

# **Modelling and 3D Visualisation of Landscape Changes in the Roşia Montana Basin**

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## ***Abstract***

The town of Roşia Montana is located above one of the largest gold and other precious metal deposits in Europe. Gold and silver have been mined for centuries here, even as early as pre-Roman times, as proven by recent archaeological results indicating the presence of Celtic inhabitants as well. Since then but mostly in the 20<sup>th</sup> century the landscape has undergone significant changes. Until the dawn of open pit mining the ores were extracted using shafts and tunnels, or panning from the river, leaving little if any marks on the surface. Large-scale open cast mining began in the late 20<sup>th</sup> century when two large pits were excavated in the immediate vicinity of the little town. After a few decades their production rate decreased, relocating the mining activities into a neighbouring valley. Presently the Roşia Montana Gold Corporation (RMGC) is planning to reopen the gold deposits in the area by starting the largest open cast mine site in Europe. The project aroused much controversy and international protests regarding its consequences on the population and the environment.

The current study aims to model the landscape in the past in some selected time periods. In addition, a significant section will attempt to predict and visualise the future landscape after the full development of the project.

## ***Keywords***

landscape change, open cast mining, GIS, visualisation, prediction scenarios

## ***Introduction***

Roşia Montana (German name: Goldbach, Hungarian name: Verespatak) is the oldest recorded and still operational mining settlement in Europe. It is located in the central-western part of Romania, about 80 km NW from Alba Iulia, the capital of Alba County (Fig. 1). It is surrounded by the Apuseni Mountains, the famous region called “the Golden Rectangle” for

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centuries. This area conceals the largest reserves of gold, silver and other precious metals in Europe, which have been mined in the Arieş valley for millennia.

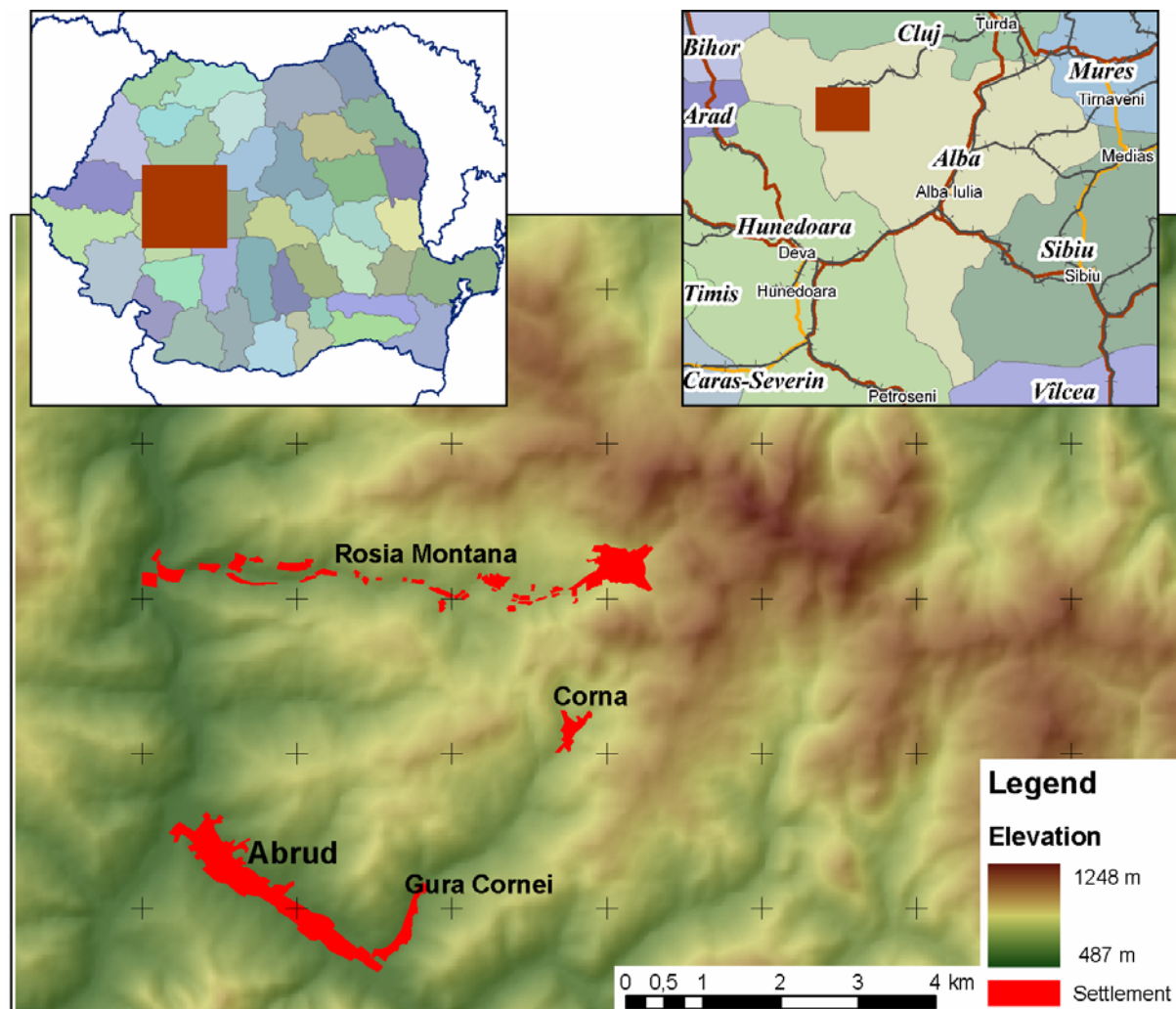


Figure 1. Location of the study area (ESRI ArcMap; insets data: ESRI, 2001)

As mining techniques developed throughout the centuries, less and less attention was paid to environmental impacts. The most impressive example of environmentally friendly methods (and perhaps “long term thinking”) was the Roman period, when the settlement was called Alburnus Maior. “Mining experts” were brought from Illyria and Dalmatia who oversaw thousands of slaves burrowing through and through the mountains. The result was an extensive network of tunnels and shafts, often interconnected, in the length of several kilometres, always following the veins of gold. Some of these tunnels can now be visited as part of a mining museum in Roşia Montana (Fig. 2) and the neighbouring Cîrnic. The intriguing thing about these tunnels is that most of their entrances have been sealed off after their resources were depleted, so that no one could accidentally enter them and (probably) also to decrease the visual impact on the landscape. Today these tunnels can be seen as holes in the walls of mine pits. The Romans deemed it unnecessary to transform the natural

conditions; it is known they have had an understanding of energy produced from water and the wind, but they did not exploit them for exactly the same reason.



*Figure 2. Roman mineshafts in Roșia Montana open for public (photo by authors, 2005)*

It is important to note here, that these shafts are unique in the whole of Europe, they represent extraordinary archaeological values. The museum also displays replicas of some wax tablets containing mining contracts (e. g. from 6<sup>th</sup> February 131 A. D., Fig. 3).



*Figure 3. Monument of contract tablet in the wall of mineshaft entrance open for visitors (photo by authors, 2005)*

Of course nowadays the main driving force behind any enterprise is profit, so (where the conditions are favourable) open cast mining is preferred instead of the “old” underground techniques. This method is much more cost efficient, requires less human resources, the miners are exposed to much less risk, etc. Today's technology enables mining companies to extract, transport and process several thousands of tons of rock per day. There is of course the question of profitability. According to the previously conducted feasibility study of RMGC, the Roșia Montana region possesses the largest contiguous gold and precious metal deposits



in Europe; a metric ton of rock contains 1.52 g gold and 7.47 g silver in average, close to the 1.2 g/ton cutoff grade, which is the minimum ore content required for profitable extraction.

Open cast gold mining is a very controversial issue, especially because the usage of the extracted gold, as environmentalists often campaign, does not justify the huge environmental impact of the mining operations. Most of the mined gold is used in the jewel industry, resulting in very little practically usable product at the expense of entire hectares of natural landscapes, leaving contaminated waters, risks of dam failure, Acid Rock Drainage (ADR) and mass relocations behind.

The environmental impacts of open cast mining are always considerable, which is why there is much controversy around this technology, especially in case there are populated areas in question. Of course, there is much less impact if the landscape is already barren and uninhabited: apart from the terrain, not much will change after the pits and waste dumps have formed. On the other hand, populated areas rich, might as well say extremely rich (as in our case) in cultural, historical, aesthetic and of course natural values [including more than 70 protected and strictly protected species of plants, some of which grow only here (Géczi – Bódis, 2003)] experience much more loss (Fig. 4.).



*Figure 4. Aerial photograph (from ESE) of the Roșia Montana mining site (Cetate pit) with the town in the background (photo: RMGC website, 2002)*

Unfortunately many open cast mine sites are located relatively close to settlements (another financial aspect: workers must be transported over the least possible distance), partly which is why mining projects are required to prepare a recultivation, rehabilitation strategy. This means that they have to plan in advance how they intend to repair the damages done to the original landscape. These plans however cannot always be completely achieved, which can result in unfinished forestations, uncleaned tailings lakes, etc. This latter is especially dangerous, because open cast gold mines use toxic compounds such as cyanide for the purification process. During the previous, state owned mining operation mercury was used instead of cyanide, which is much less efficient in the gold extraction process. The poisonous remains of the gold bearing rocks are liquefied and collected in large ponds, even lakes, which later have to be somehow reintegrated into the landscape, possibly even into human activities. The present study aims to visualise several phases of the Roşia Montana mining activities. We say activities, because the time-span of the research reaches back as far as the Roman times. From then on, we demonstrate how various GIS techniques and graphics software can be used to visualise landscape changes. The final result will be a time lapse animation showing landscape development in the Roşia Montana catchment basin from the Roman times up until the year ca. 2025, when RMGC plans to cease all mining operations completely, after of course the recultivation of artificial features. Future dates are to be viewed hypothetically, since the RMGC project is currently still undergoing the process of permission (in 2005).

## ***Methods & Data sources***

In the present paper we used several GIS techniques in order to perform the visualisation and modelling. Some of these were advanced digital terrain modelling, GPS measurements, satellite imagery interpretation and modification, digital mapping, etc. Almost all of these procedures were performed using ESRI software, such as ArcView GIS 3.2, Arc/INFO 8.2, and ArcGIS 8.2 (with Spatial Analyst and 3D Analyst). The modification of satellite images was completed in a free graphics software application (GIMP for Windows)<sup>2</sup>. 3D images and animations were created in ESRI ArcGIS ArcScene; still images were further enhanced for more realism in GIMP.

In order to visualise landscape as precisely as possible we need many types of GIS data. For the present study we used LandSat satellite images from the year 2000 to represent the current land cover patterns. This image has a spatial resolution of 25 metres (meaning the smallest individual picture element is 25×25 metres), which enables us to “fly” above the virtual terrain as low as 2-3000 metres. This resolution allows the distinction and recognition of

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<sup>2</sup> <http://www.gimp.org>

landscape elements larger than 100-150 meters in “diameter”, so it has some limits. Much more detail and precision can be achieved using aerial photography, which we plan to include in the future developments of this research. The images were “updated” to show the proposed landscape by taking colours and textures from relevant existing objects such as lakes, tailings ponds, waste dumps and placed them into the locations of planned features.

Of course, even with the expression “a picture speaks for a hundred words”, for visualisation we need the terrain as well. Many methods have been developed in the past few years in Digital Elevation Modelling (DEM) for accurate representation of terrains. For the purposes of this study we turned to the global elevation database compiled by NASA, the National Geospatial Intelligence Agency (NGA) in conjunction with the German Aerospace Centre (DLR) and the Italian Space Agency (ASI) originating from the Shuttle Radar Topography Mission (SRTM)<sup>3</sup>. This dataset was generated using a 60-metre-aperture radar located on board the Space Shuttle Endeavour in February 2000. The mission utilised radar technique to measure the terrain of the planet between the Northern and Southern 60° latitudes. The result is a global Digital Surface Model (DSM), which represents more or less accurately the surface of our planet. More or less accurately, because there can be some disturbances in the interpretation of the radar reflections causing errors in the surface. These misreadings can be corrected quite simply however, so the SRTM database is an optimal choice for GIS research involving terrain modelling on the regional level (e. g. hundreds of hectares and above). The SRTM model describes the surface in ca. 90×90 meter units called “cells” in raster elevation modelling. Each of these cells contains an integer value signifying the elevation of the given cell in metres. The raw SRTM data often displays as very rough, jagged terrain because of the integer values, so we had to modify it a little. In order to minimise this jaggedness, contour lines were generated with 5-metre intervals and another surface was interpolated from them using the TopoGrid module of ESRI Arc/INFO 8.2 (based on AnuDEM by Hutchinson, M. F. 1997). This resulted in a 20-metre-resolution DEM, which is much more appealing to the viewer. It is important to point out, that while the spatial resolution did increase (cell size became less), the actual information content did not change: all we achieved was a smoothed surface, having not only integer values as opposed to the original SRTM data. Nevertheless the resolution and precision of the other data used in the research and the artificial features built into the terrain did not require much more detail.

The third and final data source we used were the actual maps of the mine operation stages. These would be used to model the artificial elements of the terrain, such as mining pits,

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<sup>3</sup> <http://www2.jpl.nasa.gov/srtm/>

tailings ponds, waste dumps. The maps in question contain the planned extent, location and depth/height of the features mentioned above. The modelling process required the entry of these data only, so we did not have to process all the elements displayed in the maps (contour lines, roads, grid lines, etc.). The few items we did process were the following:

- external boundary of artificial features (pits, tailings ponds, waste dumps, other objects) as 3D lines with elevations taken from the original refined SRTM surface;
- outline and elevation value of flat areas (pit bottoms, waste dump “plateaus”, water surfaces, and levelled terrain) as polygons.

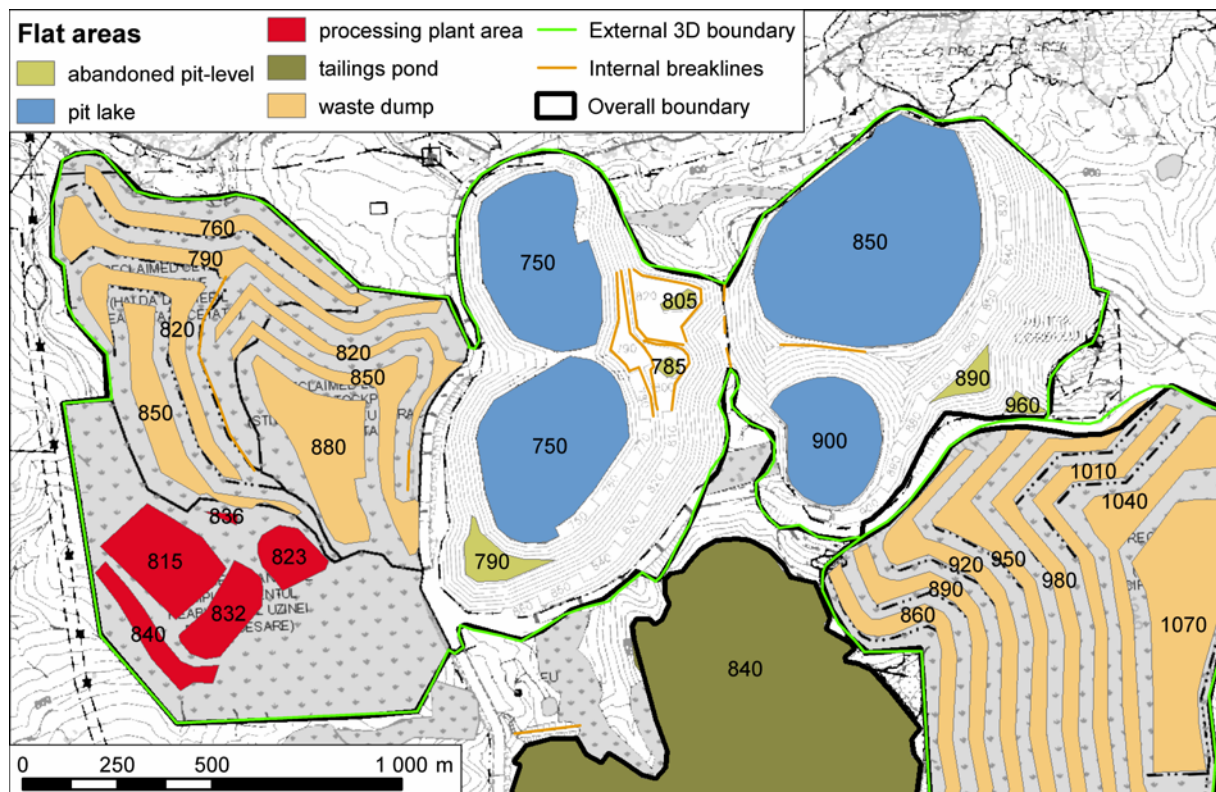


Figure 5. Example of digitised vector data (RMGC year 21), elevation in metres (ESRI ArcMap; base map: RMGC 2004)

The above features were digitised and mapped for all the available time stages using ESRI ArcView GIS 3.2 and ArcGIS 8.2. These maps were available on the Internet as PDF files (RMGC, 2004), so after some conversions we were able to integrate them into our models. Integration consisted of selecting and digitising the required vector features, generating a TIN<sup>4</sup> surface from them, converting this TIN into raster format and merging the new raster model into the original DEM. The conversion was required mostly for aesthetic reasons: natural terrain looks too sharp-edged in TIN models. The whole procedure described above can also be performed using solely TIN methods. Future developments of the research will

<sup>4</sup> Triangulated Irregular Network – terrain modelling technique which uses node points of known elevation and edges between them forming irregular triangles to describe the surface; suitable for artificial terrains.



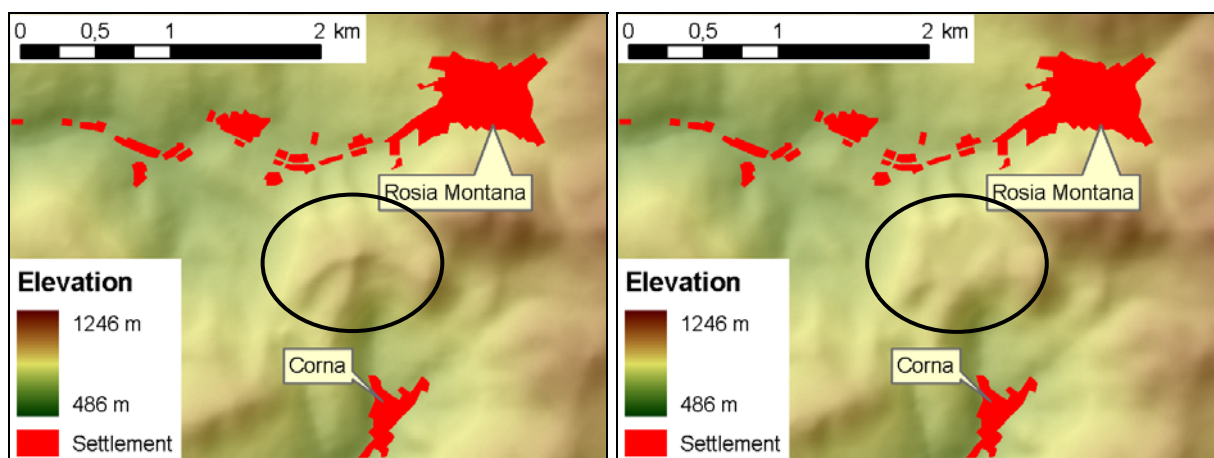
include aerial photography, which enables us to construct much more detailed terrain models with roads, buildings, facilities and other structures as well.

## Results

The Results section of this paper may appear quite unusual, because pictures, illustrations will dominate most of it. The images show the terrain in two ways: the one on the left displays the Digital Terrain Model (DTM) colour coded for elevation, the right hand side of the images show it the way it would look from an aeroplane's point of view. The orthographic map also shows the various flat areas as taken from the RMGC plans. The two display modes enable us to view the area through different glasses at the same time. Below the image of each development stage there is a table summarising the amount of material that is to be relocated compared to the previous phase. These amounts can be calculated in most GIS applications using the “before” and “after” surfaces of the given stages. There is also a textual explanation describing the changes. North is indicated by blue arrow in perspective images, which display the terrain in two times vertical exaggeration for better visualisation.

### Roman era – 18<sup>th</sup> century

The image on the left (in Fig. 6) shows the area in close-up in its initial state: no visible damages to the environment, no sign of the enormous, presently visible open cast pit to the east, everything is “as it was”. Due to the lack of contemporary maps we display the current extent of the settlement for reference. The terrain of this period was approximated based on the amount of material that has already been extracted from the existing quarries just south of the town. The morphology and characteristics of the surrounding hills also provided hints as to how the mountains looked that have been destroyed by mining during the 70's and 80's (Cetate pit).



*Figure 6. The terrain before the beginning of open cast mining (note Cetate missing in the right hand image; ESRI ArcMap)*



The 18<sup>th</sup> century brought about little change concerning the environment: mining was still conducted underground, with additional panning sites along the river. The most significant impact is the rapid growth of the settlement: this is the time when Queen Maria Theresa “imports” mining experts from Austria, and settlers from several locations establish the core of today's Roşia Montana. There is still no evident sign of trauma, destruction to the natural environment, only a few narrow strips of forest were cut down, partially to make way for the newly built railroad and two small lakes were formed (Lake Brad and Lake Mare).

## **20<sup>th</sup> century – Mass production**

Beginning in the late 19<sup>th</sup> century, processing the ore is becoming more and more machine based. Water driven stone mills (now on display in the museum of Roşia Montana) are replaced with state-of-the-art steam powered equipment imported from even as far as the United States, and later from the Soviet Union. This is the time of the largest scale environmental destruction: very little (if any) attention is paid to nature, the population and most importantly to the rehabilitation of devastated areas. The two large quarries are excavated in the 50's and continue to grow throughout the years. Mass production is the main goal without much regard for anything else. The area is occupied by the state owned mining company, offering jobs to the local inhabitants, providing services for the miners and their families, but these turn out to be short-lived achievements. By the end of the 80's the economic conditions made mining extremely inefficient, with the amount of ore decreasing in the pits, the number of miners became too high, thus the entire operation was gradually closed down. Copper, lead and other metals are still mined however in the neighbouring valley to the east. The Cetate pit lies abandoned since, and nature slowly finds its way back into it.

However the amount of extracted material in the past 30 years seems quite insignificant when compared to the volume of material to be relocated by the RMGC project (as confirmed by our calculations as well, see Conclusion).

## **RMGC year 0 – Preparations**

The images (Fig. 7) show the area almost as it was in 2000. Fortunately both the elevation model and the satellite image come from the same period of time, so they can be combined perfectly. We can see the so-called Cetate pit (light green), the remnants of the most recent mining operation. Smaller waste dumps are also visible in the image (pink). The only change is the tailings pond's appearance in the Corna valley (peach), reaching just below the village of Corna. The dam is planned to be constructed gradually according to the height of the

material accumulated behind, initially it is planned to reach an elevation of 742 metres above sea level, creating a pond of almost 60 hectares (Table 1).

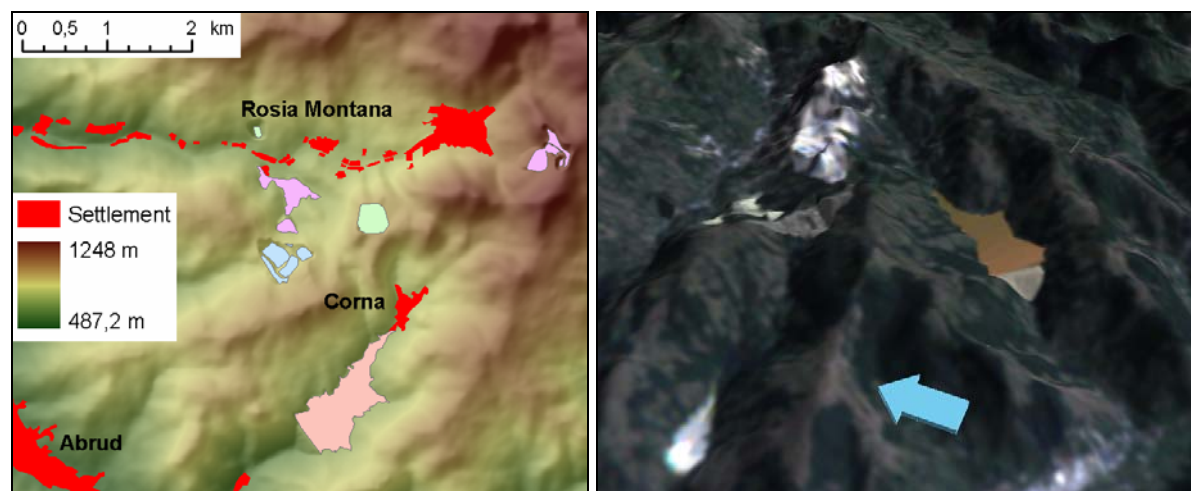


Fig 7. The terrain and perspective view of the study area in the initial stage (ESRI ArcScene)

Land form	Volume change (1000 m <sup>3</sup> )		Area change (hectares)	
	Compared to year 0	Total volume (since 2000)	Compared to year 0	Total volume (since 2000)
Tailings pond	-	+ 15150	-	55

Table 1. Area and volume changes due to material relocation (ESRI ArcView 3D Analyst)

## RMGC Year 7 – Initial mining operations

The two operational pits (light green) are being mined intensively: Cetate has become much deeper and extended to the north, while the neighbouring Cîrnic pit has developed in less than seven years into almost the same size as Cetate (Fig. 8). This can tell us something about the enormous excavating capacities involved in the mining operation.

The eastern waste dump (pink) has also grown out from the ground quite rapidly. These structures are built in a way so that future re-plantation and water-drainage could be performed more efficiently. Vegetation can take use of the regularly spaced flat terraces planned along the slope every 30 metres in elevation. Water drainage is facilitated by the establishment of a complex network of draining pipes, leading seepage into the tailings pond.

The tailings pond itself (light blue) has grown quickly in the first seven years. The bottom of the pond is sloped to lead all water towards its central part, from which it can be discharged through the dam into purification plants below. The dam (crest elevation: 810 m) has grown rapidly about 40 metres since its establishment. The pond now covers an area of 153.4 hectares (Table 2), its length being 2.3 kilometres, flooding Corna entirely.

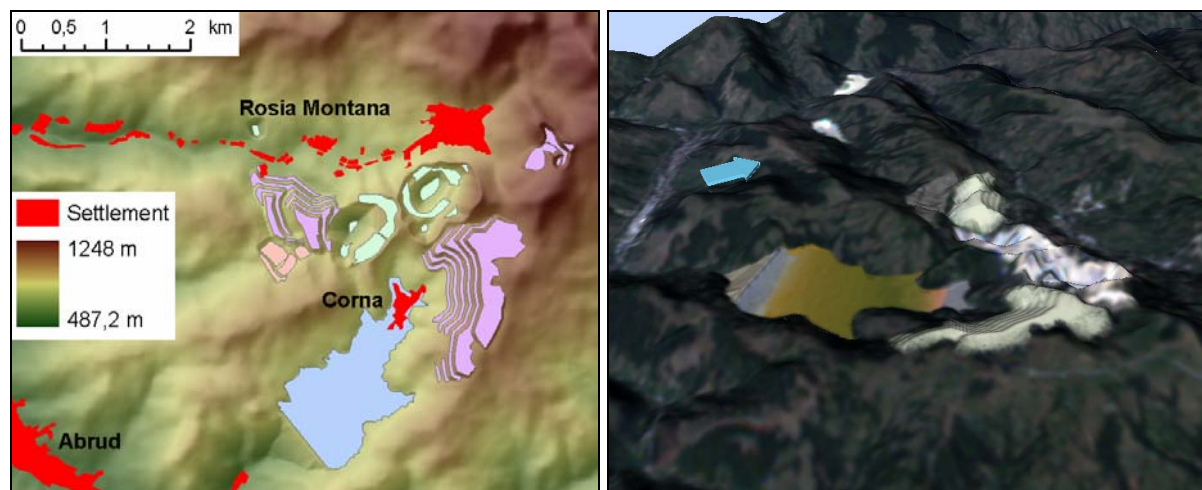


Figure 8. The terrain and perspective view of study area in year 7 (ESRI ArcMap / ArcScene)

Land form	Volume change (1000 m <sup>3</sup> )		Area change (ha)	
	Compared to year 0	Total volume (since 2000)	Compared to year 0	Total area (since 2000)
Tailings pond	+ 52538	+ 67688	+ 98	153
Cetate waste dump	+ 25202	+ 26902	+ 58	62
Cîrnic waste dump	+ 39988	+ 39988	+ 125	125
Cetate pit	– 26259	– 27398	+ 50	68
Cîrnic pit	– 74795	– 74795	+ 64	64

Table 2. Area and volume changes due to material relocation (ESRI ArcView 3D Analyst)

## RMGC Year 14 – Mining related features fully developed

By year 14 all the newly planned pits (peach) are completed. The Cetate pit is expanded to almost three times its original size, both horizontally and vertically. The two new pits (Orlea & Jig) are located just “on top of”, or more precisely: below residential areas. While the Orlea pit seems to pose less risk, the Jig pit is right beside the “Historic protected area”, which encompasses the current town itself (Fig. 9). RMGC claims that the daily use of several tons of dynamite will not damage the buildings in the town.

Another significant change is the two large lakes or ponds, which cover the remains of the Cîrnic pit (light blue). We can see that the southern, smaller pond fills a secondary pit, created in a few years prior to this stage. The tailings pond (pink) has almost reached its full extent, the dam crest is at an elevation of 831 metres, and the area of the pond is 245.5 hectares (Table 3). Reclamation of the largest eastern waste dump (light green) has begun by draining its contaminated water content into the tailings lake through an intricate pipeline network.

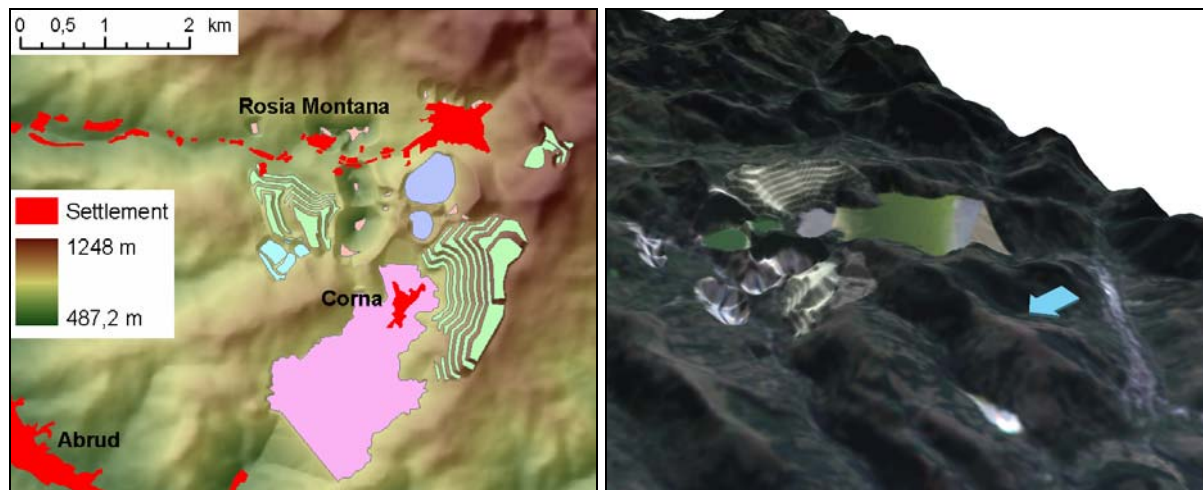


Figure 9. Terrain and perspective view of study area in year 14 (ESRI ArcMap / ArcScene)

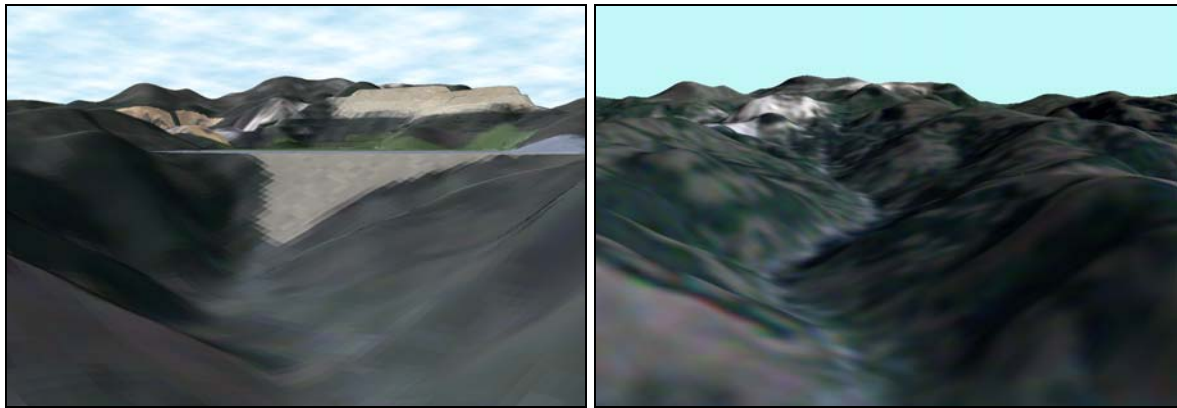
Land form	Volume change (1000 m <sup>3</sup> )		Area change (ha)	
	Compared to year 7	Total volume (since 2000)	Compared to year 7	Current area
Tailings pond	+ 71448	+ 139136	+ 92	245
Cetate waste dump	0	+ 26902	0	62
Cîrnic waste dump	+ 25885	+ 65874	+ 18	143
Cetate pit	– 41428	– 68826	+ 21	71
Cîrnic pit (lake)	+ 24871	– 51548	0	68
Orlea pit	– 24051	– 24051	+ 36	36
Jig pit	– 6164	– 6164	+ 21	21

Table 3. Area and volume changes due to material relocation (ESRI ArcView 3D Analyst)

## RMGC Year 21 – First results of rehabilitation efforts

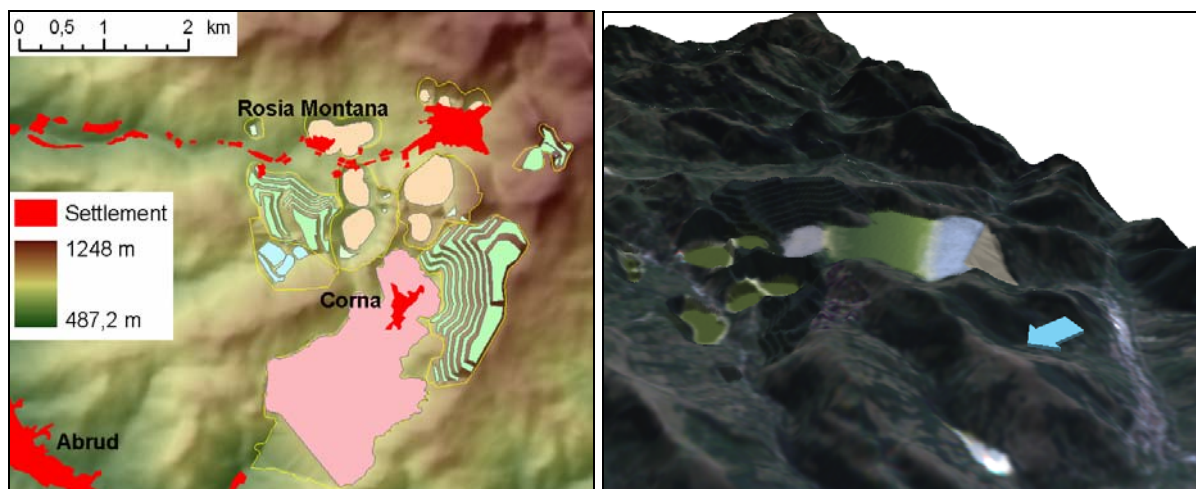
The remaining water from the tailings pond is to be pumped over into the pit lakes (tan). The surface of the accumulated tailings material (pink) is to be covered with a layer of topsoil, with special attention to possible seepage into the subsurface waters. The area previously covered with contaminated water and discharge from the waste dumps is almost 300 hectares, the total volume of accumulated material is ca. 180 million m<sup>3</sup> (Table 4). The dam crest is now at an elevation of 847 metres, towering over the valley by 173 metres, almost reaching the ridge at its eastern end. An extensive monitoring system is to be established to measure and prevent potential pollution, as well as the stability of the dam. The lower parts of the valley are to be occupied by water treatment facilities, so that contaminated seepage from the pond's area may not reach the Abrud river uncleaned. The population of Abrud can in turn keep worrying about the dam above them less than 2 km away (Fig. 10).





*Figure 10. View with/without tailings dam from the hilltop south of Abrud, vertical distortion:  $1.5\times$  (ESRI ArcScene + Gimp)*

The pit lakes will be allowed to fill from precipitation, with occasional additions from the tailings pond. In case of too high water levels, the water can be discharged through several valve-controlled discharge facilities into purification plants before finally reaching the river. The sides of pits will be built to form terraces, which enable vegetation the reclaim the area more rapidly. The pits will eventually turn into “natural lakes” and given enough time the water may become so clean, that no treatment will be required before releasing it into the river (Fig. 11).



*Figure 11. The terrain in year 21 – Tailings pond in its full extent, all pits filled up into pit lakes, waste dumps and processing plant area reclaimed (ERI ArcMap / ArcScene)*

Recultivation of the waste dumps (light green) will be progressive from the beginning of mining operations. Gradual soil covering and re-plantation from the bottom up will consolidate the topsoil and prevent direct water and debris run-off. According to the plans of RMGC, the affected area can be restored to close-to-natural conditions by the end of year 25 after the first steps of mining. The concession area is to be monitored thoroughly even years after the operation’s closure. Traffic census points and environmental measurement sites continue to provide data about the “aftermath” of mining. The dam’s structural integrity is

also to be kept under close monitoring for the possibility of any damages. Even though the pond's location and the dam is planned with many aspects taken into consideration (e. g. soil stability, bedrock conditions, potential for slope movements, etc.) something can always go wrong. Environmentalists (e. g. Greenpeace) claim that if an accident similar to the one that happened near Baia Mare in March, 2000<sup>5</sup>, causing the extensive contamination of the Tisza river system, the effects could be several magnitudes more severe.

Land form	Volume change (1000 m <sup>3</sup> )		Area change (ha)	
	Compared to year 14	Total volume (since 2000)	Compared to year 14	Total area (since 2000)
Tailings pond	+ 40966	+ 180102	+ 39	+ 284
Cetate waste dump	+ 343	+ 27245	+ 7	+ 69
Cîrnic waste dump	+ 1518	+ 67392	+ 9	+ 152
Cetate pit (lake)	– 31	– 59526	+ 2	+ 73
Cîrnic pit (lake)	– 612	– 52160	+ 3	+ 71
Orlea pit (lake)	+ 12359	– 11692	+ 2	+ 38
Jig pit (lake)	– 1411	– 7575	+ 2	+ 23

*Table 4. Area and volume changes due to material relocation (ESRI ArcView 3D Analyst)*

## Conclusion

The present study aimed to model and visualise the changes of the landscape in the Roşia Montana catchment basin from the Roman ages until the planned finalisation of the most recent open cast mining project planned by RMGC. The purpose was to test and improve terrain modelling and visualisation techniques. We also wished to demonstrate the possibilities of freely available graphics programs for modelling landscape changes in satellite images. The final results speak for themselves: the textures of existing features identified in the original Landsat image can be used to recreate the newly planned artificial constructions easily; much more detail can be achieved using aerial photography, even as far as realistic terrain and landscape reconstruction. Terrain information can be downloaded for free from the USGS SRTM distribution server, then refined to decrease the rough, jagged appearance of SRTM data; maps published in (e. g.) PDF format on the web can be converted, georeferenced and edited to serve as basis for detailed terrain modelling; the artificial features can be merged into the original SRTM data using several GIS programs, in our case ESRI ArcView, but any other application can be used with raster and TIN processing capabilities. Volume calculations were performed as well using the built in functions of ESRI 3D Analyst,

<sup>5</sup> <http://www.deh.gov.au/industry/industry-performance/minerals/booklets/cyanide/baia-mare-cs.html>

while area changes can be measured in any basic GIS. Landscape changes can be modelled and visualised with great efficiency and very self-explanatory results using GIS methods. It is also possible to perform relatively accurate mass, area and volume calculations, the precision of which depends mostly on the resolution of available terrain data.

Calculations indicate the following mass relocations in the scope of the research:

- 846 hectares are planned to be affected;
- 405 million m<sup>3</sup> of material is to be moved during the 20 years of mining operations and subsequent rehabilitation, including solid and liquid state materials as well.

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