in the first shift in good weather conditions without lightning discharge.

CHAPTER 7 FORECAST ON THE EFFECTS GENERATED BY BLASTING ON THE PROTECTED ZONE STRUCTURES

Calculations for the forecast on the effects generated by blasting were done using the results of the research conducted in the Rosia Montana mining district.

The first researches were completed in 1985 with blasting being conducted in blasting chambers and blast holes with discontinuous stemming. The chambers were emplaced at elevation +957m and the recording points for the seismic wave parameters about 100 m below, in the Roman – Catholic Church yard and in house no. 294 in Rosia Montana.

The completed seismic measurements indicated as follows:

- at smaller distances to the blast centre the movement and vertical velocity were lower than the radial ones.

Differences between the radial and vertical components occur with the lowering of the level of the benches, including:

- when the blast centre will be at the level of the structures, the two components (radial and vertical) will be approximately equal.
- when the blast centre will be situated below the level of the structures, the vertical component will be greater than the radial component.

In terms of the real values of these components, they will be influenced by the geological structure of the massif between the blast centre and protected structure, by the tectonic disturbances, saturation degree, etc. Also, they will be influenced by the orientation of the mining blocks against the protected structure (along the breaking direction, opposite the breaking direction or diagonally)

Transmission of the seismic effect generated by the blasting operations from the blast centre to the protected structure is influenced by several factors, including:

- geological constitution of the massif;
- propagation distance;
- ground morphology.

The attenuation of the seismic effect generated by blasting has different values along certain directions and there are preferential propagation directions or directions where attenuation is maximal.

The attenuation factor may only be determined by testing.

To assess the effects of the blasting operations in the Rosia Montana pits on the protected zone structures or on other heritage structures we considered the assumption that the seismic effect will be transmitted in a homogenous environment, the attenuation being generated only by the distance to the blast centre, resulting a maximum velocity of 0.2 cm/s in the structure area.

This assumption includes an additional safety factor and we can expect that the geologic environment will contribute to an additional attenuation of the seismic effect generated by the blasting operations.

7.1. Monitoring of dynamic parameters

Permanent seismic monitoring of the blasting works to be carried out in the future pits will be established for the seismic protection of the heritage structures.

In this sense, a fixed digital seismograph network (drawing 4) with three components installed at the main structures to be protected and a mobile network including three portable seismographs located on a longitudinal section between the protected structure and blast centre will be established.

The mobile seismic stations will serve to create an initial database based on which the final formula for determining the non-hazardous load prior to reaching zone II will be established thus ensuring the conditions to implement further measures for ensuring the protection of the structures in the protected zone.

Each fixed seismograph will be equipped with real time data transmission system (antennae) sending data to a central station where it will be stored and processed.

The seismograph network will be commissioned with the first blasting operations and will operate until the end of the operational phase of the Project.

After each blasting operation, the central station will list out an evaluation report for the seismic effect recorded by the seismograph network.

7.2 Monitoring aims

- Determine the value of the significant dynamic parameters of the waves generated by the industrial blasting conducted in the Carnic, Cetate, Jig and Orlea pits at 100, 200, 300 and 400 m from the blast centre;
- Process the data obtained under industrial conditions in the Rosia Montana pits and determine the law of variation of the dynamic parameters of the seismic vibrations (seismic effect attenuation factor).

CHAPTER 8 CONCLUSIONS AND PROPOSALS

The completed rocks mechanics study aims primarily to evaluate the effects generated by the blasting operations to be carried out in the Rosia Montana pits on the protected zone structures and identify the technological options to ensure the protection of the structures located in the protected zone or of other heritage structures.

For the blasting effects not to result in degradation or damage of the protected zone structures, the maximum vibration velocity measured near the protected structure must not exceed 0.2 cm/s.

This figure was adopted by consulting the specialist standards in force in countries having tradition in this area and meets the requirements of the German standard DIN 4150/83.

The completed analysis showed that the conventional blasting technology with explosives emplaced in blast holes may be employed up to distances of maximum 300 m to the nearest structure.

This technology may be employed for an area representing about 85% of the pits area.

At smaller distances, in order for the vibration velocity measured near the structure to be maximum 0.2 cm/s, the seismic effect be thus negligible, special blasting technology involving reduction of the blast hole diameter and length, reduction of the amount of explosive detonated per blasting bench or operation, etc must be implemented.

This zone covers about 15% and includes small quantities of ore requiring breaking by blasting. Zone II extend up to maximum 300 m from the nearest structure. The main criterion for this division is the 0.2 cm/s ground vibration velocity required under DIN 4150.

Zone II was also divided in three blasting option sub-zones, i.e.:

- o II A up to 100 m from the protected structures conventionally called immediate protection;
- o II B between 100 and 200 m from the structures – protection zone.
- o II C between 200 and 300 m from the protected structure

The technology to be employed up to 100 m involves short blast holes with restricted explosive load per blasting operation.

In the interval between 100-200m the blasting technology will involve 125 mm diameter blast holes in 5 m high sub-benches or 10 m high benches. Use of 125 mm blast holes in 5 m high sub-benches allows for splitting the explosive load of a blasting operation in several holes and thus the number of delay levels is increased. Use of 210 mm blast hole would result in a reduction of the number of loads per operation, increase of the load per delay level, reduction of the blasting time and increase of the particle vibration velocity.

Between 200 - 300 m, both the 125 mm and 210 mm diameter blast holes may be used.

Each sub-zone has a corresponding maximum explosive load per blasting operation.

In sub-zone IIB, up to 200 m, the 125 mm diameter blast holes in 5 or 10 m benches or the 210 mm diameter blast holes with restricted number of holes may be used.

To quantify the effects of blasting on the protected zone structures and on other heritage structures, implementation of a monitoring system was proposed comprising a fixed digital seismograph network with three components installed at the main structures to be protected and a mobile network including three portable seismographs located on a longitudinal section between the protected structure and blast centre.

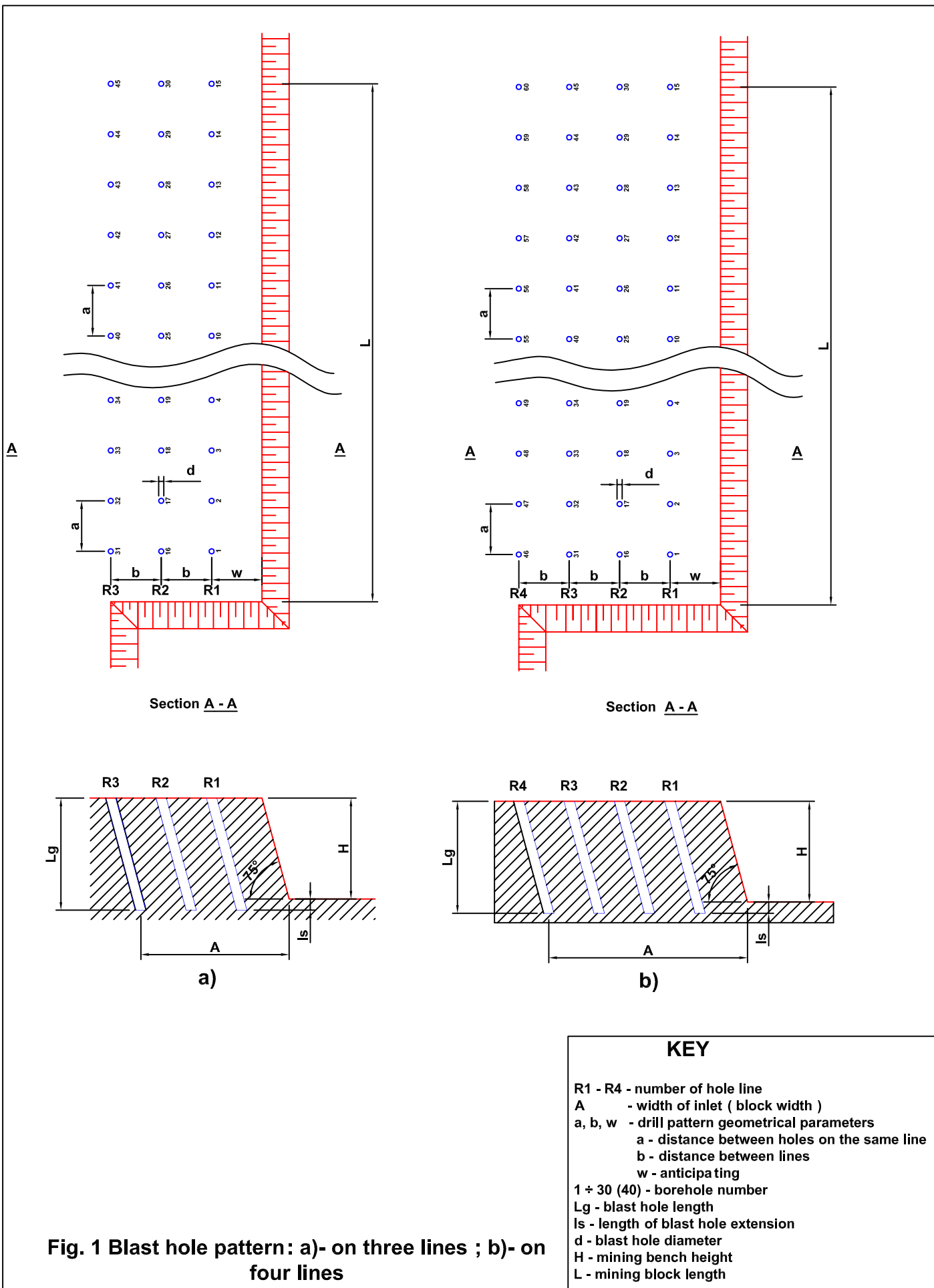Section **A - A**   Section **A - A**

a)   b)
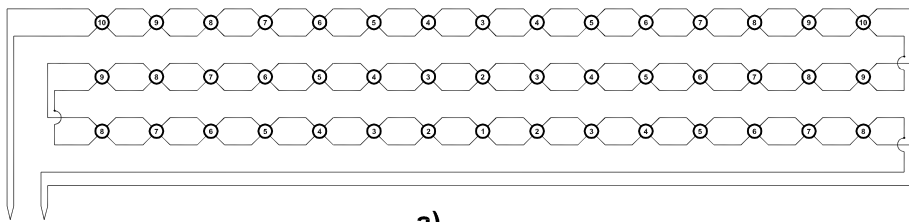
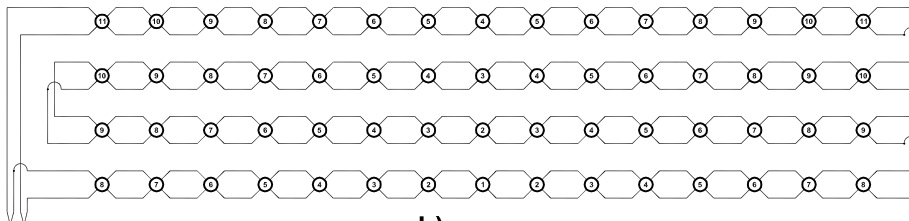**Fig. 1 Blast hole pattern: a)- on three lines ; b)- on four lines**

KEY

R1 - R4 - number of hole line
A   - width of inlet (block width)
a, b, w   - drill pattern geometrical parameters
           a - distance between holes on the same line
           b - distance between lines
           w - anticipating
1 ÷ 30 (40) - borehole number
Lg - blast hole length
ls - length of blast hole extension
d - blast hole diameter
H - mining bench height
L - mining block length
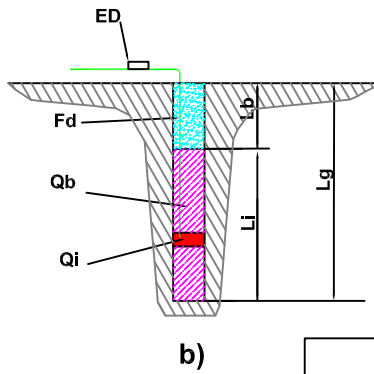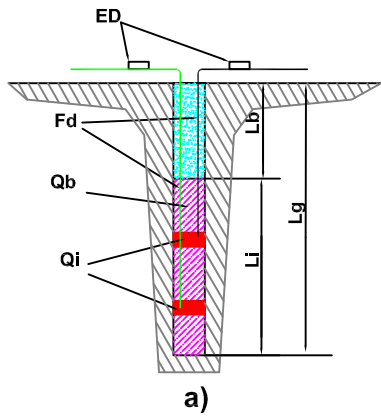
Fig. 2 Construction of explosive charges in the blast hole :
a) - 8 m high bench
b) - 10 m high bench

KEY

Lg - blast hole length
Lb - stemming length
LInc - explosive charge length
Qb - base charge
Qi - initiation charge
Fd - blasting fuse
ED - electric detonator (fuse cap)

Fig. 3 Mixed blasting pattern - clasting fuse in hole and caps with micro-delays at surface - series connected:
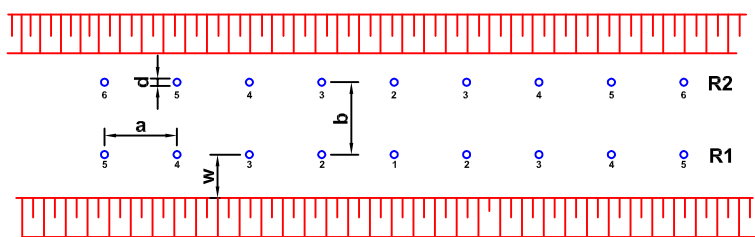**a)- on three lines ; b)- on four lines**
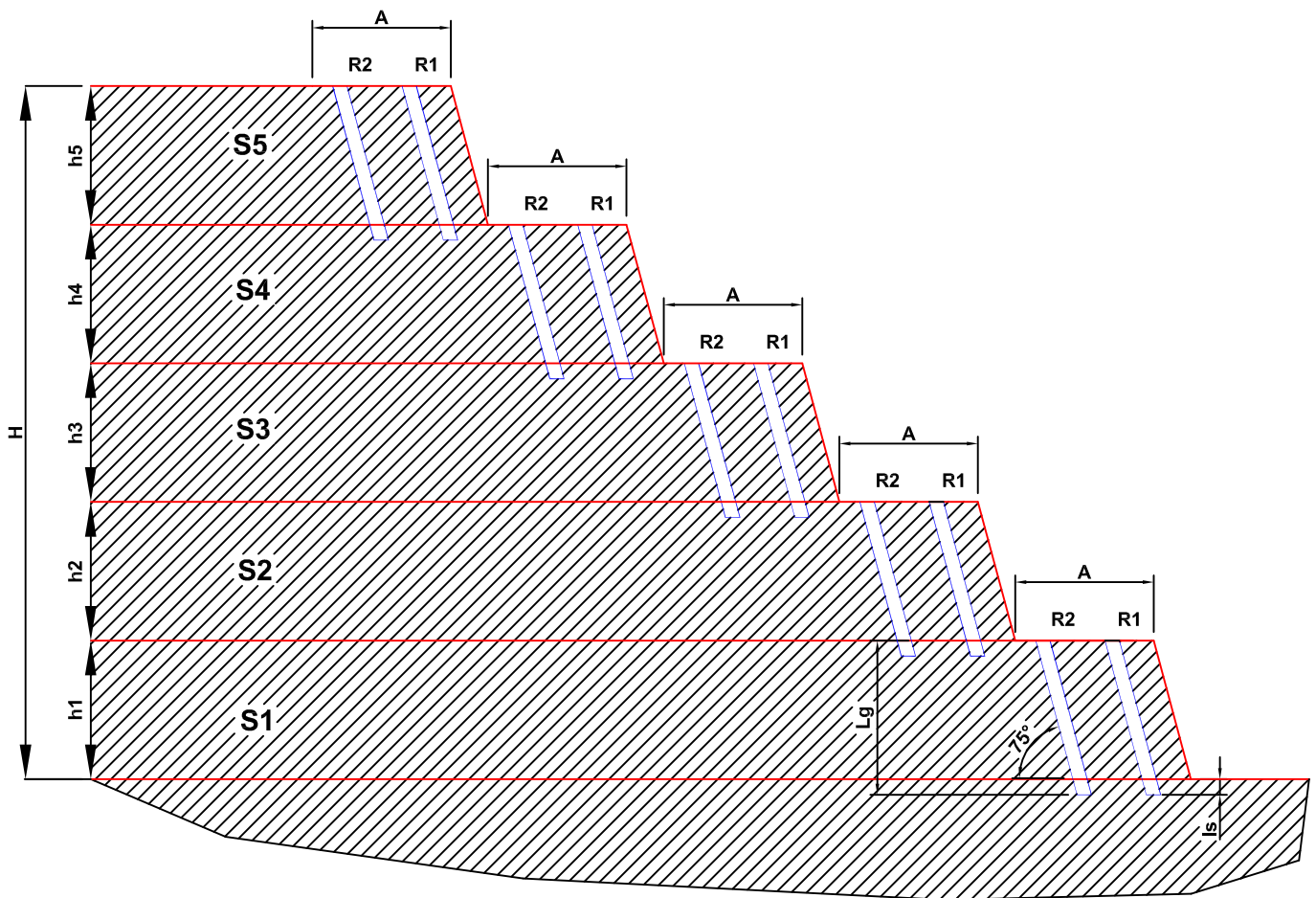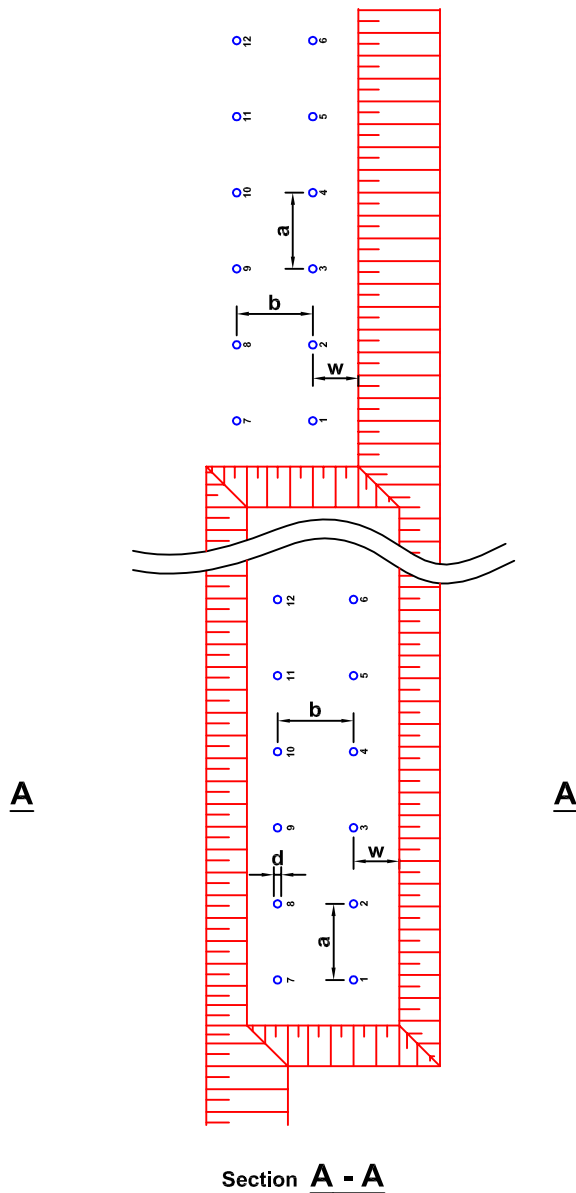**1 ÷ 10 (11) - delay levels**

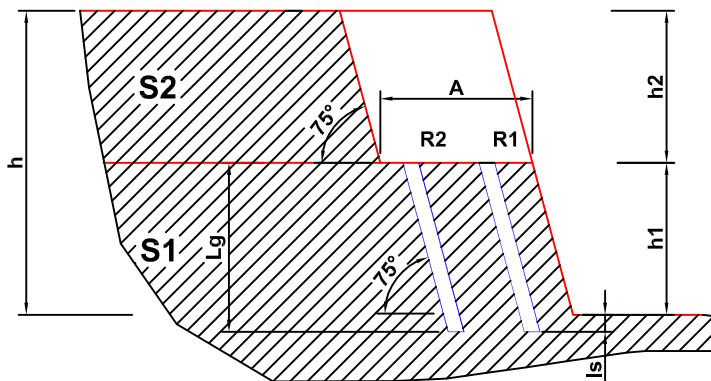**Fig. 4   Blasting method using explosives in blastholes and sub-benches splitting**

Key

S1 ÷ S5 - sub-benches

h1 ÷ h5 = 2m - sub-bench height

H = 10m - mining bench height

A - sublevel inlet width

R1 ; R2 - blast hole lines

a - distance between holes
b - distance between lines
w - anticipating
d - blast hole diameter
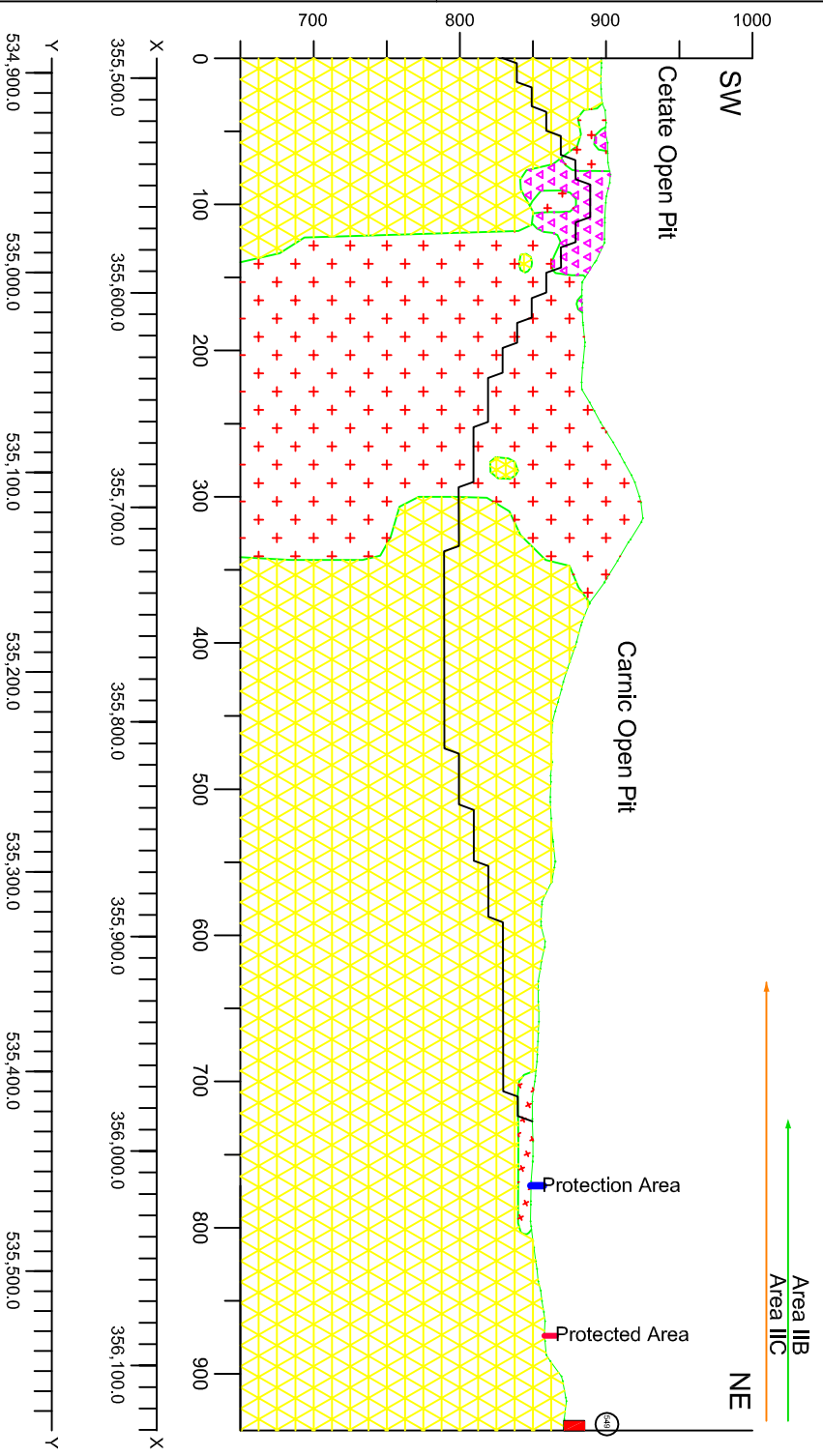lg - blast hole length
ls - length of blast hole extension
1 ÷ 6 - delay level

Excavation Order:

- ascending S1 ÷ S5
- descending S5 ÷ S1
- simultaneously S1 ÷ S5

Section **A - A**

Key

S1 ; S2 - sub-benches

h1=h2=5m - sub-benches height

h=10m - mining bench height

A - sub-bench inlet width

R1 ; R2 - blasthole lines

a - distance between holes

b - distance between lines

w - anticipating

d - blast hole diameter

lg - blast hole length

ls - length of blast hole extension

1 ÷ 12 - blast hole number

Blasting Method:
- instantaneous blasting 1 ÷ 12
- micro-delays blasting:
    - hole and delay level
    - grouping of holes by delay level

Fig. 5   Blasting method using explosives in blastholes and splitting in sub-benches

Section 4-4'

SW — Cetate Open Pit — Carnic Open Pit — NE

Protection Area
Protected Area

Area IIB
Area IIC

KEY

- Vent Breccia
- Dacite
- Black Breccia
- Area IIB
- Area IIC

S.C. IPROMIN S.A.
BUCURESTI

Designed	Geol. Cegu Adrian
Verified	Eng. Gabriel Neamtu
Project Mgr	Dr. Eng. D. Panait

Note

GABRIEL
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BENEFICIARY:
S.C. ROSIA MONTANA GOLD CORPORATION S.A.

Geo-mechanical Study for Assessment of
Blasting Operations of Protected Area Buildings

GEOLOGICAL CROSS-SECTION 4-4'

Scale 1:5000	Date: March 2006

Dnw # 6

Phase:Study