Geological and engineering heritage of Lungro rock salt (Calabria, Italy)

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Article

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ABSTRACT

Nearby the municipality of Lungro (Calabria) is the longest-running Italian rock salt mine, exploited almost continuously from antiquity until 1978. The mining activity is recorded since the Middle Ages, although archaeological studies suggest that salt production by near-surface excavation dates to the Greek and Roman civilization or even to prehistoric times. During the Middle Ages, mining methods pointed to the maximum profit, and the salt deposit, rather than being rationally mined, was exploited vertically, following the winding path of high-quality salt layers. This approach led to troubles such as rock instability, inadequate ventilation and water infiltration, that characterised the site up to its recent abandonment. Although the mine was partially renovated at the end of the 19th century, both in its structure and work organization, a steep decline began. Easy access to the underground works was never solved: still in the 1970's, two of the eight working hours of each daily shift were spent reaching the workplace, as there were over 2000 steps to walk. Poor mining methods persisted throughout the 20th century, leading to its abandonment in 1978.

KEYWORDS: rock salt, mining history, Geoheritage, Lungro salt mine.

INTRODUCTION

Salt has always been a vital commodity for human life, not only for seasoning food, but also for preserving fish, meat, olives, for the preparation of cheese and dairy products, as well as for dyeing, farming, *etc*. (Bergier, 1984). Since ancient times, and still today, the humankind produced food-grade salt from three main sources: by natural evaporation of sea water, by forced evaporation (boiling) of sea water or brines produced from salt springs or saltwater wells, or by extracting salt it in its natural solid form (halite), from underground rock salt mines (Kurlansky, 2002; Harding, 2014).

The traditional and most widespread technology used in the Mediterranean area, characterised by hot and dry summers, was the production of salt from sea water by evaporation, an operation easily carried out in the low and sunny coastal lagoons, gradually transformed and engineered as saltworks, or "salt pans". This method was used since the Neolithic (Weller, 2015), and many salt pans such as that of Trapani (Sicily) and Cagliari (Sardinia) were built by the Phoenicians. Later, salt production from coastal salt pans was widely used and improved by Roman technology, and many of these have survived to this day (Lowe, 2018; Alessandri & Attema, 2022). Today, besides salt production, several Italian coastal saltworks stand as naturalistic geosites for cultural heritage conservation, biodiversity and bird sanctuaries, as well as sustainable touristic destinations.

However, in some inland areas of Sicily and Calabria there are several outcrops of evaporitic and post-evaporitic formations of Messinian age, with macroscopic evidence of rock salt and sulfur. In these locations, although geographically centered in the Mediterranean Sea and relatively close to the coastline, a mining industry developed, first for local purposes, but soon generating a sort of international trade center for both sulfur and, more important, rock salt.

In Sicily, until the early 20th century, the excavation of rock salt was allowed to everyone for their own use, upon authorization of the landowner, and no tax was imposed on salt. This principle also applied to the costal salt pans: "Contrary to the rest of the kingdom of Italy, in Sicily there is no legal restriction regarding the production and trade of salt" (Jervis, 1881). William Paget Jervis (1832-1906), a British mining engineer naturalised Italian, lists and describes about a dozen of open pit or underground salt mines in Sicily (although still at shallow depth at that times). Besides several

sites near Racalmuto (Pantanelli, Giona and Sacchitello mines), in which black powder was necessary for tunnelling through the very hard massive rock salt, Jervis recalls the mines of Cammarata, Mussomeli, Casteltermini, and finally the one of Petralia Soprana, likely the first large underground rock salt mine in Sicily, with its dedicated inclined tunnel to access the underground works (Jervis, 1881). Nevertheless, the surface excavation of rock-salt was only sporadic and of local importance, at least until the turn of the 20th century, when the modern industrial phase began. Today, three large underground mines are still active in Sicily (Realmonte, Racalmuto, Petralia Soprana) and are operated by the Italian company "Italkali" with state-of-the art mining technology, producing a total of approximately 2 million tons of rock salt per year, both food-grade and industrial grade.

In Calabria many salt mining sites were active and documented since at least the end of the Middle Ages (Rende, 2015). Apart from the Altomonte-Lungro mine, located in the *Calabria Citra* historical region (at present, approximately the province of Cosenza) described in detail in the following chapters, several mines were known and exploited also in the *Calabria Ultra* region (at present, the provinces of Crotone, Catanzaro and Reggio Calabria). Among the others, it is worth recalling "Salinella di Neto mine" near Altilia, "Basilico mine", "Zinga mine" and "Miliati mine" near Cerenzia, all located in the present province of Crotone, some of which are still existing landmarks that were visited by Melograni in early 19th century (Melograni, 1822; Pesavento, 2015). Furthermore, many archival documents are kept in central and local archives that deserve further studies. Among them, we recall the State Archives of Naples with the collection of documents concerning the exclusive salt concession (*arrendamento*) of rock salt in Calabria (D'Arienzo, 2006; Cataldo, 2012).

GEOLOGICAL SETTING

The Lungro mine is located on the western side of the tectonically controlled Crati Valley, bordering the Pollino chain (Van Dijk et al, 2000). The boundary, represented by a NE-SW fault strictly related to the regional Sangineto line, places the Miocene-Pliocene sediments of the Crati Valley in contact with the metamorphic basement which includes Anisic-Carnic meta-clays and meta-carbonates (Ietto & Ietto, 2010). A geological map of the Calabro-Peloritano Arc and the location of the Lungro mining area is reported in Figure 1.

In particular, the Lungro area is characterised by the presence of the San Donato di Ninea Formation, represented by metacarbonates and dolomites of Triassic age in contact, through extensional systems, with the Liguride units of the Frido Formation of Cretaceous age. The Crati Valley stratigraphic sequence, which lies in transgression on the basement, is composed by terrigenous-carbonate conglomerate deposits of Tortonian age that evolve into Messinian detrital-evaporitic sedimentation (Perrone et al., 1973) up to 250 m thick, capped by blue-grey clayey-silty layers of Lower-Middle Pliocene age.

The rock salt deposit historically exploited in the Lungro mine is part of the Member of clay with gypsum and gypsum arenites (Ietto & Ietto, 2010) which, in the upper part, contains thick beds of gypsum arenites exhibiting a zoned-rounded structure, for a maximum thickness of 35-40 m. At Lungro, within the clays, are thick, non-outcropping halite beds, which allowed the underground mining that is the subject of the present work.

The Messinian level subject to mining is represented by marly clays interbedded with thick gypsum beds and halite of the historical rock salt deposit. The latter is in the form of a sub-vertical rock salt lens extending for one km in a NE-SW direction and over 500 m in depth (Ogniben, 1969). The lens is known up to an elevation of 150 m above sea level, *i.e.* up to a depth of approximately 250 m from the entrance of the mine, nearby the still existing external building and facilities of the mining site. The rock salt exploited through the centuries shows layers varying in thickness from a few cm to several dm, averaging about 10 cm, although salt masses of greater thickness have been mined in the past. The layers consist mainly of blackish rock salt with clay interbeddings; layers of white salt and halite crystals are rare (Roda, 1979).

In the miner's slang, a distinction was made between: 1) *Cervino* salt, the purest, produced in blocks of grey-white or grey-blue color, that disappears after grinding, turning into white salt; 2) *Bardoso* salt, rock salt with a higher clay content, discarded by manual sorting, but still with a high salt content and used as filling material inside the mine; 3) *Sterri*, fine-grained salt, often of good quality, coming from blocks cutting and on-site sorting operations; this salt was not utilised, but occasionally was transported outside and dumped in an adjacent stream, where it dissolved and vanished in winter time.

The morphology of the Lungro area is heavily affected by landslides and subsidence (Guerricchio et al., 1993; Antronico et al., 2015). The external buildings of the abandoned mining site are today threatened by landslides and subject to subsidence of approximately 1.0-1.5 cm per year, estimated by InSAR data (Cianflone et al., 2018). Increasing subsidence might cause further damages to buildings and roads, making it difficult to reclaim the abandoned site.

THE LUNGRO MINING SITE

The mining activities related to salt production in the Altomonte-Lungro area (at present, province of Cosenza) is well documented in archival sources from the last ten centuries, which attest to a substantial continuity of the mining and salt trading industry, persisting until 1978 (Fig. 2). However, it is quite likely that salt production from open pit or near-surface excavation dates to the Greek and Roman civilization of the area, or even to prehistory (Samengo, 1845). In fact, investigations at the mining site have revealed the presence of archaeological finds (pottery, obsidian, terracotta artefacts from the Greek and Roman times) and it is therefore possible to hypothesize that the site was inhabited, also for the exploitation of rock salt, since the Neolithic. It is very likely that the mine continued its production during the Magna Graecia civilization, probably also in connection with the nearby Greek colony of Sibari, and salt mining may have contributed to the economic splendor of the town, which continued throughout the Roman imperial age until the city's decline in the 6th century C.E. (Patané, 2023).

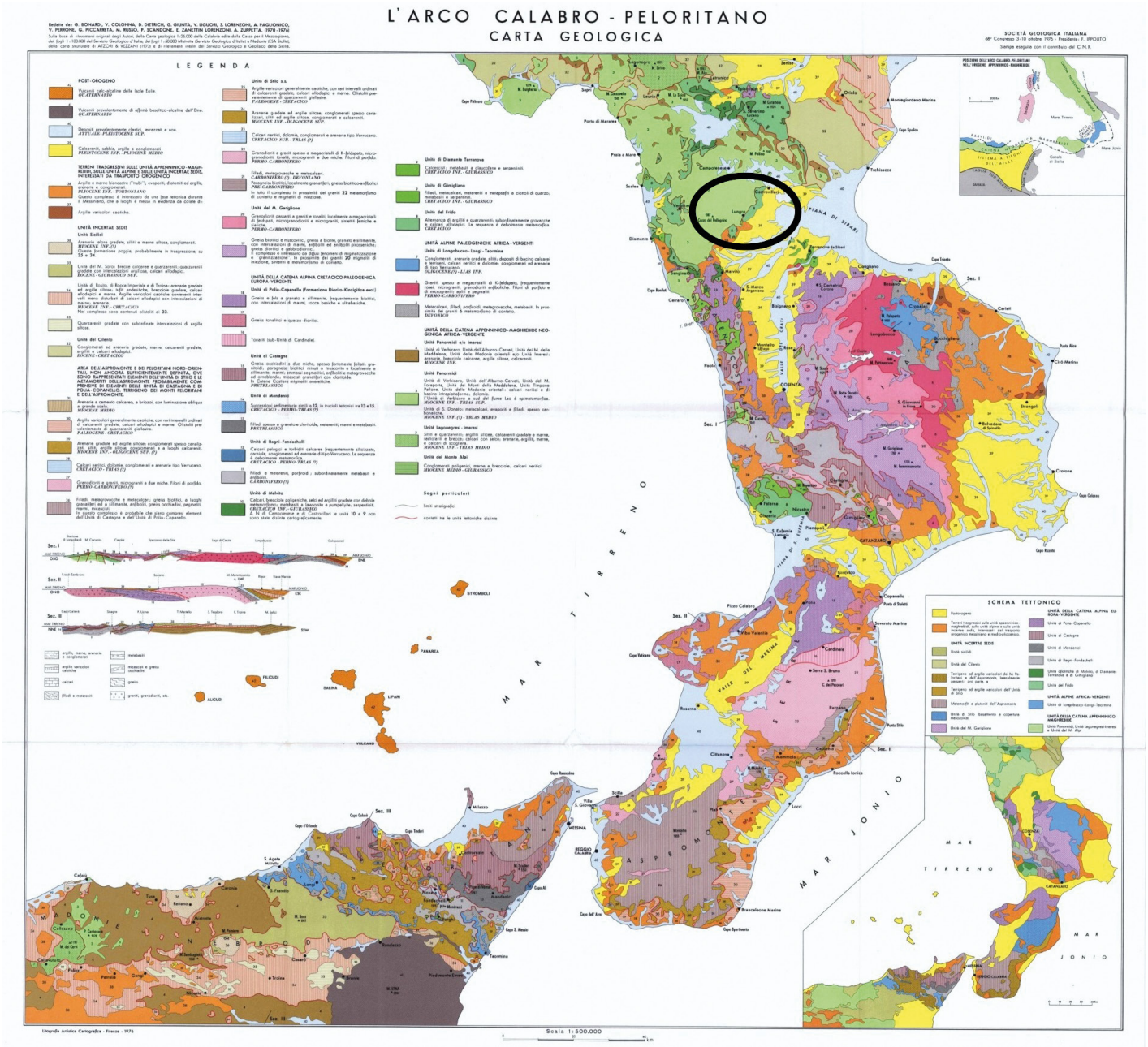

Fig. 1 - Geological map of the Calabro-Peloritano Arc; the black circle shows the location of the Lungro mining area. (Modified from Amodio-Morelli et al., 1976).

After the 10th-11th century, the Altomonte-Lungro mining site history was linked to the succession of the feudal lords governing the area. Over time, mining rights were increasingly codified. With the foundation of the Basilian monastery of Santa Maria delle Fonti in 1156 (today no longer extant), the site took on greater importance and constituted, for both the monk-barons and the populations of the Altomonte area, a very important source of economic wealth. Since the Swabians domination, the salt was declared a commodity of State revenue and as such, several provisions were issued regarding the trade and taxation of the mineral.

During the kingdom of Frederick II, the Holy Roman Emperor in Southern Italy, there was a further rationalization of the imperial rights on underground resources, and mining rights were considered an attribute of sovereignty (*Iura Regalia*, and hence the term Royalties), a characteristic institution of the German Law. It seems that it was Frederick II himself to fix the price of salt, to establish rules for its taxation and the terms of mining concessions, in order to control the salt transportation and the management of storage in dedicated sites strictly controlled by the crown. Upon the death of Frederick II (1250) the mine became the property of the lords who came from France following Charles I of Anjou. On the complex issues of taxation at the Altomonte-Lungro mining site see also Mastriani (1838) and Sole (1981).

It is worth recalling that salt tax is one of the oldest tax levies. Since ancient times, State monopolies developed with the aim of controlling prices, regulating the revenues of intermediaries and subjecting them to taxation. In ancient Rome, salt was such a precious commodity that soldiers were paid with it, hence the term "salary", still used today. In the kingdom of Naples, a consistent part of the royal revenues came from the exclusive concession of

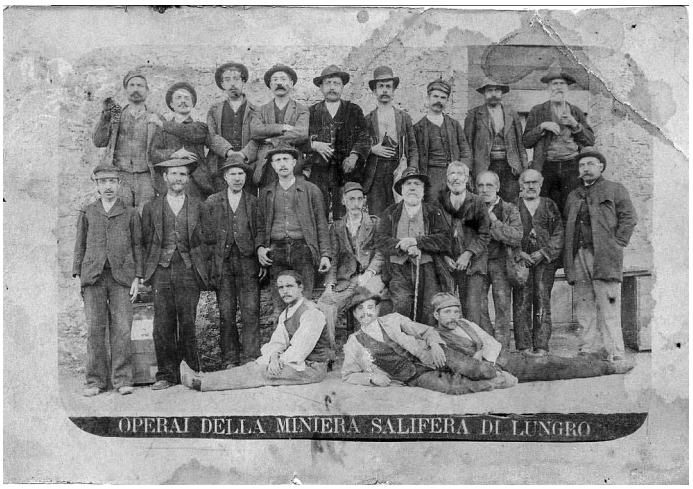

Fig. 2 - Workers of the Lungro salt mine, early 20th century (Municipality of Lungro, historical archive, http://www.san.beniculturali.it/web/san/dettaglio-oggetto-digitale?pid=san.dl.SAN:IMG-00003687).

salt production (Cataldo, 2012). After the Italian unification (1861), the law 710 (13 July 1862) on the monopoly of salt established a new tariff on the price of salt (and tobacco), conceived as an indirect tax on consumption. A few years later, the Royal Decree 2397 (15 June 1865) established that the production, storage and trade of salt was an exclusive right of the State monopoly, whose administration also managed salt extraction sites and supervised the related industrial and trading facilities. This was valid only in the territory subject to the monopoly, i.e., all of Italy except for Sicily and Sardinia (Moncada, 1940).

Already at the beginning of the 15th century the Altomonte-Lungro mine began to be exploited with a network of tunnels that were no longer merely open pit trenches or artisanal and temporary excavation, but became a relatively structured, reinforced and maintained infrastructure for safe and continued underground access over time (Sole, 1981). The modern phase of salt production began in this period, and moved completely to underground mining, which probably occurred in conjunction with the Albanian emigration to Calabria and the consolidation of the Arbëreshë community. Today, the municipality of Lungro is the seat of the Eparchy (a sort of diocese) for the Arbëreshë of continental Italy of the Byzantine Catholic Church, directly subject to the Holy See of Rome.

Among the geographical and erudite descriptions of Calabria published between the 16th and 19th centuries, we recall the one of the Bolognese Dominican friar Leandro Alberti (1479-1552), the "Description of the whole Italy" (Alberti, 1550). Obliged to the duty of itinerant preaching, in the second decade of the 16th century he travelled extensively throughout Italy (and France), and he also visited the area of Altomonte, writing: "One mile away (*from Altomonte*) there are the salt mines. It is amazing to step into those long tunnels that enter the bowels of the high mountains, some of which extend for half mile, others for a mile and others even more, down to the salt excavation" (Alberti, 1550).

A few decades later, Gabriele Barrio (1506-1577) describes the beauty and the natural riches of the Altomonte area in his *De antiquitate et situ Calabriae* (Barrio, 1571), recalling that "in this area there are mountains of white native salt, which is cut like stone; it is dense, shiny, and inside some smooth and not too hard aggregates you can discover salt crystals, white and transparent". Which seems like a realistic and convincing description, but unfortunately, a few lines later, the author narrates that in the surroundings of the salt mine there are also two gold mines, and one of silver and iron (Barrio, 1571), which we know is not true. Only two centuries later did Lorenzo Giustiniani (1761-1824) in his *Dizionario geografico ragionato del Regno di Napoli* (Giustiniani, 1797) take up the descriptions of the erudite writers and historians of the previous centuries, confirming the constant and continuing production activities of the Altomonte-Lungro salt mine, but fortunately definitively denying the presence of all the other supposed mineral riches of the area (Giustiniani, 1797).

During the Middle Ages and up to the early 19th century, the mining methods utilised to develop the Altomonte-Lungro mine were aimed to get the maximum profit in the shortest time, regardless of health and safety of the workers. Thus, the mine, rather than being rationally exploited and developed by regular and systematic horizontal levels, was deepened along the vertical, following the winding path of the high-quality salt layers, overlooking the need of constructing an adequate vertical connection by means of ventilation and transportation raises and shafts. Inevitably, this soon caused problems of rock instability, scarce ventilation and frequent water accumulation and flooding of the lower excavation sites, that characterised this mine up to its recent abandonment.

From 15th to 19th century, Aragonese, Spanish, Bourbons alternated in ruling the kingdom of Naples, and so too did the ownership of the Altomonte-Lungro mine. It is worthy remind that in the second half of the 18th century the city of Naples was the most populated, important and economically active city in Italy, four times the population size of Rome and twice that of Milan. Naples was the third largest city in Europe, after London and Paris. At that time, four salt mines were active in Calabria; property of the Kingdom, the mining activities were contracted out to private individuals, almost always to local noble families (Sole, 1981).

After the Napoleonic invasion of the Kingdom of Naples (1806-1815), the modernizing spirit of the new rulers (Joseph Bonaparte and later Joachim Murat) was aimed to reorganize the rigid administration of the ancient feudal kingdom, trying to eradicate feudalism and reduce most of the rights and privileges of the old nobility. Mines were nationalised, and the mineral resources of Calabria aroused the interest of the French government, due to potential advantages for increasing both the internal production, for raising taxation revenues and, not the least, for the military needs, as in the case of the iron mines of Mongiana (present province of Vibo Valentia) and the related Royal ironworks.

Thus, experts from Academia, military and technical Corps were soon engaged in several technical assessments and site inspections, and most of the mineral samples collected in Calabria were analyzed by the *Real Istituto di incoraggiamento alle scienze naturali* (Royal Institute of Natural Sciences) of Naples, which expressed very positive opinions for many sites and highlighted that mineral resources were generally underexploited and poorly valued, also due to a complete lack of geological knowledge of most of the territory (Marcelli, 2006).

Concerning rock salt production, the naturalist and geologist Giuseppe Melograni (1750-1827) published a detailed report of his field trip of 1811 (*Description of the saltworks of Calabria*), rich in geological and geographical considerations, technical descriptions, surveys and practical recommendations for a modern and rational mining operations (Melograni, 1822). Native to Calabria, scholar and ecclesiastic very close to the *élite* of the kingdom of Naples, in 1789 Melograni was invited by the Neapolitan government to undertake a technical and educational journey to Germany, France and England. The purpose of the trip was to learn - among others - about recent mining and metallurgical techniques that could be practiced on an industrial level. In 1797, at the end of the long stay abroad, he returned to Naples, and by order of the King he was sent to Calabria together with other colleagues, to reorganize the Mongiana weapons factory, the Ferdinandea foundry, the Stilo ironworks, as well as reporting on the mining activity in the area. At that time, he also covered the position of Inspector General of Water and Forestry.

Again in 1811, Marquis Giuseppe de Turris (1759-1843), commissioned Pietro Pulli (1771- 1842), Inspector General of the ammunition, gun powder and saltpeter production of the Kingdom of Naples, to provide information on the economic and social conditions of the Altomonte-Lungro salt mine (Pulli, 1813, 1817). Giuseppe de Turris was a politician and an administrator very close to Murat, President of the Council of Arts and Manufactures of the kingdom, as well as Director of the General Administration of General Duties and Customs.

In the early 1800's, the rock salt deposit of Altomonte-Lungro was mined by large underground voids (chambers), connected by a network of tunnels and rudimental inclined stepped ramps, forming 3 to 4 irregularly superimposed levels. The excavation of tunnels and rock salt mining was done by hand, with pickaxes, while the transport of the selected salt blocks to the surface was done using bags carried on the miners' backs, weighing up to 40 kg each. Access to the underground was granted via a single inclined and spiral-shaped tunnel, through over 1000 steps cut in the salt mass.

In 1820 the municipality of Lungro was promoted to "main town" of the district, instead of Altomonte, and therefore from that date the mine was generally indicated with only the toponym of Lungro (Lungro mine, or Royal Saltwork of Lungro, and in a few cases, San Leonardo mine, after the name of the nearby church dedicated to San Leonardo, the patron saint of salt workers, now disappeared due to landslides).

Melograni visited the Lungro mine again in 1814, "to propose the repairs that the decrepit and inadequate state of the mines required; starting first with the Lungro mine, which is the most famous, the most interesting and the richest in salt of all; and whose work, blocked and chocked by poor technology, deserved to be resumed immediately" (Melograni, 1823).

He proposed to carryout wall and roof reinforcements in various sections of the tunnel network (especially in the large chambers, also by means of large wood piles, as in German mines), to enlarge the critical underground passageways, as well as to rationalize rock cutting in front of the salt mass under exploitation and, not the least, to improve safety of the workers. He also proposed the excavation of a vertical shaft, connected to a horizontal passageway to facilitate ventilation and water drainage (Melograni, 1822, 1823). He commissioned a modern topographical sketch of the mine, although limited to the representation of a simplified scheme of the main access tunnel and without indicating the survey methods. From a historical and cartographic standpoint, this document is among the first rational planimetric representations of an Italian mining site, apparently based on instrumental measurements of angles and distances (Fig. 3).

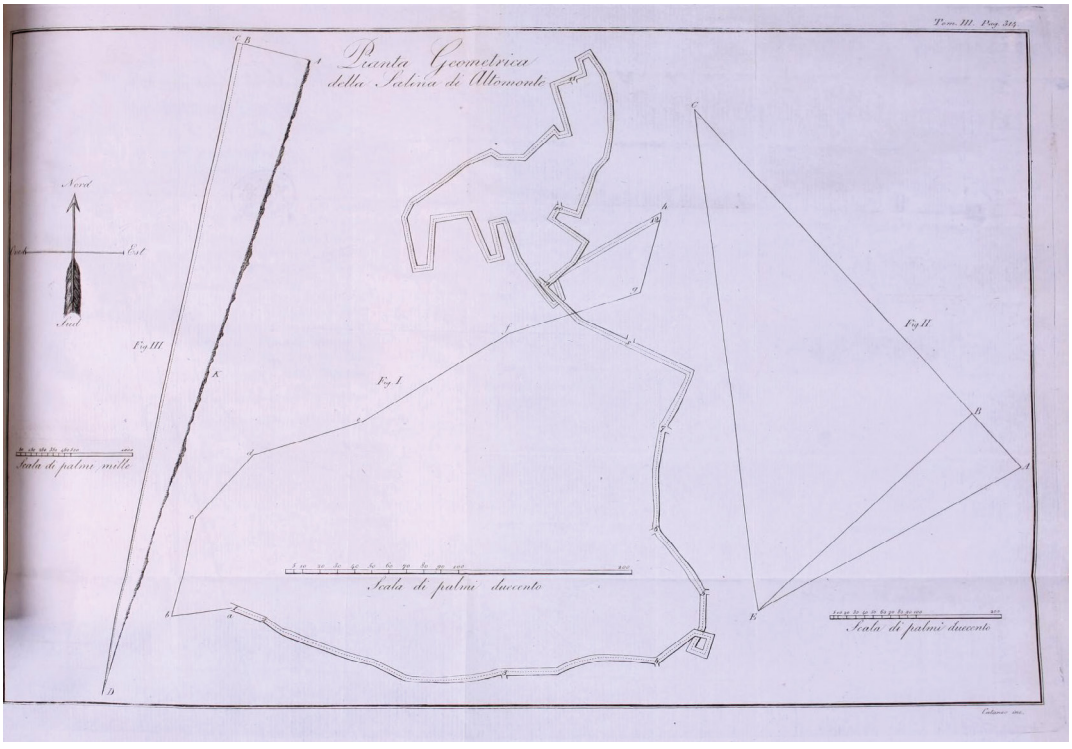

Fig. 3 - Geometric survey of the underground works of the Lungro salt mine (horizontal plane), depicting a simplified scheme of the main tunnel; survey performed in 1811-1814 (Melograni, 1822).

The technical improvements proposed by Melograni were not approved by the central administration in Naples. A few years later, Thomas Hallam, an English entrepreneur owner of numerous steam spinning mills for silk production in Villa San Giovanni (near Reggio Calabria), was called to examine the mine from a technical standpoint. He modified the Melograni's project, downsizing it, especially in the vertical shaft and drainage tunnel configuration; however, also this project was not approved. Only in 1823 the mine Director Gabriele Lamannis received the approval and funding to improve the internal conditions of the mine. The Royal Corps of engineers (*Real Corpo del Genio*) was entrusted to perform a detailed external topographical survey to design and plan the excavation of the abovementioned vertical shaft (Accattis, 1877).

Gregorio Galli (1799-1847), an official of the Royal Corps of Engineers born in Tropea (Calabria), was sent to Lungro in January 1825. He wrote a detailed report of the internal and external geometry of the mine, pinpointing the necessity of excavating a new vertical shaft (Galli, 1828). His report includes an accurate leveling, numbering and measurement of the main key points, referenced on a new map, much more precise and detailed than that of Melograni (Fig. 4). He also carried out a vertical survey of the mine and elaborated a detailed cross-section, unusual for the time (Fig. 5). The leveling was necessary to plan and design the shaft to cross an existing tunnel, midway to the deepest point of the mine, in order to improve ventilation. However, water drainage problems would not have been fully resolved, since the deeper horizontal drift construction dedicated to water drainage was not approved.

After one month of topographic measurements and surveys, on 5 March 1825 the excavation of the shaft began, based on the topographic measurements carried out by Galli himself in the previous month. Galli also supported the mine Director during its construction: he knew the *boisage perdu* technique described by Christoph Traugott Delius in his textbook for Maria Theresa's imperial mining academy in Schemnitz (Delius, 1778), and probably the shaft much resembled this configuration (Fig. 6). The shaft had a square section 2 m wide. At a depth of about 35 m, scarce ventilation was experienced at the bottom of the shaft, and forced ventilation was necessary to continue the excavation; it was carried out with an external device operated by a double-box bellows system. The shaft reached precisely the programmed point, the roof of the *Sopracielo* underground chamber, on 13 September 1827, at a depth of 300 Neapolitan palms (about 80 m).

Fig. 4 - Geometric survey of the underground works of the Lungro salt mine (horizontal plane); survey performed in 1824. The colors approximately indicate the different levels of the mine (Galli, 1828).

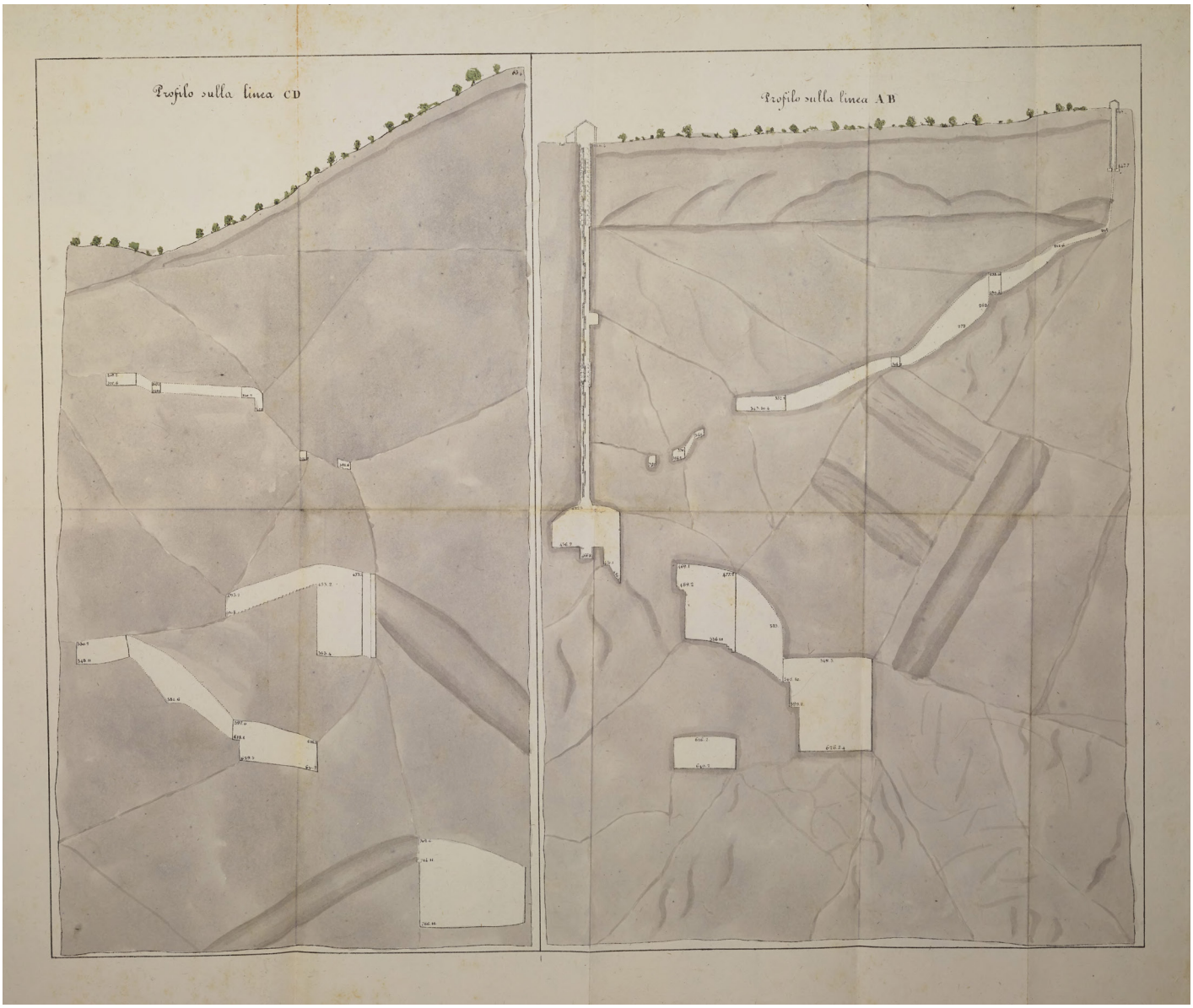

Fig. 5 - Geometry (vertical cross-section) of the underground works of the of the Lungro salt mine; survey performed in 1824 (Galli, 1828).

The excavation works lasted 2 years and 6 months, less than 10 cm per day of excavation rate. During the construction, a stairway with wood ladders and an external manual winch was installed to lift the debris with canvas bags. This shaft was then named *Pozzo Galli* (*Galli* shaft). Unfortunately, in the next 50 years it was used only for ventilation: in fact, the winch and the stairway, useful as an alternative safety passage to the underground works, were removed soon after its construction (Sole, 1981). Galli himself reminds: "It is noteworthy that this work, unique in the Kingdom, so many times planned, discussed and authorised, and which has never been dared to be started, was carried out in a country without resources, and in which unimaginable obstacles had to be overcome". Galli, as obviously does Melograni, knows and describes the already famous large salt mines of Poland, and particularly those of Bochnia and Wieliczka, and compares them to that of Lungro (Melograni, 1823; Galli, 1828).

In the mid-19th century, the Lungro salt mine, with its four production levels, a ventilation shaft and a large but messy tunneling network, was the most important industrial enterprise and the greatest concentration of workers in Calabria, with over 400 miners plus technical and administrative staff, and related industries, a number comparable only to the steam spinning mills of Villa San Giovanni. The revolutionary movements of 1848 also reached Calabria and led to violent occupations of croplands and farms and to local riots against taxes. In May 1848 extreme poverty pushed the laborers to also occupy the Lungro mine, to exploit it independently. Only military force put an end to the occupation (Basile, 1960). Regarding strikes and union conflict among miners in Italy, it should be remembered that the first cases of modern strikes occurred in the sulfur mines of Sicily. After the first cases of work abstentions which occurred around 1880, the first large-scale strikes developed in 1890, due to the continuous decline in the daily wage level (Barone, 2002).

In 1879 Torquato Taramelli (1845-1922), professor of mineralogy and geology at the University of Pavia, was on a field trip to Calabria. He visited Lungro almost by chance (and very quickly,

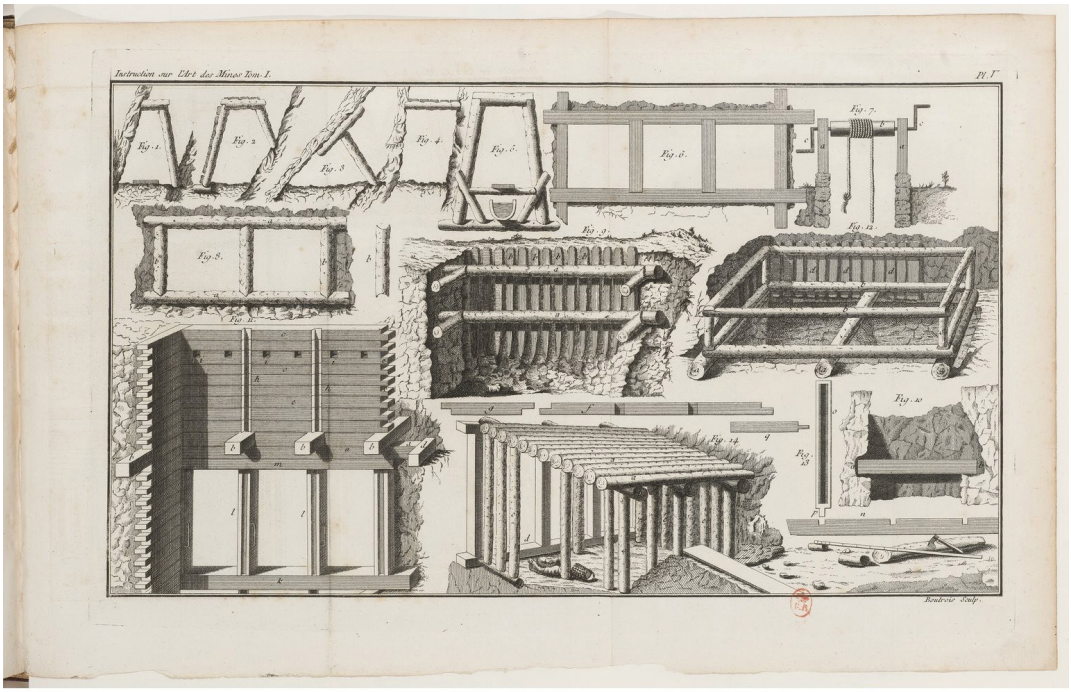

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Fig. 6 - Schematic of shaft excavation and wall reinforcement by Delius' *boisage perdu* technique, quoted by Galli (1828): probably, the first modern shaft excavated from 1825 to 1827 in the Lungro mine much resembled this configuration (Delius, 1778).

indeed) reporting stratigraphic and paleontological observations of the surrounding formations, both still very unknown at the time. Concerning the size and shape of the mine, he confirms the data published a few years earlier by Luigi Bennati di Baylon (Bennati di Baylon, 1875). "the salt mass, especially in the upper part of the deposit, is alternated with parallel layers of clay and marl; the layers are inclined 45 degrees towards the north-east in the upper part and almost vertical in the deepest part; the mined rock mass is about 100 m wide and 300 m long, with an irregularly elliptical section; it is a large lens, interstratified with clay; the excavations cover up to 220 m of depth, and no decrease in salt thickness is observed with depth" (Taramelli, 1880).

In addition, his report contains also a first-hand description of the working conditions he witnessed inside the mine. The miners, "about 400 people, tireless and patient like ants, go up and down in double row about 1500 steps, naked, out of breath, panting, and go back up carrying at least 40 kg of salt on their backs. Other miners with great skill take advantage of the stratification of the rock, and cut large parallelepipeds, which with great noise fall to the ground of the large excavation chambers, shatter into smaller pieces, which are selected by the "sorters". The less pure material, which however always contains at least four fifths of salt, is discarded and dispersed in a stream near the entrance of the mine. On the top of the main shaft, I saw a hoist, but it didn't work. Backpacking is cheaper, and those people don't earn more than a lira a day" (Taramelli, 1880).

Taramelli also recalls that in 1835, the Italian geologist Leopoldo Pilla (1805-1848) visited the mine of Lungro, and considered the site, in terms of size, one of the largest in the world. "The Lungro salt mine is almost completely unknown, and equal in size to the most famous mines of the globe. So, I deem it useful to give here a brief account of it, which I rewrite from the notes taken during my journey to Calabria. The rock salt of that territory forms an enormous mass. When I visited the mine in 1835 there were large but disorderly organised tunnels arranged on four levels. To get the lowest one, one must walk down 1200 steps directly cut into the salt mass and, also at that depth, there is no evidence of any termination of the deposit. It is made entirely of massive rock salt sometimes white and very pure, sometimes grey and less pure, but not interrupted by substances of different nature, not by clay, not by gypsum. So that, once one set foot in the mine, one saw nothing else than salt down to the lowest point of the mine" (Pilla, 1851). Taramelli reports this short note in his paper (Taramelli, 1880) but criticizes Pilla's statement that the salt mass is not interbedded with clays, highlighting that he had not surveyed carefully the tunnels at the boundary of the deposit.

Despite the attention of so many scholars and technicians towards the *Reale Salina di Lungro* (Royal Lungro saltworks) in the second half of the 19th century, the central administration was always very reluctant to solve the problems that afflicted the mine (transport, ventilation, underground stability, health and safety of the workers), and was caring only about maintaining or increasing the production of rock salt. In the mid-1850s the development of the underground works, which by then only took place in the deeper sections of the mine, below the level of the *Sopracielo* chamber, also made the *Galli* shaft inadequate for the ventilation of the most productive stopes.

After the unification of Italy, the mine was visited, studied and described by numerous engineers and geologists of the Royal Corps of Mines. Giovanni Sole (Sole, 1981) reports that Felice Giordano wrote a report in 1862, followed by another one by Nicola Pellati in 1866 (both inspectors of the Royal Corps of Mines); numerous mine Directors prepared technical reports for the Ministry of Finance, such as those of Bermanni in 1868, Bertolisi in 1870 and 1877. Unfortunately, to date it has not been possible to find the original documents of the above sources.

Between 1871 and 1876 the *Galli* shaft was enlarged, in view of its use also as an extraction shaft (*i.e.*, for the mechanical hoisting of salt), reaching a final cross-section of 2 x 3,6 m. The shaft was then supposed to continue from the original base level of the *Sopracielo* chamber down to the *Provvidenza* level, 34 m deeper. But the surrounding rocks revealed inadequate geomechanical properties (part of the shaft was dug into a fractured salt mass), and the shaft was continuously subject to rainwater infiltration, which further weakened its internal structure. And in fact, on 20 October 1879 an accident occurred. The collapse of about 7 m^3 of rock from the *Galli* shaft dropped onto the reinforced wooden roof assembled to protect the new works to deepen the shaft down to *Provvidenza* level. The rock mass smashed the roof, killing 2 miners and injuring 3 others, who fortunately survived this major accident (Foderà, 1882).

The official report signed by Ottone Foderà, then Engineer-in-chief of the Corps of Mines (Naples Section), written after his official inspection activities, highlights the precarious arrangement and poor maintenance of underground works, calling for the suspension of excavations in some dangerous stopes, the continuation of production only in the deeper and most productive sections, and for carrying out reinforcement works and the excavation of a new shaft dedicated to the mechanical hoisting of the rock salt, thus relieving the hard work of transportation personnel, that employed also many children (Spadaro, 2019).

In 1880 the central Administration of Finances assigned the mine director Giovanni Bellavite with the task of further improving the overall working and productive conditions of the mine, which was about to be closed due to poor ventilation. His project was approved by the National Council of Mines and financed, and in 1883 he completed a new shaft 3 m in diameter and 120 m of depth (out of the originally planned 250 m), which connected most of the internal levels of the mine, partly solving ventilation problems. Obviously, the new shaft was named *Pozzo Bellavite* (*Bellavite* shaft). The shaft was also equipped with a steam hoist, with a nominal installed power of about 10 HP (7,5 kW). He also promoted the use of compressed air underground. It is worthy recall that only a decade earlier, in 1871, the use of black powder for tunneling and rock-cutting had been introduced (together with manual hand drills for blast hole boring), which on one hand reduced excavation times and significantly increased production, while on the other aggravated underground ventilation problems once again (Bellavite, 1884).

In 1886, the engineers of the Corps of Mines prepared an updated and very detailed general report on the geological, engineering, technical, and economic issues of the Lungro salt mine (Foderà & Toso, 1888). After the description of the geological and structural framework of the site (Fig. 7), the report examined the state of the structural stability of the mine, which was judged to be generally satisfactory, except in some sections, for which a consolidation plan was proposed, already agreed with the mine Director.

Furthermore, the report highlighted how the mining method used up to now (rooms and pillars of irregular shape) was not adequate to guarantee an acceptable salt production for the future and to ensure underground stability (in past times, some pillars were occasionally scraped arbitrarily to obtain an easy production of good quality salt, however reducing the mechanical resistance of the pillars themselves). Instead, they proposed to apply a new mining method, adopting a regular geometry with separate vertical levels cut in the salt mass, each one mined with an underhand cut-and-fill method (Fig. 8, Fig. 9).

The same authors report that at the time most of the vertical transport of the salt was already done mechanically, fortunately, by means of the hoisting machine installed at the top of the *Bellavite* shaft. However, the miners were obliged to access the underground production levels on foot, walking down to 200 m and vice-versa, on each shift. The steam engine used to drive the hoist had a nominal power of about 15 HP (11 kW). Lift speed was about 2.4 m/s, and the steam engine required about 400 kg per day of good quality wood as fuel. The hoisting system was able to lift 120 carts loaded with 500 kg of salt each one, for a total production of 60 tons per day. However, the *Bellavite* shaft was only 120 m deep, and the rock salt was mainly produced in stopes at 200 m depth, so there was again

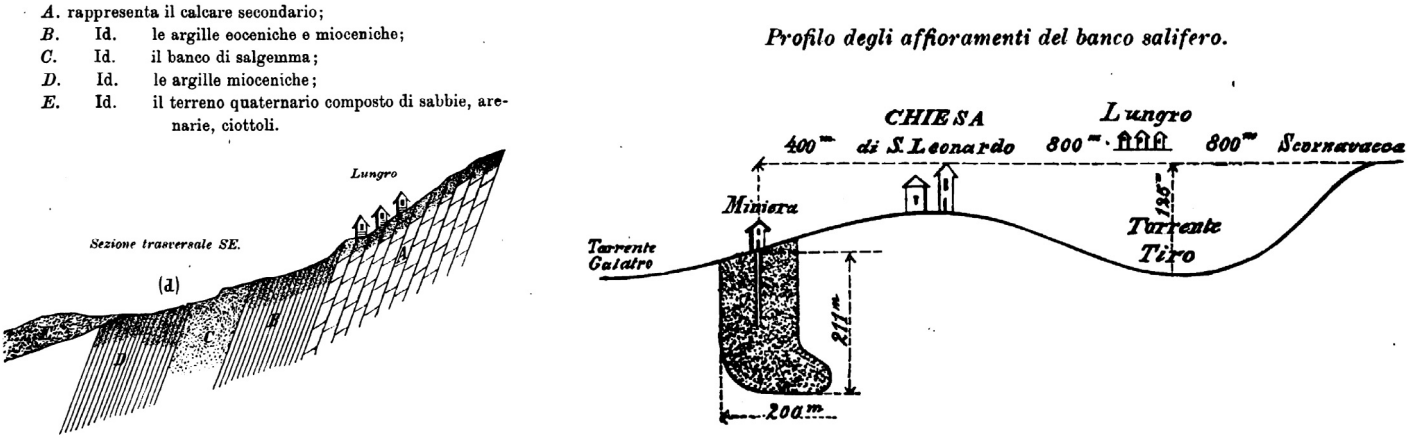

Fig. 7 - Left: Vertical cross section of the Lungro area. Captions of the geological cross section on the left: A, secondary limestone; B, Eocene and Miocene clays; C, rock salt bank; D, Miocene clays; E, quaternary sediments, composed of sand, sandstone and gravel (the mound at the far left of the section). Right: schematic profile and size of the supposed configuration of the Lungro salt mass. The authors report that the rock salt is not outcropping due to the overlapping of nearby landslides (Foderà & Toso, 1888).

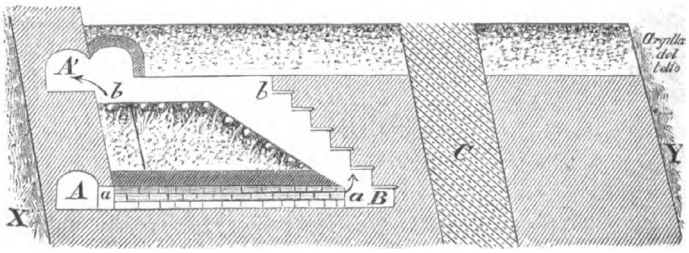

Fig. 8 - Vertical cross-section of the proposed mining method by underhand cut and fill. X and Y are the foot and hanging wall of the salt mass, respectively. Tunnels A and A' are the pair of horizontal drifts used for salt transport by small minecarts on rails. C, salt contaminated with clay. The artificial tunnel a-a is reinforced with hard blocks of rock mined in C; in cut-and-fill mining, the salt mass is removed in a series of slices progressing in horizontal direction. When each slice is removed (b, the downward slice), the void is progressively filled with waste material and impure/scrap salt mined in b and C, and the next slice of salt is mined (Foderà & Toso, 1888).

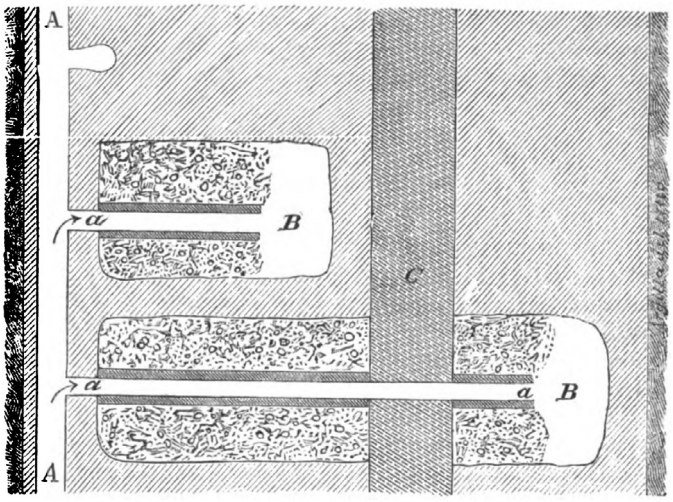

Fig. 9 - Horizontal cross-section of the proposed mining method by underhand cut and fill. B is the stope utilised for the manual sorting of rock salt, then transported via the transversal drift a-a to the haulage tunnel A, and hence to the *Bellavite* shaft hoisting shaft (Foderà & Toso, 1888).

80 m of internal height difference that must be covered by shoulder transport, by the infamous backpacking method. Foderà and Toso were both skeptical about the technical and economic possibility of deepening the *Bellavite* shaft down to the deepest production stopes of the mine (Foderà & Toso, 1888). It is worth mentioning that the gross daily production indicated above was achieved by employing approximately 450 people underground and another 30 people employed in the packaging plant at the surface. Almost all the workers came from Lungro and the nearby area, and therefore the mine was the largest employment site of the entire province, at the time quite underdeveloped as for other productive activities and agriculture, as is still partly the case today.

At the beginning of the 20th century the definitive decline of the Lungro mine began. In fact, the Italian Government evaluated that the sea salt produced in Sicily was cheaper than the rock salt produced in Lungro; at the time, the Government owned not less than 10 coastal saltworks. It is worth mentioning that at the end of the 19th century the Lungro salt production was about 7.000 tons per year, with more than 400 people employed. As a comparison, in 1901 Italy produced about 23.000 tons of rock salt in 20 mining sites, while the sea salt production from coastal salt pans amounted to over 480.000 tons (Ministero, 1902).

At Lungro, the "slow death" technique was used, *i.e.* the ever decreasing mine exploitation until all the workers retired, without layoffs but without hiring. Nevertheless, the mine remained active, especially because local and central politics had to deal with the agricultural crisis which was getting worse at the end of the 19th century, the significant workers' struggles, as well as the continuous emigration that affected Calabria in that period. So, the mine remained active, although with decreasing production and employment. In 1912 the mine produced less than 5.000 tons per year (and 200 peoples employed), against the 35.000 tons per year of rock salt produced in the underground mines of Sicily (provinces of Palermo, Agrigento, Catania and Caltanissetta).

In the years between the two World Wars the mine of Lungro was still active, though at slow pace, and was also described in the eminent handbook of the Director-General of Mines and Metallurgy Luigi Gerbella: *Arte mineraria* (Mining technology), the milestone of 20th century mining engineering in Italy. Here, the Lungro mine is mentioned as an example of the application of an optimised mining method (Fig. 10) accomplished by underhand cut and fill with "vertical slices" (Gerbella, 1938). This method is basically the same already proposed by Foderà and Toso in 1888, although rationalised in the light of 20th century technology. A second surface access tunnel (known as *Puntellata Nuova*) dug parallel to the original one,

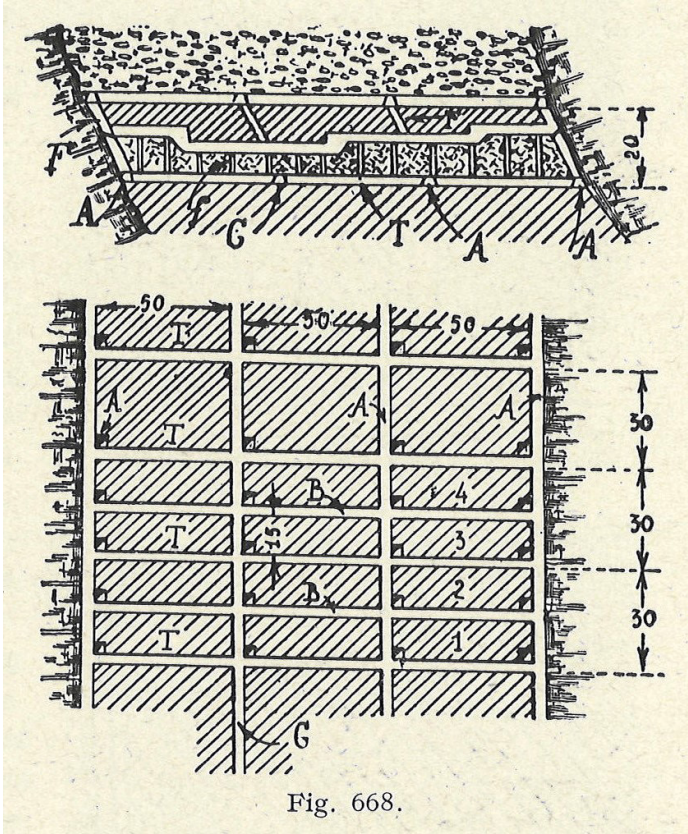

Fig. 10 - Mining method utilised in the 20th century at the Lungro mine, accomplished by means of underhand cut and fill with "vertical slices" (Gerbella, 1938).

but outside a landslide zone for safety reasons, already designed in the late 19th century (although already considered useless and expensive by Foderà and Toso in 1888) was completed in 1937.

In the same years, the writer and journalist Ulderico Tegani prepared an article for the monthly magazine of the Italian Touring Club (Tegani, 1927), in which he carefully illustrates the Lungro mine, also for touristic reasons. Apart from the slightly rhetorical style of the time, the mine description is substantially correct and realistic. The article contains several precious photos which testify to the state of the external buildings, as well as of the underground working conditions of the miners (Fig. 11, Fig. 12, Fig. 13 and Fig. 14).

Miners access to the underground was never solved: still in the 1970's, two out of eight working hours of the daily shift were lost to go up and down, as there were over 2000 steps to walk. Overall, in Lungro basic mining methods, poor design and scarce planning were adopted until the end of the 20th century, with almost no investment in technology as well as in the mechanization of production practices and health and safety issues. In the

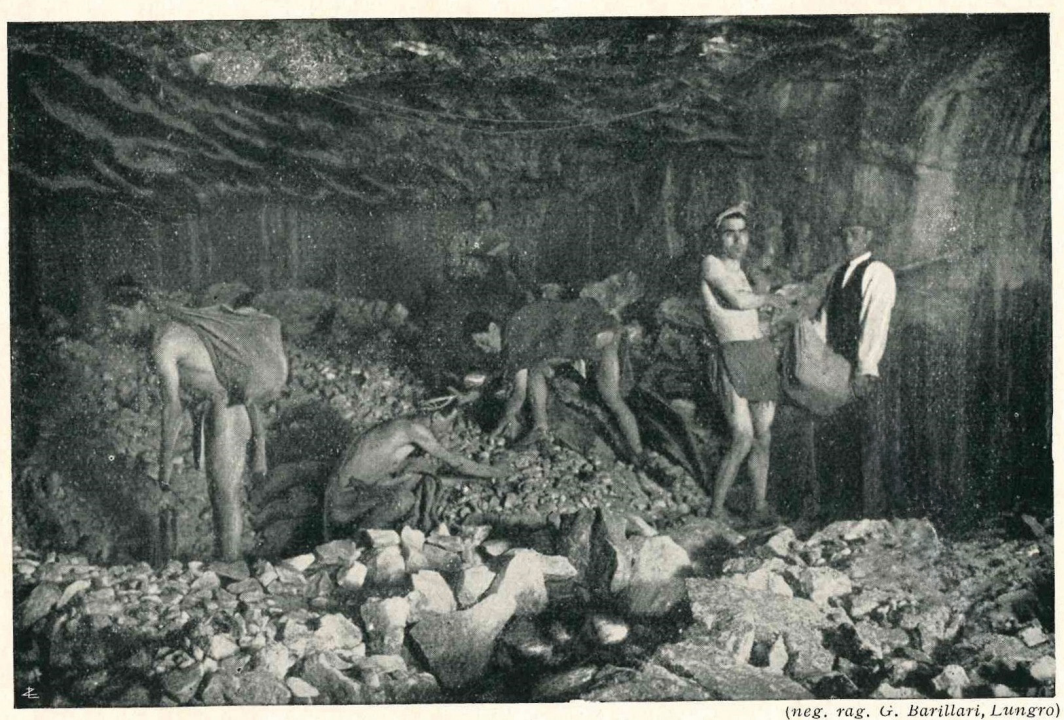
(neg. rag. G. Barillari, Lungro)

Fig. 11 - Working conditions inside the Lungro mine. Most of the operations were hand-made, including salt block selection and part of the salt transport, largely carried out by the infamous backpacking method. Poor ventilation forced the miners to work naked and without any personal protective equipment (Tegani, 1927).


(neg. rag. G. Barillari, Lungro)

Fig. 12 - An official visit to the underground chambers of the Lungro mine. A modern compressed air drill (center) and an older manual drill (right) are visible. The underground lighting is accomplished by carbide lamps (acetylene gas lamps). As in the previous picture, the miners work naked (Tegani, 1927).

Fig. 13 - Historical picture of the external mine yard located in front of the main mine access, the stone-reinforced arc lining the tunnel in the center-right of the photo (Tegani, 1927).

Fig. 14 - General view of the mining site in 1927, south to north, with the access road that today starts from the SP 263 road junction. In the background, the *San Leonardo* hill. Today, the old buildings and facilities of the abandoned mining site, although partially recently restored, are threatened by active landslides and subject to subsidence (Tegani, 1927).

1970's, after a period of workers' and trade unions struggles not fully supported by either the local political parties and the Italian government, the mine was finally closed and abandoned. On 5 August 1976 the State Monopolies decided to renounce the mining concession, and the ratification by the Ministry of Industry took place on 8 March 1978.

CONCLUSIONS

The modern Italian mining activity, before and after the industrial revolution, encompassed the exploitation of a large number of small mineral deposits; some of them were very important, at least for the continuity of mining knowledge, sometimes dating back to Etruscan

or even prehistorical times. However, in some cases, especially in the rock salt production sector, mining was significant not only for the temporal continuity of mining operations, but also for the social relationships of the nearby population and the development of a particular taxation regimes and of specific administrative, production and trading systems.

In particular, the mining site of Lungro testifies the long-lasting coexistence of extremely complex social, political, technological, and economic issues that characterised salt mining through the centuries, as workforce organization (employment Vs. migration), long-debated child labor issues, salt monopoly, salary conditions, feudal privileges, poor technology Vs. high profits, health and safety of underground working conditions, inadequate mechanization of production practices, trade union struggles, *etc*.

In recent years, some external structures and buildings of the Lungro mining site has been restored and made accessible to the public, together with the "Historical Museum of the Lungro rock-salt mine" (https://cultura.gov.it/luogo/ex-miniera-san-leonardo). Moreover, since several years, the mine and the museum are part of the National Network of Italian Mining Parks and Museums of the "ReMi Project" of ISPRA - Italian Institute for Environmental Protection and Research (Patané et al., 2023; La Russa, 2024), which aims at the recovery and enhancement of these interesting and often neglected expressions of the historical and cultural heritage of local areas, as well as to encourage the use of the geological and mining heritage for tourism and cultural purposes.

REFERENCES

Accattis L. (1877) - Le biografie degli uomini illustri delle Calabrie, Vol. IV. Tipogr. Migliaccio, Cosenza, 501 pp.

Alberti L. (1550) - Descrittione di tutta Italia, nella quale si contiene il sito di essa, l'origine et le Signorie delle Città et delle Castella. A. Giaccarelli, Bologna, 469 pp.

Alessandri L. & Attema P. (2022) - From briquetage to salterns in protohistoric Central Italy. Research of a fundamental subsistence commodity. IpoTESI di Preistoria, 14, 161-168, https://doi.org/10.6092/issn.1974-7985/14338.

Amodio-Morelli L., Bonardi G., Colonna V., Dietrich D., Giunta G., Ippolito F., Liguori V., Lorenzoni S., Paglionico A., Perrone V., Piccarreta G., Russo M., Scandone P., Zanettin-Lorenzoni E. & Zuppetta A. (1976) - L'Arco Calabro-Peloritano nell'orogene Appenninico-Maghrebide. Mem. Soc. Geol. It., 17, 1-60.

Antronico L., Borrelli L., Coscarelli R. & Gullà G. (2015) - Time evolution of landslide damages to buildings: the case study of Lungro (Calabria, southern Italy). Bull. Eng. Geol. Environ., 74, 47-59, https://doi.org/10.1007/s10064-014-0591-y.

Barone G. (2002) - Zolfo. Economia e società nella Sicilia industriale. Bonanno, Roma, 209 pp.

Barrio G. (1571) - De antiquitate et situ Calabriae. Joseph. De Angelis, Roma, 452 pp.

Basile A. (1960) - L'occupazione di una miniera di sale in Calabria Citra nel 1848. Archivio storico per la Calabria e la Lucania, 19, 37-45, https://periodici.animi.it/rassegna/anno-xxix-1960-fasc-1/.

Bellavite G. (1884) - Cenni sulla miniera di salgemma in Lungro. Ministero delle Finanze, Direzione Generale delle Gabelle, Eredi Botta, Roma, s.p.

Bennati di Baylon L. (1875) - Le saline del Regno d'Italia: notizie sulla produzione e sull'amministrazione del sale. Tip. Giachetti, Prato, 34 pp.

Bergier J.F. (1984) - Una storia del sale. Marsilio, Venezia, 239 pp.

Cataldo V. (2012) - Commercio e contrabbando di sale in provincia di Calabria Ultra agli inizi del Settecento. Incontri Mediterranei, 22, 65-73.

Cianflone G., Tolomei C., Brunori C.A., Monna S. & Dominici R. (2018) - Landslides and subsidence assessment in the Crati Valley (Southern Italy) using InSAR Data. Geosciences, 8(67), 1-22, https://doi:10.3390/geosciences8020067.

D'Arienzo V. (2006) - La produzione di sale nelle aree interne del Regno di Napoli. L'arrendamento dei "sali di Monte di Calabria" nella seconda metà del XVII secolo. In: Inland salt works and salt history: economy, environment and society, Siguenza, 6-10 sept, Universidad Rey Juan Carlos, Vol. 2, 593-608.

Delius C.T. (1778) - Traité sur la science de l'exploitation des mines, trad. par Mr. Schreiber. Tome I, Philippe Denys Pierres, Paris, 518 pp.

Foderà O. (1882) - Infortunio nella miniera di Lungro. In: Annali di Agricoltura, Relazione sul Servizio Minerario nel 1879, Appendice al Rapporto sul distretto di Napoli. Eredi Botta, Roma, 278-289.

Foderà O. & Toso P. (1888) - Miniera di Lungro. In: Annali di Agricoltura, Rivista del Servizio Minerario nel 1886, Appendice alla Relazione sul distretto di Napoli. Eredi Botta, Roma, 197-215.

Galli G. (1828) - Memoria sulla salina di Altomonte in Calabria citeriore. B. Borel, Napoli, 26 pp.

Gerbella L. (1938) - Arte mineraria. Vol. 2, Hoepli, Milano, 639 pp.

Giustiniani L. (1797) - Dizionario geografico ragionato del Regno di Napoli. Tomo 1, V. Manfredi, Napoli, 314 pp.

Guerricchio A., Bruno F. & Mastromattei R. (1993) - Centri abitati instabili in Calabria: deformazioni gravitative profonde di versante e grandi frane nel territorio comunale di Lungro (Calabria settentrionale). Geol. Appl. Idrogeol., 28, 479-488.

Harding A. (2014) - The prehistoric exploitation of salt in Europe. Geol. Quart., 58 (3), 591-596, http://dx.doi.org/10.7306/gq.1164.

Ietto A. & Ietto F. (2010) - Note illustrative del Foglio 543 Cassano allo Ionio alla scala 1:50.000. ISPRA, Servizio Geologico d'Italia, Roma.

Jervis G. (1881) - I tesori sotterranei dell'Italia, Parte terza, Regione delle isole, Sardegna e Sicilia. E. Loescher, Torino, 539 pp.

Kurlansky M. (2002) - Salt, a World History. Bloomsbury Publ., New York, 484 pp.

La Russa M.F., Patanè A., Apollaro C., Bloise A., Fuoco I., Ricca M., Russo L. & Vespasiano G. (2024) - Quantitative Assessment of Geosites and Mine Heritage as a Resource: The Case Study of Lungro Salt Mine (Calabria, Italy). Geoheritage, 16, 77, https://doi.org/10.1007/s12371-024-00978-2.

Lowe B. (2018) - Manilius and the Logistics of Salting in the Roman World. J. Marit. Archaeol., 13, 467-480, https://doi.org/10.1007/s11457-018-9220-4.

Marcelli A. (2006) - Sviluppo economico nella Cosenza ottocentesca attraverso gli atti della Società Economica di Calabria Citra. Aracne, Roma, 199 pp.

Mastriani R. (1838) - Dizionario geografico-storico-civile del Regno delle Due Sicilie. Tomo 2, Raffaele De Stefano e soci, Napoli, 462 pp.

Melograni G. (1822) - Descrizione delle saline delle Calabrie. Atti del Real Istituto di incoraggiamento alle scienze naturali di Napoli. Tomo 3, F. Fernandes, Napoli, 287-312.

Melograni G. (1823) - Descrizione geologica e statistica di Aspromonte e sue adiacenze. Coll'aggiunta di tre memorie concernenti l'origine dei volcani, la grafite di Olivadi e le saline delle Calabrie. Stamperie Simoniane, Napoli, 298 pp.

Ministero di Agricoltura, Industria e Commercio (1902) - Rivista del Servizio Minerario nel 1901. Bertero, Roma, 475 pp.

Moncada C. (1940) - Il sale nell'Italia e nell'Impero. Rosenberg & Sellier, Torino, 180 pp.

Ogniben L. (1969) - Schema introduttivo alla geologia del confine calabro-lucano. Mem. Soc. Geol. It., 8, 453-763.

Patané A., Sisti R., Lasco A. & Stellato A. (2023) - La Rete nazionale dei Parchi e dei Musei minerari. Viaggio nell'Italia mineraria. Edizione 2023. ISPRA – SNPA, ReMI, 157 pp.

Perrone V., Torre M. & Zuppetta A. (1973) - Il Miocene della Catena Costiera Calabra. Primo contributo: zona Diamante-Bonifati-S. Agata d'Esaro (CS). Riv. Ital. Paleontol. S., 79, 157-205.

Pesavento A. (2015) - Estrazione e commercio di sale nelle miniere di Miliati e di Neto. Archivio storico Crotone, https://www.archiviostoricocrotone.it/luomo-medievale-e-moderno/estrazione-e-commercio-di-sale-nelle-miniere-di-miliati-e-di-neto/.

Pilla L. (1851) - Trattato di geologia, parte seconda. Vannucchi, Pisa, 626 pp.

Pulli P. (1813) - Trattato teorico-pratico su la raccolta del nitro. A. Trani, Napoli, 161 pp.

Pulli P. (1817) - Statistica nitraria del Regno di Napoli. Tomo 2, Chianese, Napoli, 376 pp.

Rende P. (2015) - Risorse minerarie ed attività estrattiva in alcune aree del Crotonese e della Sila in età antica e medievale. Archivio storico Crotone, https://www.archiviostoricocrotone.it/ambiente-e-paesaggio/risorse-minerarie-ed-attivita-estrattiva-in-alcune-aree-del-crotonese-e-della-sila-in-eta-antica/.

Roda C. (1979) - I giacimenti di salgemma della Calabria. L'Industria Mineraria, 5-6, 142-152.

Samengo P.G. (1845) - La Real Salina di Lungro. Il Calabrese: foglio periodico, Anno 3, n. 16 (30 giugno), 123-124.

Sole G. (1981) - Breve storia della Reale Salina di Lungro. Brenner, Cosenza, 85 pp.

Spadaro C.M. (2019) - Il lavoro minorile nelle miniere calabresi in età borbonica tra antiche regole e nuovi "diritti". Ital. Rev. Leg. Hist., 5(5), 168-200, https://doi.org/10.13130/2464-8914/12645.

Taramelli T. (1880) - Sul deposito di salgemma di Lungro nella Calabria citeriore. Atti R. Acc. dei Lincei, Mem. cl. sci. fis., mat. e nat., Ser. 3, Ann. 277, 5, 136-143, http://emeroteca.braidense.it/beic_attacc/sfoglia_articolo.php?IDTestata=924&CodScheda=00AF&IDT=31&IDV=269&IDF=0&IDA=8753.

Tegani U. (1927) - Una miniera millenaria: il salgemma di Lungro. Le vie d'Italia, Rivista del TCI, 33, 1185-1192.

Van Dijk J.P., Bello M., Brancaleoni G.P., Cantarella G., Costa V., Frixa A., Golfetto F., Merlini S., Riva M., Torricelli S. Toscano C. & Zerilli A. (2000) - A regional structural model for the Northern sector of the Calabrian Arc (Southern Italy). Tectonophysics, 324, 267-320.

Weller O. (2015) - First salt making in Europe: an overview from Neolithic times. Documenta Praehistorica, XLII, 185-196, https://doi.org/10.4312/dp.42.12.