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THE RESTORATION PROJECT FOR THE GAVORRANO MINING AREA (TUSCANY, ITALY): THE EXAMPLE OF THE RAVI MINING PARK

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INTRODUCTION

Mining activity in Italy has decreased progressively over the last few decades. The abandoning of a mine give rise to a series of problems concerning social safety, health and the economy. Mine closure is regarded as an environmental threat and an economic problem in those regions where it had constituted the main industrial activity for a long time and where no alternative activity, in this economical sector, has been introduced. The case described in the paper is actually concerned with the decommission of a mine district in Central Italy. The Gavorrano mining area is located within the Colline Metallifere mining district in southern Tuscany (Figure 1). The Gavorrano mine has a history of a century of pyrite mining and it was one of the largest pyrite mines in Europe. Production ceased in 1981 and since then the mine has been under care and maintenance. A multi-purpose study started in 1995 to evaluate the possibilities of creating a natural reserve and mining park by recovering the mining area with all its historical mining structures. The environmental rehabilitation of the area involves recovering of quarries (with trekking and rock climbing tracks and the construction of an open theatre), tailing ponds and surface mining areas by reforesting, stabilization, and restoring the significant old mining structure (museum). One major aspect of the rehabilitation involves the recovery of water resources (where the hydrogeological system is relatively complex because of the existence of two subsystems: a superficial karstic system and a deep hydrothermal one) and the evaluation of the stability of slopes and underground openings (Sammarco, 1995; Crosta and Garzonio, 1998a) as well as that of the pollution deriving from the mining activity (Crosta and Garzonio, 1998b). This activity involved ore excavation and the disposal of wastes, both of which developed over the last century using different techniques.

In particular the paper describes one important phase of the planning of the Gavorrano mining area: the Ravi mining park. Ravi is a mine site which had a its own history, and it was successively closely connected to the main activity of the Gavorrano mine (Impero and Roma shafts, and Valmaggiore shafts through a gallery system).

The main aspects of the preliminary project for the mining park, recently approved by public administration, are analyzed. Work is currently underway on the executive design and planning and the different steps of the design and work are being programmed in relation to the funds (National and European financing).

Besides dealing with the different aspects of the planning and the realisation' problems of the mine park, we have also considered another important element which links this area to the Gavorrano village (Roma shaft mine village). This regards the slope of Mt. Calvo overhanging the Ravi mine village, where the subsidence induced by mining activity could become a tourist resource, as it has produced a particular and spectacular rocky landscape.

MORPHOLOGICAL AND GEOLOGICAL OUTLINES

The study area is located on the southern border of the Metalliferous hills, a few kilometers from the sea. The morphology is characterized by a small ridge with rapid topographic changes, passing from very flat plains (Follonica gulf to the west, and the alluvial valleys of the Bruna river, towards the Grosseto plain), up to rocky hills. The reliefs in the stretch under examination reach an elevation of about 500 m asl in Mt. Calvo. The region represents a passage zone where the typical appenninic (NW-SE) and anti-appenninic structures (NE-SW) assume a rotation towards N-S and E-W. In particular, NNW-SSE elongated post-orogenic basins

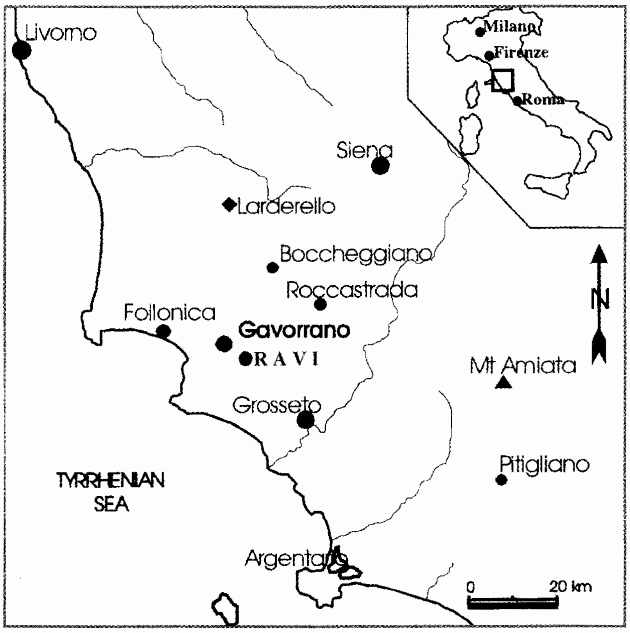

Figure 1. Location map of the Gavarrono area and of the Ravi mine (southern Tuscany, Italy).

developed over an antecedent extensional horst and graben structure consequent to the Thyrrenian sea opening. Intrusive bodies, with decreasing age from west (7-8 My) to east (4 My), are typical of this tectonic province. The activity of the region is confirmed by important geothermal fields (Larderello, Travale, Amiata) located within a major mining distritc (Campiglia, Elba island, Massa Marittima, Mt. Amiata, Manciano, etc.).

The Tuscan geological series (Triassic-Oligocene) outcrops completely in this area together with a Pliocene (4,9 My) quartz-monzonitic intrusion oriented NNW-SSE (Bertini et al., 1969). It is overlaid by the Sub-Ligurian and Ligurian Units. The underlying Permian metamorphic complex (phyllites, schists) outcrops only N of Gavorrano and close to Ravi. The sedimentary sequence is represented by the Calcare Cavernoso (Figure 2), a brecciated and karstified limestone (Noric) with powdery levels ("Cenerone") and gypsum lenses. The Cavernoso appears partially metamorphosed at the contact with the intrusion, covered by the avicula limestone, dolomitic limestone and marl (Rhaetic). The Liassic Calcare Massiccio follows in the series with massive limestones and a peculiar brecciated facies. The upper Tuscan series, from the Liassic to the Oligocene (Rosso Ammonitico limestone, Selcifero limestone, Posidonia marls, Macigno sandstone), outcrops as we move southward. The Eocene flysch (Sub-Ligurian Unit) is placed over the Ophiolitic complex (shales and limestones, Ligurian Unit) as a result of a tectonic contact. These formations outcrop at the outer margin of the area and they concern part of the more surface mining works. The quartz-monzonitic intrusion, with successive micro-granitic dikes prevalently oriented N-S, NE-SW and NW-SE, is weathered at the surface and it is frequently bounded by a thick zone of loose soil-like-material ("renone"). This weathering and alteration has been found along the tectonic contact and in the Ravi mine village. The renone outcroppings also correspond to erosion phenomena with gullies and rills.

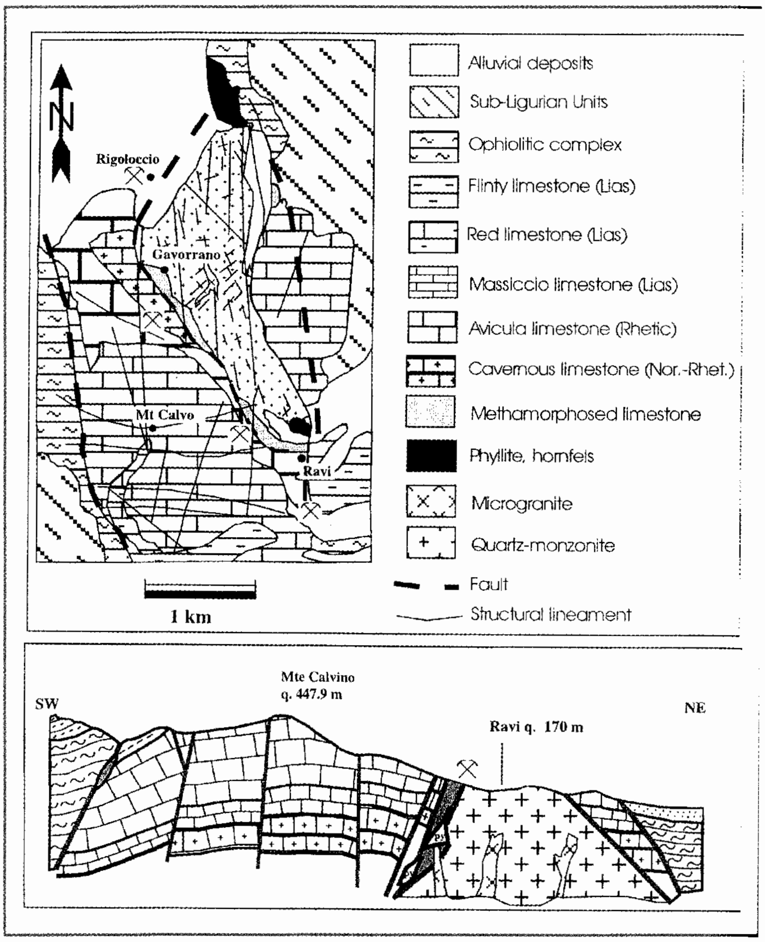

Figure 2. Geological sketch map of the Gavarrano-Ravi area and cross section through the Mt. Calvo-Ravi area.

The pyritic ore (massive, cataclastic up to dusty) was cultivated in lenses or masses of irregular shape at the contact between the intrusion and the Calcare Cavernoso, and sometimes along the main faults, as well as between the phyllites and the Cavernoso (as in many cases in Ravi) (Arisi Rota et al., 1971). The intrusive body is limited by two normal faults at the eastern (45° dip) and western sides (60° dip). Minor faults are located to the north of the intrusion (Rigoloccio), and to the west of Mt. Calvo, and they have led to the contact between the Tuscan series and the Ligurian units. The main eastern fault coincides with the Ravi mining area.

PARTICULAR GEOMORPHOLOGICAL FEATURES

The limestones, in particular the Massiccio limestone for the attitude and the wide outcroppings, are extensively karstified both at the surface (dolines, lapies or karrens, lapies wells, caves, etc.) and at depth (calcare cavernoso and Massiccio). Micro up to macro-forms are present, ranging from few millimeters to several tens of meters in size. Karstic conduits are commonly found in these formations and many features can be recognised in the field (Figure 3). These features played an important role in worsening geomechanical properties and weakening the rock mass and the ore bodies and in controlling the geomorphological evolution of the landscape (fall sinkholes, scarps, open fractures, etc.). The combination of human action and the existing environment certainly contributed to the acceleration of karstic phenomena. Contributing factors may have been the lowering of the base level and the increase in hydraulic gradient by water drainage during mining and the forced circulation of air and water through the tunnel system. The new underground environmental conditions led to the solution of carbonate rocks by the chemical reactions of iron sulphides. The chemical reactions that allow the rapid breaking down of iron disulphide minerals and pyrite, under the influence of weathering, generate acidity (H^+) by producing ferrous and ferric sulphates and sulphuric acid.

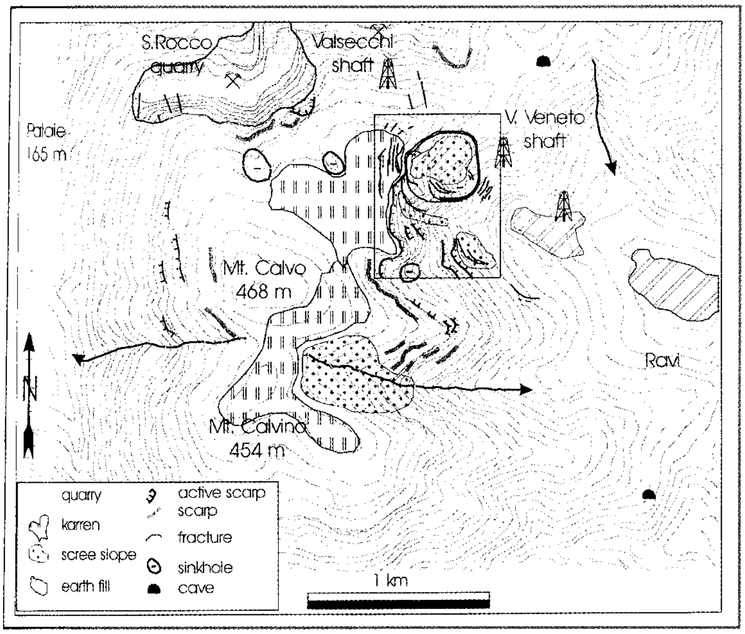

Figure 3. Main geomorphological signs in the Mt-Calvo area.

Some important and interesting caves are present in the area. In particular near Ravi, just up from the slope of the mine, we have the Artofa cave, where some significant remains of animals belonging to ancient ages with different climatic conditions were found and are present (in particular bears). Another cave is located near the small historical inhabited center of Ravi, on the opposite relief of the Ravi mining village, namely the Artofago cave. It is a large cave, with traces of Paleolithic populations. Both caves present important and widespread concretions, stalactites and stalagmites, but partially they have been damaged by man.

The East flank of Mt. Calvo, overstanding the shafts of Ravi-Marchi, is characterized by structures that must be attributed to a subsidence process. Cracks having different length, orientation, aperture, relative displacement, depth and continuity have been surveyed (Figure 4). Cracks beyond the crest, discernible up to 200 m. from the slope crest, have a roughly subvertical N-S linear trend and display increasing length, aperture and jagging close to the crest. Fracture depth ranges between 1m and 20 m and reaches 30 m (as shown by speleological surveys organized to implement research data) and probably continues up to 60 m, with a general V shaped aperture. The average spacing among major fractures ranges between 15 and 20 m with very few dispersed data. Quite a different situation can be found starting from and below the hill crest, facing Ravi, where major composite fractures become more curvilinear with a sub-circular trend, while minor fractures present in a radial orientation. The sub-circular depression, with a maximum diameter of about 450 m, is delimited by two main composite cracks and some related scarps to the NNE and the SSE boundaries. The NNE crack is almost 550 m long, 350 m of which are 3 to 6 m wide and 20 to 30 m deep. The SSE crack has a width ranging between 0.5 m and 6 m with a maximum depth of about 10 to 12 m and a maximum aperture in the middle part. Some more concave upward cracks appear at the slope feet suggesting a maximum depression point somewhere in the lower half of the hillslope. On the whole, a maximum displacement of some tens of meters (30-40 m) could be inferred from the distribution and aperture of the major fractures, and prevalently in a downward direction. Analyses of the relationships existing between rock mass features, mining activity and the depression area have been carried out for a better understanding of the phenomenon. This area is located at the southern end of the Boccheggiano ore body (with mining levels between +170 m a.s.l. and –236 m b.s.l., the latter being connected to Gavorrano mine) aligned NNW-SSE and slightly to the N of the Quercetana ore body, close to the Mt. Calvo pyritic lens (both enclosed between mining levels at +10 m a.s.l. and –130 m b.s.l.). Once again, the slope (which develops between +250 m and 405 m a.s.l.) dips SE, i.e. in the direction of major drifts and tunnels (developed between +90 m a.s.l. and –205 m b.s.l.), the quartzmonzonite/limestone contact being slightly to the E with a general NNW-SSE trend. The Mt. Calvo pyritic mass is located close to the Vignaccio ore body which represents the most important mineralization of the Ravi-Marchi mining. Numerous cracks, scarps and trenches are in fact present along the contact, thus highlighting the effects of the superficial cultivations and producing a particular and suggestive landscape within a slope which is now wooded.

Main discontinuity sets have been identified by geomechanical surveying both on the surface and along mining drifts (going into the Gavorrano' shafts and in the powder of Ravi). Subvertical joints and faults with abundant karstic features have a general N-S direction, roughly parallel to the intrusion. They represent the most frequent and persistent structural features. This assemblage of fractures is the reason for the more common types of instability (toppling, falls) along the slope. The same sets are present along the slope, together with more subvertical E-W trending discontinuities. Karstic features or very

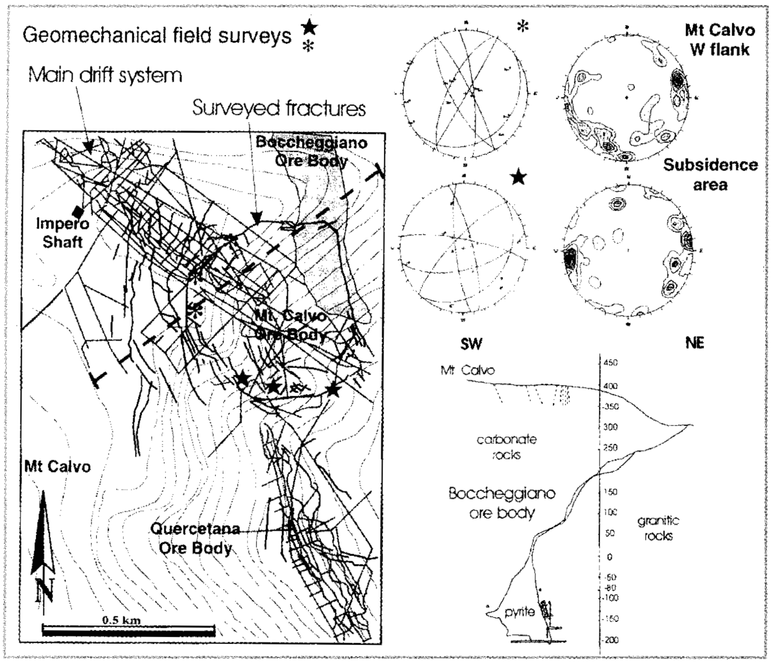

Figure 4. Map of the SE flank of Mt. Calvo with the system of major fractures on the upper karstic plateau and around the subsided area. The network of main mining drifts is also shown together with the limits of main bodies. Stereoplots summarise the geomechanical data for the N and the SE flanks of the Mt. Calvo. A cross section describes the geometry and relationships of ore bodies with the carbonate and granitic rocks.

persistent and smooth surfaces, with rare subhorizontal steps characterized by fresh rough fracture surfaces, were identified throughout.

Signs of instability phenomena were identified along the southern slope crest, upward from Ravi, caused by the same mechanisms cited above (toppling, falls) and linked to some vertical cliffs. These instability phenomena and some deeper ones are presumed to be related to the collapse of karstic dolines and the successive influence of mining and the above described subsidence.

Another important aspect of the geomorphological features is represented by the stratified slope-waste deposits or "grèzes litées" or "éboulis ordonnés" (Guillien, 1951; Tricart and Cailleux, 1967; Wasson, 1979) which are widespread on the base of the E flank of Mt. Calvo. The origin is connected with the cold climate conditions of the Pleistocene, the period in which a periglacial environment developed in Italy. After the degradation and/or complete elimination of vegetation, the slopes were subject to intense erosional processes connected to the action of frost and snow. These phenomena led to the accumulation of thicker debris. The limestone and marly limestone outcrops of the formations which constituted Mt. Calvo are particularly susceptible to frost shattering. Some pedological levels of paleosoil, which correspond to the phase of temperate or warm climate conditions, have been surveyed. In the past these materials were utilized for the local limekiln, and for the backfillings of the mining excavations.

All of the above described geomorphological aspects assume an important value for the planning of the mining park where the naturalistic features correlated to antrophic interventions are fundamental.

THE RAVI MINING PARK

The Ravi Marchi mine (Figure 5) is a separate chapter in the history of Gavorrano mining, and its territory is very limited also with respect to the one excavated by the "Società Montecatini", again in Ravi. The peculiarity of this mine lies in its relatively small extension, given the presence of all the excavation and working phases of pyrite. The mining system is easily understood even by people who are not experts in the field. The mineral extraction activity started in 1910, with the excavation of three masses: Vignaccio, Radini and Ortino. The most important one was Vignaccio which was cultivated until the '50's, while Radini and Ortino worked out at the end of the '30's (Figure 6). A new ore body was identified with the mining research carried out after the second World War, namely the wide lens of Mt. Calvo, to the W of the Vignaccio ore deposit. During the 50's two more mineral deposits were discovered: Orsinghi and Quercetana, which are located further south. The yards were therefore concentrated there until the mine closure, given the fact that Vignaccio could be considered worked out. In 1965 the mine was purchased by the Montecatini Company and the underground system was connected to the other mine in Ravi which was already run by the same company. Only few constructions of the latter mine still exist today, as the processing cycle was prevalently linked to the Valmaggiore system, located to the south of Ravi, and to the Gavorrano mine and its mineral treatment plant by means of a new tunnel.

Figure 5. View of the Ravi Marchi mine in a photo taken in the 30´s.

The Vignaccio area with its shaft towers and the washeries for the treatment of the pyrite is therefore easily recognizable; the mining village, the mine headquarters, the mining waste disposals, a system of tunnels of a powder (re-opened for the planning phase) with splendid reserves for the explosive. The latter is the finest underground powder store in the Gavorrano mining area. It dates back to the '20's, with a few subsequent modifications. It is in part covered with bricks. The quartzmonzonite outcroppings in the tunnel are well conserved, as are the lighting installations to be restored and above all the explosive rooms with their original armoured doors and windows.

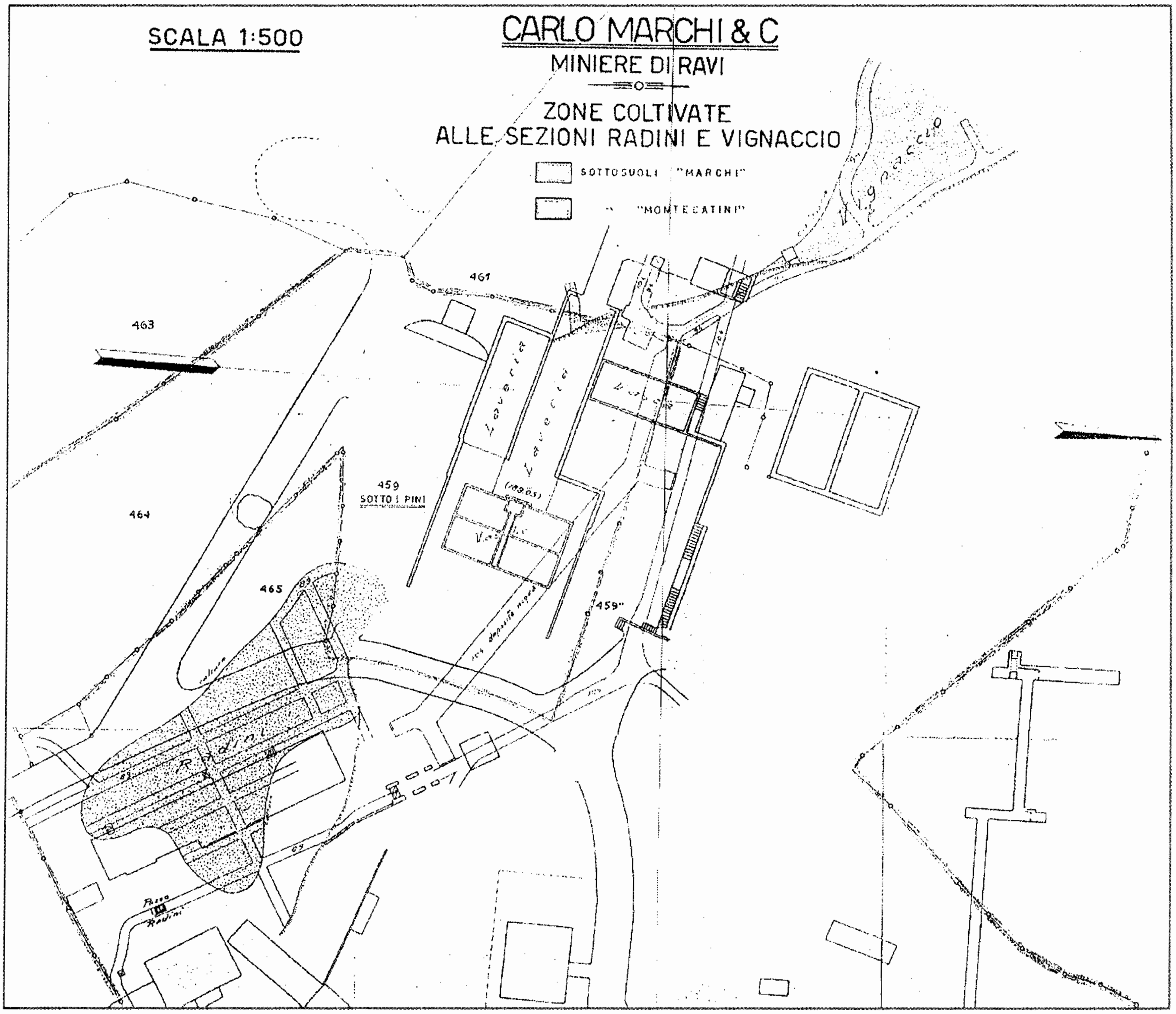

Figure 6. Ancient map of the Ravi Marchi mine.

Unfortunately, the only negative aspects is the fact that access is not possible to the underground parts, as they would have shown a fundamental aspect which regards the exploitation method (with ascending and descending cuts, an experiment with techniques applied in Italy for the first time), the back-filling method (hydraulic back-filling was introduced for the first time in Italy in this mine in 1913), the ventilation method, etc.

The project does however include the restoration of short stretches of tunnel (total 200 m), located at not great depth (20-30 m), which connected the wells with the washeries. These will allow the setting up of a museum route. There are two washeries, the first one was built in the period 1918-1920 and it was expanded about 5 years later. Its splendid masonry and complex tank system have remained. The second one, one of the most impressive washeries in the region, was built at the end of the '50's. It was not in operation for long, as the mine closed in 1965.

The residual mud in the dump to be reclaimed came in fact from this plant. Over the last few years this mud has accumulated in greater quantities, causing greater pollution problems. The geochemical data show (Fe_2O_3 = 14-17%; MnO = 0,2-0,17%; As =184-280 ppm; Cr = 20-40 ppm; Cu = 36-58 ppm; Ni = 16-28 ppm; Pb = 140-270 ppm; Zn = 160-710 ppm) a situation that is not particularly serious if compared to other waste disposals in the area. Acidification processes are obviously present and the environmental restoration intervention is aimed at controlling the waters, favouring the development of vegetation, including shrubbery which is already developing laterally, and species which can favour geochemical corrective processes. Most of the material is covered with clay levels in order to impermeabilize it, leaving portions of material uncovered and covered with special resins. The aim is to let people understand the processing cycle and the morphological modifications and the changes in the landscape, even in the mining waste, while respecting the objectives of the environmental restoration project the waste scarps are therefore made stable, but not always covered. An old small waste disposal will constitute an important element of the park as it is possible to see various waste materials and rock at the contact with the excavated mass of pyrite (related to the first ore deposits with cornubianitic schists, as well as limestones and granites). In particular, the stratification of the waste deposit is regular and inclined, with strong, impressive colour contrasts. This will therefore be stabilized, the rill waters will be controlled in order to fight the erosive processes and the stratifications will be consolidated in order to enhance the composition and the significance, also using transparent coverings. This geo-mining museum element, which also becomes a panoramic point, is situated along the walkway which connects the main elements of the landscape: from the old town of Ravi, through the chestnut wood, to the mud waste disposal, to the mining village, and on to the tour of the Ravi-Marchi mine. From the high processing square near the Vignaccio shafts (1 and 2 adjacent and equipped with relatively well conserved electric motors and winches), which is surrounded by rocky or debris scarps, and by Mediterranean maquis (with cork oaks) the path proceeds from the high level of the monumental washery. It enters the wood where we find impressive scarps and cuttings, fractures and openings of tectonic and mining origin (first of all in the granites and limestones with varying degrees of metamorphosis, and then in the massive limestone). We then arrive at the above mentioned small discharge and climb the slope of Mt. Calvo. We find some artificial dolines (collapsed shafts and holes filled up with coarse debris) and the "gréze litées", used in part in the kilns and in part as back-filling. Finally we come upon the rocky landscape of the subsidence, of the calcareous cliffs and of the karstified top plain with dolines. In the future the route should continue towards the area of the Gavorrano park (main mining area of the Roma shaft).

Without describing the entire restauration project for the mining plant given the extent and complex nature of subject, we should however like to underline the logic behind it; i.e. the desire to connect all the aspects of the history and the mining processes using the objects which can today be seen and restored (from the washeries, to the brickwork silos, to the shafts, to the kilns, all of important value in terms of industrial archeology), strengthening the museum and recreational function with, for example, suitably lit routes at depth, which come out in one of the numerous risers which go back up into the new washery. At the same time the controlling and the collection of rainwater, using canalization, makes it possible to accumulate considerable volumes in the tanks and cisterns to be restored. This will then be pushed up to the higher level of the new washery by means of suitable installations, and then made to come down like a fountain, in order to simulate the cycle of pyrite processing. Finally we must take into account the fundamental aspect of the collection of historical data and archives, the subject of a first museum, related to Ravi, awaiting the more important one in Gavorrano. In this case too the aspects connected with the surrounding territory territory, the natural and geological environment (waters and springs, geomorphological positions of the waste disposals, quarry materials, surface and deep-seated stability problems in relation to the geostructural elements) will be highlighted.

CONCLUSIONS

The aim of this paper was to describe the case of the Ravi mining park project currently being built within the wider context of the mining and natural park of Gavorrano. In particular we wanted to analyze the geomorphological elements and the instability processes, induced or accelerated by man, in relation to the environmental restoration and reclamation project, restoration of constructions and the enhancement of the park. The above mentioned elements and processes constitute not only a consolidation problem, but also a value for the creation of the park. In this respect we have mentioned the karsic environment, the natural cavities, the caves. We have described the stratified slope deposits and their importance for the history of the mine. We have analyzed the impressive subsidence phenomena which produce a striking landscape. The latter situation, which must be monitored, checked and stabilized in places, represents the possibility of a panoramic route, with the back up of appropriate interventions. It also constitutes the possibility of having a laboratory for the study of these phenomena: a dynamic element for the future activities of the park. For this reason to conclude this paper we have shown some results from preliminary analyses on the gravitational phenomena. A series of numerical simulation (UDEC: Universal Distintict Elements Code, ITASCA, 1993) have been run taking in account for the discontinuities distribution, the location of main ore bodies and a range of values for rock mass strength properties. Carbonate formations were considered the less resistant and more deformable (γ = 25 kN/m^3, K = 11 Gpa, G = 5 Gpa, φ = 35°, σt = 40 Mpa, c = 30 Mpa) while the granitic intrusion was assumed as very strong and rigid (γ = 27 kN/m^3, K = 44 Gpa, G = 28 Gpa, φ = 43°, σt = 400 Mpa, c = 80 Mpa). Successive mining stages were simulated by performing consecutive excavation steps. Each excavation step was started after forces reequilibrated themselves within the backfilling material (γ = 15 kN/m^3, K = 10 Mpa, G = 5 Mpa, φ = 30°, σt = 0,1 Mpa, c = 0,2 Mpa). This approach was adopted because ore bodies (γ = 26 kN/m^3, K = 2 Gpa, G = 0.9 Gpa, φ = 33°, σt = 5 Mpa, c = 3 Mpa) were comple-

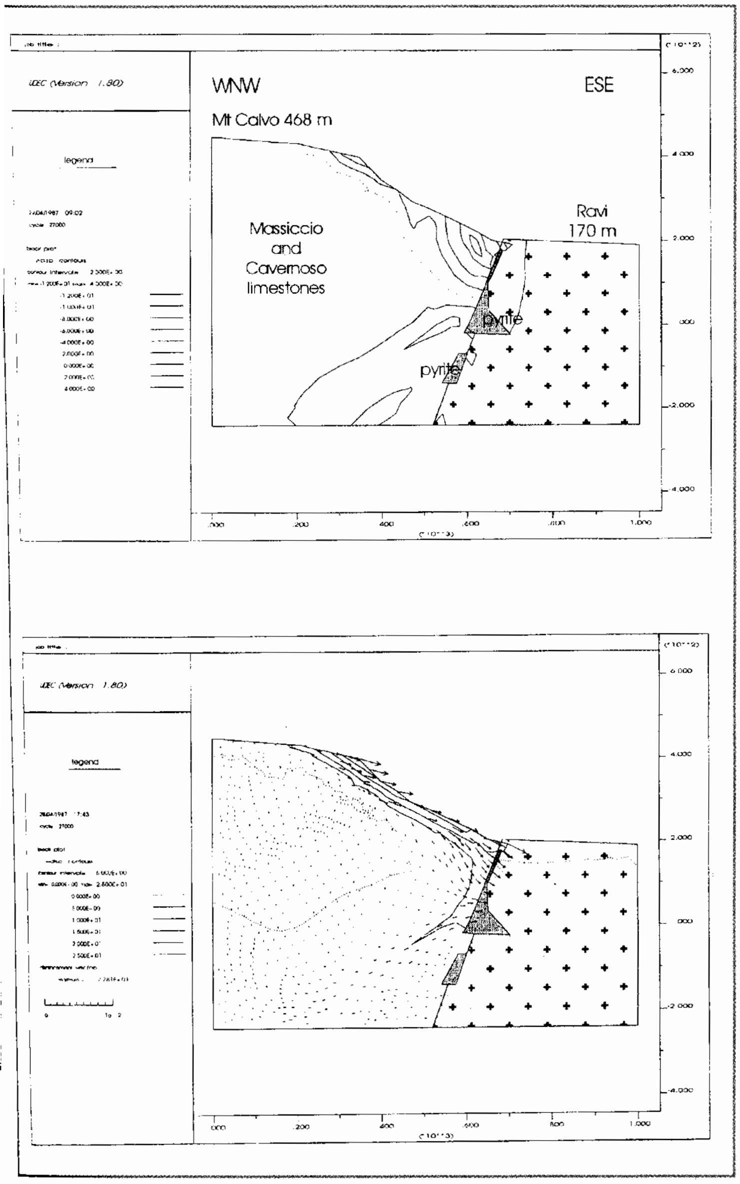

Figure 7. Numerical results: a) Contours of vertical displacement component; b) Horizontal displacement contours with total displacement vectors.

tely mined out and mining simulation through successive detailed drifting and backfilling steps was not realistic at the model scale. The results of the numerical modeling are illustrated in Figure 7.

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