# THE IRON MINERAL DEPOSITS OF ELBA ISLAND: STATE OF THE ART

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ABSTRACT

A number of metallic (Fe, Cu, Mn, Sb) and non-metallic deposits (Mg silicates, magnesite, sericitized aplites, granite, pegmatites) have been the target of exploration and exploitation in Elba Island since the The iron deposits of Elba Island have been the target of intense exploitation since the 1st Millennium BC up to present1981. Elba is especially famous worldwide for its iron deposits and the pegmatitic minerals from Monte Capanne. All iron mines are now closed, but in the last years several steps were taken in order to preserve and promote such a valuable heritage: the inclusion of Elban mining and mineralogical areas into the UNESCO's World Heritage provisional list of geological sites (1990), the project of the "Elba Island Mineralogical and Mining Park" (started in 1991 and now underway), and the establishment in 1996 of the "Tuscan Archipelago National Park". In this paper we summarize the state of the art of the research on Elba Island's mineral iron ore deposits, with particular focus onto the iron ores of eastern Elba. In the course of almost three thousand years of exploitation, not less than 60 million tons of Fe ore have been won. Fe. Notwithstanding the many studies on these deposits carried out by Italian and foreign scholars over more than two hundred years, many aspects of their setting, genesis and evolution still need to be clarified and better constrained. This is due to various factors, including the complex (and only partially understood) geological framework of the island, and the closure of mining activity, with consequent inaccessibility to many mine-workings. We stressand emphasize the some mostproblematic aspects, which are fundamental clues not only for the understanding ofof the ore-forming genetic processes of and evolution of Elban's mineral deposits, but also for the reconstruction of the overall geologic evolution of the Apenninic chain.

## INTRODUCTION

Lotti (1877, p. 187) defined Elba Island as a "marvellous open-air mineralogical Museum". Elba's mineralogical heritage is actually of exceptional richness: about 150 mineral species have been so far discovered therein (Tanelli, 1995a), and some species, such as the beautiful "lamellar" hematites from Rio Marina, or the "nigro-head" and "watermelon" tourmalines from San Piero pegmatites, are renowned for their aesthetical value (see Ruggieri and Lattanzi, 1992, and Aurisicchio et al., 1999, for details on pegmatite minerals). The skarn mineral ilvaite and the Li-rich end-member of the tourmaline group, elbaite, owe their names to this little island in the Mediterranean Sea. Some of these mineral commodities have been the target of more or less extensive exploration and active mining. Apart from iron deposits, described here below in detail, some mining activity occurred in the past in scattered Cu ± Mn mineralizations, mostly associated with ophiolitic suites (Table 1). Of much greater economic significance are some industrial rock and mineral deposits, such as the serpentinite bodies mined for Mg silicates and magnesite at Monte Fico and near San Piero, the Monte Capanne granite, and the "eurite" (= more or less altered aplites; see below) deposits of La Crocetta and San Rocco di Marciana mines. But it is mainly to iron resources that Elba Island owes its long-lasting fame. There are a few indirect archaeological evidences indicating that exploitation, processing and trading of iron ores from Elba was possibly accomplished as early as in the eighth century B.C. (Corretti and Benvenuti, 2000). However, the oldest archaeometallurgical products found in the island date back to the fourth century B.C. maximum, and indicate that extensive "in situ" reduction of iron minerals was accomplished (preferentially along coast) in the Roman period (3rd century B.C.: Corretti, 1988). After a long period of quiescence, mining and metallurgical activities in north-eastern Elba (from Cavo to Rio Marina) flourished under the domination of the Pisa Republic (11th-14th century AD), and in the Medicean and Asburgo-Lorena periods (16th-18th century AD). After the Vienna Congress' Restoration (1815), Elba was definitely included within the Granducato di Toscana. In this period new mine workings were developed at Terra NeraTerranera - Capo Bianco, and, by the end of the century, at Punta Calamita, Sassi Neri and Ginevro. After the Unification of Italy all mines at Elba became a state property and were granted in concession to different mining companies, up to 1981, when the last mine (Ginevro) shut down. As above recalled, nowadays mineral exploitation at Elba is exclusively focussed onto the aforementioned industrial deposits.

Three millennia of intense mining activity left profound marks in the landscape, culture and history of Elba Island. It must be admitted that serious environmental concerns arise from past and present-day mining activity, especially in eastern Elba, where sulphide-bearing ores have been exploited and/or processed (due to potential heavy metal pollution; cf. Benvenuti et al., 1999), or at the La Crocetta and San Rocco di Marciana mines, where exploitation severely conflicts with landscape preservation. On the other hand, such a long mining tradition and invaluable mineralogical heritage make Elba Island a unique site for both scientific research, and educational purposes (Tanelli and Benvenuti, 1996). This is the reason why UNESCO introduced the Elban mining areas into the provisional list of

Table 1 - Mineral deposits and occurrences from Elba Island (excluding iron ores)

| | Mineral occurrences/ prospects | Ore type | Host rocks | Mining |
|---|---|---|---|---|
| (a) | Mt. Perone | Cu | ophiolitic seq. | pre-Roman Age ? |
| (b) | Pomonte | Cu | ophiolitic seq. | pre-Roman Age ? |
| (c) | Le Tombe (Fetovaia) | Cu | ophiolitic seq. (serpentinites) | - |
| (d) | Santa Lucia | Cu | ophiolitic seq. (serpentinites, cherts) | pre-Roman Age ? |
| (e) | Colle Reciso-Mt. Orello | Cu | ophiolitic seq. | pre-Roman Age ? |
| (f) | Norsi | Cu | ophiolitic seq. | - |
| (g) | Acqua Calda | Cu | ophiolitic seq. (basalts) | - |
| (h) | Magazzini, Volterraio | Mn (Cu) | ophiolitic seq. (cherts) | XX cent. (Mn) |
| (i) | Procchio | Sb | quartz-stibnite veins (hosted by Monte Capanne intrusion and porphyries) | - |
| (l) | Sant'Ilario-San Piero | precious and semiprecious | Monte Capanne pegmatites | XVIII-XX cent. |
| (m) | San Piero-San Florio | magnesite | ophiolitic seq. (serpentinites) | XIX-XX cent. |
| (n) | Monte Fico | Mg silicates | ophiolitic seq. (serpentinites) | XIX-XX cent. |
| (o) | Sant'Ilario - San Piero in Campo Seccheto, Cavoli | granite | M.te Capanne stock | Roman Age - XX cent. |

Data from Benvenuti et al. (1991), Tanelli (1995a), and references therein.

geological sites of the World Heritage, and in 1991 it was started a project, now underway, for the establishment of the “Elba Island Mineralogical and Mining Park”. Increasing public awareness in Italy for the relevance of conservation of natural heritage, including valuable geo-mineralogical sites (the so-called “geosites”), was the back-force that favoured the establishment in 1996 of the “Tuscan Archipelago National Park” (PNAT). All mining and mineralogical areas of Elba Island are presently under PNAT’s administration.

In this paper we shall focus almost exclusively onto the iron ore deposits, which are the most important both from an economical and scientific standpoints (see next chapter). In spite of this, there was no much recent research on the deposits, perhaps because of mine closure at the beginning of the 1980s. As a consequence, while for other mining districts of Tuscany, extensively studied in the last three decades, both descriptive and genetic models - although not unanimously accepted - are available (cf. Tanelli, 1983; Lattanzi et al., 1994, and literature therein), a rigorous definition of the metallogenic framework and ore-forming processes of Elba’s iron ores is still lacking. The recent literature includes a review paper by Zuffardi (1990), and few studies on specific deposits (Capo Calamita: Torrini, 1990; Sassi Neri: Del Tredici, 1990; Terranera: Seeck, 1998). On the other hand, recent research was carried out on the still active industrial deposits, like the “eurites” mined at La Crocetta (Porto Azzurro; cf. Maineri et alii, 1999; 2000; Lattanzi et al., 2001). The results of these studies may have some implications for the iron ores as well

## THE GEOLOGICAL AND METALLOGENIC FRAMEWORK

### Geology

The overall picture proposed for Elba Island by Trevisan (1950), who distinguished five main tectonic units (Complexes I to V), is substantially valid even now. However, recent research and detailed field mapping is unravelling a much more complex tectonic and stratigraphic history (e.g. Pandeli &and Puxeddu, 1990; Duranti et al., 1992; Corti et al., 1996; Bortolotti et al., 2001). According to the latter authors, the tectonic frame of central and eastern Elba Island is made up of the following nine major tectonic units (from the geometrically lowermost upwards): (1) Porto Azzurro Unit (ex Trevisan’s Complex I); (2) Ortano Unit and (3) Acquadolce Unit (corresponding to Trevisan’s Complex II); (4) Monticiano-Roccastrada Unit, (5) Tuscan Nappe Unit and (6) Gràssera Unit (corresponding to Trevisan’s Complex III); (7) Ophiolitic Unit with seven subunits, corresponding to Trevisan’s Complex IV; (8) Paleogene Flysch Unit and (9) Cretaceous Flysch Unit, making up Trevisan’s (1950) Complex V. According to Bortolotti et al. (2001) tectonic model, units (1), (2), (4) and (5) belong to the Tuscan Domain, (3) and (6) to the Piedmontese Domain, and units (7), (8) and (9) to the Ligurian Realm. In eastern Elba the units of this tectonic stack are characterised by a general top to east vergence, and are separated each other by roughly NS low-angle tectonic surfaces (thrusts and detachments). The various units, originally deposited in quite different palaeogeographic domains, were deformed and piled up into their present position during the compressional stage of the Apenninic orogeny, and later affected by an important extensional phase. This stage was also accompanied by the emplacement of several magmatic intrusions at shallow crustal levels (cf. Westerman et al., 2000, and references therein): the Monte Capanne pluton (7.2-5.9 Ma; 6.8 Ma), the monzogranitic stock of Porto Azzurro (5.9-5.1 Ma), swarms of aplitic and pegmatitic dikes (the latter almost exclusively found associated with the Monte Capanne pluton), and a laccolith complex made of subvolcanic porphyritic rocks (8-6.85 Ma). Westerman et al. (2000) suggest that the emplacement of the Monte Capanne pluton triggered the movement of an important extensional detachment fault (Central Elba Fault, CEF), which controlled the eastward translation of about 10 km of upper plate rocks (including Complex V with intruded laccolith complex) from their original position on the top of Monte Capanne pluton. There are many evidences that CEF triggered an intense fluid circulation, which is held responsible of the pervasive hydrothermal alteration of porphyritic aplites and formation of the "eurites" exploited at La Crocetta and Marciana mines. According to Maineri et al. (1999; 2000) and Lattanzi et al. (2001), the mined material consists mainly of sericite replacing primary albite and K-feldspars. At 5.9-5.1 Ma, the emplacement of Porto Azzurro stock caused CEF deactivation, although additional eastwards tectonic translations took place along another major low-angle fault, the Zuccale Fault (Pertusati et al., 1993). The last tectonic stage at Elba Island is mainly represented by N-S trending high-angle extensional faults affecting the entire N-Tyrrhenian basin, mostly ended before about 3.5 Ma (Keller and Pialli, 1990).

## Metallogeny

Together with Sardinia, Tuscany is the main mining region of Italy, where almost three millennia of exploitation yielded significant productions of iron, pyrite, base metals, silver, antimony, mercury, gold, as well as industrial minerals and rocks (cf. Cipriani and Tanelli, 1983). In addition to its economic relevance, the Tuscan metallogenic province remains of primary scientific importance due to the occurrence of diverse hydrothermal deposits associated with volcano-sedimentary, magmatic, metamorphic and geothermal environments of pre-Tethyan and Alpine ages (Lattanzi et al., 1994). They include, among the others, the Fe oxides deposits of Elba Island, the pyrite (± barite ± Fe oxides) deposits of Southern Tuscany and Apuane Alps, the base-and precious-metals deposits of the "Colline Metallifere" district (Southern Tuscany), the Hg deposits of the Monte Amiata area, the Sb deposits of the Capalbio-Monti Romani belt, often associated with invisible gold mineralization (Tanelli et al., 1991). The metallogeny of Tuscany is rather complex, and several aspects still await a definite answer. According to Lattanzi et al. (1994), three main metallogenic epochs seem to be relatively well established in Tuscany: *(i)* a Middle-Upper Palaeozoic stage, leading to the formation of protores/preconcentrations of metals (e.g., at Bottino and Levigliani in the Apuane Alps district); *(ii)* a Palaeozoic-Palaeozoic-Triassic(?) Fe (and Ba) metallogeny in various areas such as Elba Island, Southern Tuscany and Apuane Alps; *(iii)* an Apenninic event, well documented both in Apuane Alps and in Southern Tuscany (e.g. the epithermal Au deposits and the polymetallic sulphide ore bodies).

As outlined above, iron-bearing deposits in Tuscany mainly occur in three districts: the barite-iron oxide-pyrite deposits of Apuane Alps; the pyrite deposits of Southern Tuscany (Maremma), and the iron ores (with dominant oxides) of Elba. Total production from the three districts may be estimated in the order of 150 million tons ore: the Apuane deposits yielded about 0.5 million tons pyrite + Fe oxides (Lattanzi et al., 1994), whereas more than 80 million tons of high-grade mineral concentrate were obtained by exploitation of several pyrite deposits in Maremma (Gavorrano, Niccioleta, Campiano and other deposits in the Boccheggiano area: Tanelli and Lattanzi, 1983), and not less than 60 million tons Fe ore have been extracted from Elba deposits from ancient times up to nowadays (data from Fabri, 1887; Pullè, 1921). Some authors (e.g. Tanelli, 1983; Cortecci et al., 1985a) point out that in all the three districts Fe-bearing deposits normally occur as stratiform and stratabound bodies, preferentially associated with siliciclastic Palaeozoic-Triassic(?) rocks of the Tuscan Domain basement, and/or with their contacts to overlying Upper Triassic dolomitic formations. The stratiform bodies may be also more or less strictly associated with late-Apenninic extensional lineaments and/or (particularly in Maremma and Elba) with Miocene to Pliocene granitic rocks and skarn bodies. In Southern Tuscany, pyrite deposits have also variable spatial relationships to, and may be associated with, Cu-Pb-Zn sulphide showings, mostly uneconomic.

A number of hypotheses have been put forward in the last two centuries in order to explain the genesis of Tuscan Fe deposits. They can be grouped in two basic genetic models (Tanelli and Lattanzi, 1986): a) "plutonistic epigenetic"; b) "syngenetic/hydrothermal-metamorphic". According to the former model, ore genesis is a direct consequence of the intrusion of the late-Apenninic granitic stocks; the authors favouring the second hypothesis acknowledge the importance of the Apenninic tectono-magmatic event in metamorphosing and partly remobilising the iron ores, but believe that, at least as pre-concentrations, they were formed in sedimentary and/or hydrothermal sedimentary environments of Triassic and/or Palaeozoic age (stage *ii*- of Lattanzi et al., 1994).

In the last decade, further contributions to the comprehension of the Tuscan metallogenic framework came from Pb isotope analyses of mineral deposits from Southern Tuscany (Lattanzi et al., 1991; 1997) and Apuane Alps (Lattanzi et al., 1992). The isotopic composition of ore lead in the Apuane Alps is distinctly less radiogenic than that of ore lead from deposits of Southern Tuscany, which show higher 208/204 and 206/204 ratios, but have the same high-m, high-W character. The observed distribution of Pb isotope data may suggest that, in the two districts, Pb (+ other metals?) source(s) with similar evolutions of their U/Pb and Th/Pb ratios were tapped at different times (Lattanzi et al., 1992). Pyrite from the pyrite deposits of Maremma has very similar Pb isotopic composition as Mio-Pliocenic granitic rocks, which are spatially associated to several deposits. This could indicate that magmatic rocks were an important (even if not the sole) source of lead in the deposits. Pb data for Elba Island are only available for granitic intrusions (Vollmer, 1977; Juteau et al., 1986), and for a few galena samples from vein-type mineralization at Rio Marina (Falcacci stope: Lattanzi et al., 1997). The Pb isotope composition of both sets of samples does not differ from that of other magmatic rocks and sulphide deposits of Southern Tuscany.

## THE FE DEPOSITS OF ELBA ISLAND

### Generals

As emphasized by Tanelli and Benvenuti (1996), Elba's fame for its huge iron mineral resources was so widespread and sound that the belief that iron deposits were inexhaustible ("Ilva ... inexhaustis Chalybum generosa metallis": Virgilius, *Eneide, X, 174)* protracted over for centuries and centuries, and one can find traces of it in the works of the very fathers of Mineralogy like George Bauer [Agricola] (1494-1555), V. Biringuccio (1480-1538) and, later on, N. Stensen (1638-1686). It is also noteworthy that Stensen, and later on Haüy, developed their pioneering theories on crystal growth and morphologies by studying some crystals of pyrite, quartz and hematite of probable Elban provenance. In the last three centuries Elba's iron minerals and ores have been the target of many important studies by a wealth of Italian and foreign scholars: E. Pini, P. Savi, G. Giuli, L. Pilla, T. Haupt, G. Jervis, G. vom Rath, I. Cocchi, A. and G. D'Achiardi, G. Roster, B. Lotti, A.. Fabri, L. De Launay, U. Panichi, F. Millosevich, G. Pullè, E. Beneo, G. Cocco, C. Garavelli, F. Gillieron, G. Gottardi, J. Bodechtel, G. Carobbi F. Rodolico, and many others (see Benvenuti et al., 1991, and Tanelli and Benvenuti, 1997, for an exhaustive review of the geo-mineralogical literature on Elba).

### Ore setting

We report hereafter a summary of the main features of Fe ores of Elba Island (Table 2, Figs. 1 and 2) and we discuss the most interesting (and problematic) aspects. For a detailed description of the various deposits, the interested reader is referred to Lotti (1886), Fabri (1887), Pullè (1921), Beneo (1952), Debenedetti (1952), Gillieron (1959), Tanelli (1977; 1995a; 1995b), Benvenuti et al. (1991), Benvenuti (1996, and literature therein).

As shown in Fig. 1, the Fe deposits of Elba Island are restricted to a relatively narrow belt extending NS along the eastern coast of Elba Island, from Monte Calendozio (Rialbano or Rio Albano mine) to the Calamita Promontory. The ore the bodies, even at the scale of individual deposits, occur in variable settings, from stratiform to pod-like or vein-type, although the first appears to be dominant (Zuffardi, 1990). Stratiform Fe bodies, either or not associated with veins and/or irregular masses, are "strata-bound", at least in the wider meaning of the word. In fact they are predominantly hosted by Palaeozoic-Triassic formations belonging to Tuscan Domain (Porto Azzurro Unit: Calamita, Sassi Neri, Ginevro deposits; Monticiano-Roccastrada U.: Rio Marina; Tuscan Nappe: Rialbano; see Fig. 2). The exact relationships of ore bodies to the host strata are, however, not entirely clear, and is affected by changes of stratigraphic interpretations (see below). A number of Fe ores are associated

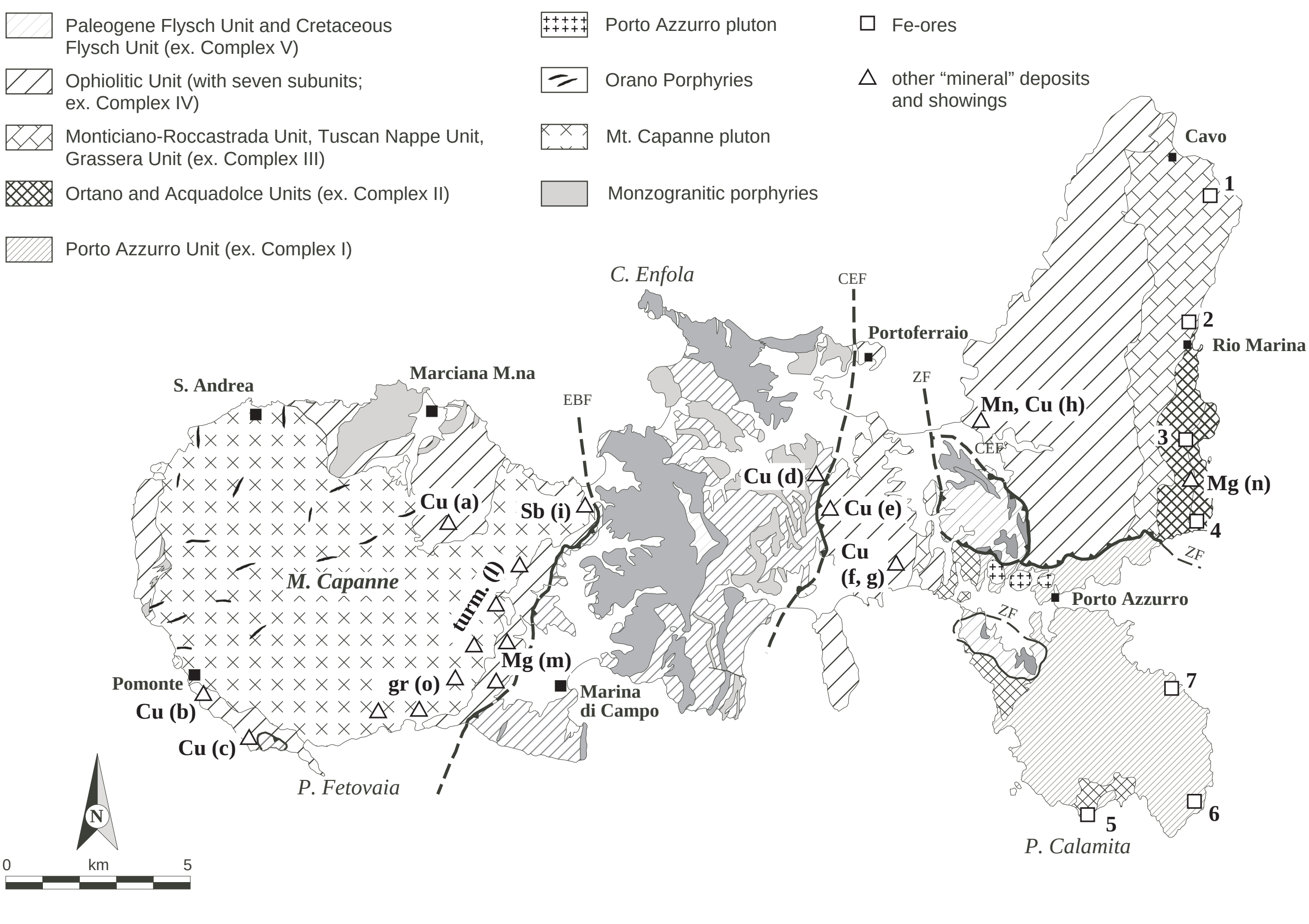


Fig. 1 - Geological sketch map of Elba Island (modified after Maineri et al., 2000), with location of iron ores, industrial deposits and other mineral occurrences. Iron deposits: 1) Rialbano; 2) Rio Marina; 3) Ortano; 4) Terranera; 5) Calamita; 6) Ginevro; 7) Sassi Neri. Abbreviations for the other mineral deposits (see also Table 1): Cu- native copper ± copper sulphides; Sb- stibnite; Mn- wad; turm- pegmatitic minerals; Mg- Mg silicates and/or magnesite; gr-granite; (a)- M.te Perone; (b)- Pomonte; (c)- Le Tombe; (d)- Santa Lucia; (e)- Colle Reciso-Monte Orello; (f)- Norsi; (g)- Acquacalda; (h)- Magazzini-Volterraio; (i)- Procchio; (l)- San Piero - Sant'Ilario; (m)- San Piero - San Florio; (n)- Monte Fico; (o)- Sant'Ilario - San Piero, Seccheto, Cavoli. Tectonic lineaments: CEF- Central Elba Fault; ZF- Zuccale Fault; EBF- Eastern Border Fault.

Table 2 - Main features of iron deposits from Elba Island

| Ore deposits | Mining History | Geologic Setting | Mineralogy* | | | | |
|---|---|---|---|---|---|---|---|
| | | | ore-minerals | | | | other minerals |
| | | | hem | mt | lim | py | |
| **1. Rio Albano** | Exploited since early Iron Age (VIII sec. BC?). Modern age: open pit and underground workings | Massive bodies of hematite and limonite (±pirite) (hosted) in Mesozoic formations of Complex III (Verrucano, "Calcare Cavernoso"). | XXX | X | XXX | XXX | cc, qz, ep, ccp |
| **2. Rio Marina** | Exploited by the Etruscans, XI- XIV sec. (Rep. of Pisa), domination of Appiani ("Codes of Rio") Medicean Age (institution of "Magona del Ferro"), Granducato of Tuscany. Modern age: open pit mining (Vigneria, Bacino, Piè d'Ammone, Valle Giove, Falcacci, Antenna, Rossetto, Zuccoletto stopes); drillings and limited underground workings at "Rio Marina profondo" ("deep-seated Rio Marina") in the '50s-'60s | a) Rio Marina (Valle Giove type): lenses, massive bodies and veins localized within Triassic Verrucano formations (Complex III) | XXX | X | XXX | XXX | cc, qz, clor, ep, gyp, ad, sph, ccp, ga, bism, ang, cer, S |
| | | b) "Rio Marina deep-seated ore": hematite ± pirite mineralization associated with skarn silicates; hosted by Complex III (?) Paleozoic basement | XXX | | | X | [hd, ilv, ep] |
| **3. Ortano** | Exploited in the '50s - '60s | Fe-sulphide ore associated with skarn silicates hosted within marble and "Calcare cavernoso" horizons (Complex II) | X | X | XXX | XXX | [hd, ilv, ep], po, ccp |
| **4. Terranera** | Exploitation started in the XVIII cent. AD and ceased in the early '70s | Fe-oxide + pyrite lenses at the contact between Paleozoic basament and Verrucano formations (Complex III) | XXX | X | XXX | XXX | arag, cc, orn, tml, sid, qz, po |
| **5. Calamita** | Exploitation started in the XIX cent. AD (Valloni, Macei, Polveraio, Punta Rossa stopes, etc.) and ceased in the '70s | pod-like and massive Fe-oxide orebodies associated to skarn rocks within carbonatic formations of Calamita Gneisses (Complex I) | X | XXX | XXX | X | [hd, ilv, andr, ep], qz, arag, clor, gyp, asp, bn, cup, po, ccp, sph |
| **6. Ginevro** | Open pit mine (1928-1969) and underground workings (1969-1981) | magnetite and skarn lenses embedded within Calamita Gneisses (Complex I) | X | XXX | | X | [Feact, Feprg, ep, grs, hd, ilv], gyp, pl, qz, sid, spe, tr, ccp, po |
| **7. Sassi Neri** | Exploitation since 1935 until 1958 | lentiform magnetite oredodies associated with skarn (Ginevro type, hosted by Calamita Gneisses (Complex I) | | XXX | XXX | X | [Feprg, ilv, ep], ad, di, horn, qz, tr, po |

* Relative abundance of ore minerals (from high: XXX to low: X). Mineral abbreviations: ad- adularia; ang- anglesite; andr- andradite; arag- aragonite; asp- arsenopyrite; bism- bismuthinite; bn- bornite; cc- calcite; ccp- chalcopyrite; cer- cerussite; clor- chlorites; cup- cuprite; di- diopside; em- hematite; ep- epidote; Feact- Fe-actinolite; Feprg- Fe-pargasite; ga- galena; grs- grossularite; gyp- gypsum; hd- hedenbergite; ilv- ilvaite; lim- limonite; mt- magnetite; horn- hornblende; pl- plagioclase; po- pyrrhotite; py- pyrite; qz- quartz; S- native sulphur; sid- siderite; spe- spessartite; sph- sphalerite; tml- tourmaline; tr- tremolite. Limonite is actually a mixture of various Fe-hydroxides, mainly goethite. Square brackets enclose skarn silicates. Data from Calanchi et al., (1976), Tanelli (1977; 1995a), Benvenuti et al. (1991), and Benvenuti (1996).

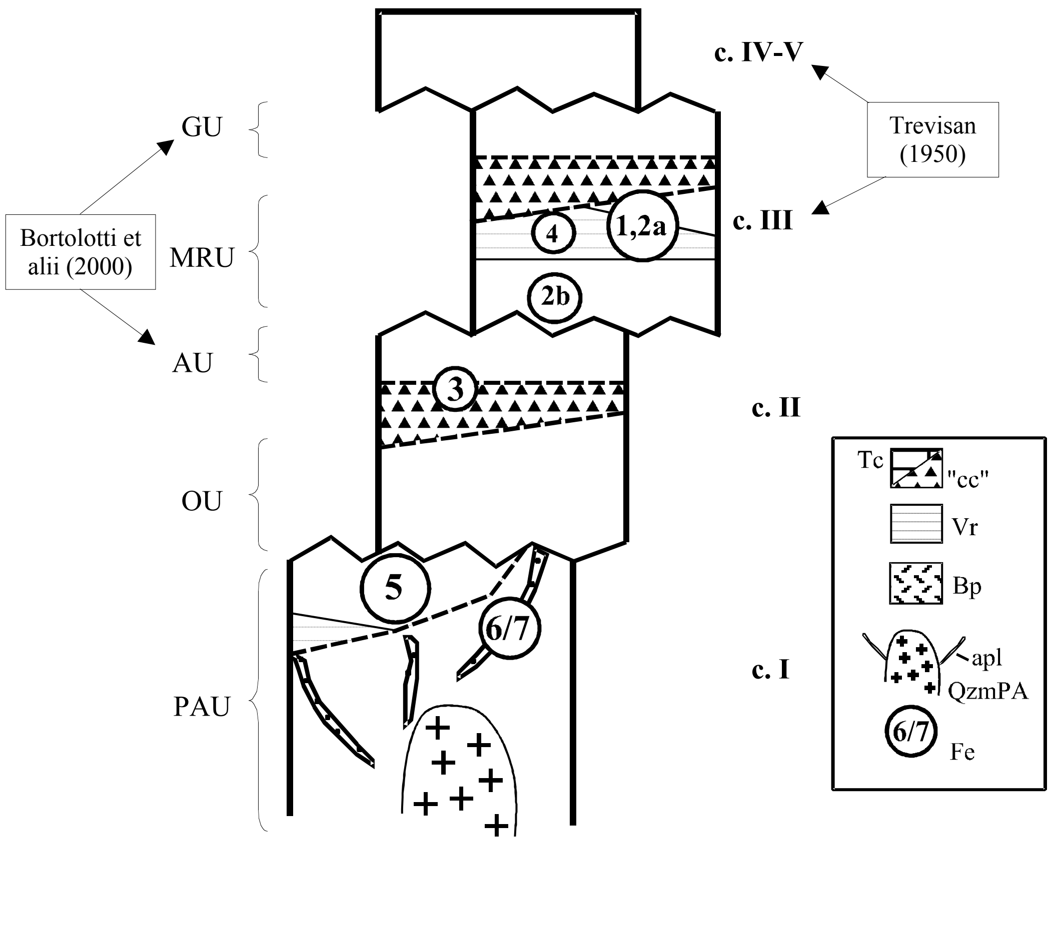


Fig. 2 - Schematic location of main iron ore deposits within the structural edifice of Elba Island according to the model proposed by Bortolotti et al. (2000). Legend: CF- Mt. Calamita Formation (Porto Azzurro Unit); OU- Ortano Unit; AU- Acquadolce Unit; MRU- Monticiano-Roccastrada Unit; TN- Tuscan Nappe; GU- Grassera Unit; Tc- carbonatic formations (dolostones, dolomitic limestones, marbles); "cc"- "Calcare Cavernoso" Auctt.; Vr- "Verrucano"; Bp- Palaeozoic Basement; apl- aplites; QzmPA- Porto Azzurro quartzmonzonite; Fe- main iron ores (same legend as in Figure 1; 2a- - Rio Marina, Valle Giove-type mineralization; 2b- Rio Marina deep-seated ore).

with faults. In particular, three main sets of faults are relevant for the setting of many Fe ores of eastern Elba (Debenedetti, 1952; Gillieron, 1959): a first set of thrust faults, striking NS and dipping 30°-45° W, corresponding to the thrust surfaces among the various tectonic units, and two sets of normal, high-angle faults, one striking NS and dipping 30°-60° E, the other one with strike NE-SW and dips of 45°-70° to NW or SE. The association with these faults was often considered as the evidence for a genetic correlation between late-Apenninic tectonics and ore-forming processes; however, a direct and unequivocal relationship between Fe ores and tectonic structures has not yet been established (cf. the discussion in Lotti, 1886, p. 223). As an example of the relevance of stratigraphic and structural interpretation towards the understanding of the ore setting and genesis, we mention the case of Fe ores associated with the "Calcare Cavernoso" (e.g., the Rialbano *pp* and Ortano deposits). Bortolotti et al. (2001) have interpreted this rock as a tectonic breccia developed at the contact between different tectonic units, the Tuscan Nappe and the Monticiano-Roccastrada Unit in the Rialbano area, or the Acquadolce and Ortano Units in the case of the Ortano pyrite-pyrrhotite deposit. Following this interpretation, these ores would be emplaced along a tectonic lineament, and more exactly the NS thrust faults; of course, in this case, the "Calcare Cavernoso" Auctt. would represent a tectonic, and not a lithostratigraphic, control ("metallotect" in the meaning of Routhier, 1980).

## Ores, magmatism and skarns

There has been a long debate on the relevance of late-Apenninic magmatism, and particularly the emplacement of the monzogranitic stock of Porto Azzurro (5.9-5.1 Ma) with related swarms of aplitic dikes, onto the genesis and evolution of iron ore deposits from Elba Island. We shall briefly review and discuss the reported evidences (at the macro-, meso- and microscale), either direct or indirect, of a magmatic imprint onto iron ores and host rocks, starting from North and moving southwards to the Calamita Peninsula.

Hematite (± pyrite, limonite) ores from Monte Calendozio stopes (Rialbano) up to the Rio Marina mining area are neither directly associated with intrusive bodies (stocks, aplites, etc.) nor with skarn bodies of presumable magmatic affiliation. However, mineralogical, textural and fluid inclusion analyses of hematite+adularia assemblage from Valle Giove stopes at Rio Marina (Deschamps et al., 1983) would indicate that it formed through reaction of relatively hot ($T \geq 310°-330°C$) saline fluids with pyrite-biotite-quartz-bearing rocks. In addition, radiometric datings of the hematite+adularia assemblages from the same mine by Lippolt et al. (1995) point to ages of 6.4 ± 0.4 to 5.32 ± 0.11 Ma (U+Th *vs* He ages of hematite and K/Ar age of associated adularia), i.e., very close to those estimated for the Porto Azzurro stock (5.9-5.1 Ma). Therefore it is conceivable that the Rio Marina hematite-bearing assemblage represents the final product of the transformation of pyrite-rich protore(s) triggered by hydrothermal-magmatic fluids.

Moving southwards from Rio Marina towards the Calamita Peninsula, the association of iron ores with skarn bodies and/or aplitic dikes becomes more and more distinctive. Actually, skarn bodies were encountered in the Rio Marina mining area as well, although at depth. Drillings and limited underground workings carried out in the '50s revealed the existence of hematite-pyrite skarn bodies replacing wedge-shaped carbonatic masses (the Vigneria Limestones of Gillieron, 1959), which are now interpreted as tectonic slices of the overlying Jurassic to Oligocene carbonatic formation of Valle Giove Limestones (Monticiano-Roccastrada Unit; Bortolotti et al., 2001). Immediately south of Rio Marina village, just a few meters after Torre di Rio, decametric skarn bodies with hedenbergite-ilvaite-epidote±quartz, chlorite, magnetite, pyrite and pyrrhotite extend along the coast (Santa Filomena - Porticciolo skarns). Mesoscale textures clearly indicate that the replacement by skarn minerals of Acquadolce Unit's calcschists occurred preferentially along the schistosity planes of the original rock, as already reported in detail by Lotti (1886, pp. 205-206). Moving southwards, other skarn bodies are encountered, often in association with Fe ores of variable size and economic relevance (Ortano, Porticciolo, Tignitoio and Capo d'Arco). The Ortano deposit shows a peculiar ore mineralogy (pyrite, pyrrhotite±hematite, magnetite), and is associated with pyroxene-epidote-ilvaite skarn bodies, which replace marbles and calcareous phyllites along a cataclastic horizon separating the Acquadolce Unit from the overlying Ortano Unit. Lenses of hematite+pyrite±magnetite occur at Terranera within the Monticiano-Roccastrada Unit, and are in close proximity to skarn bodies cropping out at the nearby Punta delle Cannelle. According to a recent study by Seeck (1998), the iron mineralization would be coeval and cogenetic to skarn development, and would have formed at 7.3 ± 0.4 Ma, based on radiometric ages of one hematite sample (Lippolt et al., 1995). In addition to the presence of skarns, Fe ores and their host rocks of southeastern Elba Island are frequently intersected by (or in close proximity to) aplitic dikes linked to the Porto Azzurro pluton. This association is particularly evident in the Calamita Peninsula, where several skarn-bearing iron deposits (Capo Calamita, Ginevro, Sassi Neri, Stagnone) are hosted by the Porto Azzurro Unit. At Capo Calamita stratiform skarn bodies develop mostly at the contact between the Mt. Calamita Formation and the overlying carbonatic formation ("crystalline dolostones and dolomitic limestones" of Bortolotti et al., 2001), partially thermometamorphosed to hornfels and marbles, respectively. Two main types of skarn have been identified in the northern stopes: a garnet (andradite)-rich skarn, quantitatively the most abundant, and an ilvaite-hedenbergite skarn (Torrini, 1990). The exploited ores were spatially associated with both types of skarns, and consisted of lenses and massive bodies of magnetite±hematite, goethite and trace amounts of base metal sulphides. The Ginevro and Sassi Neri deposits show some interesting peculiarities. At Ginevro, for instance, skarn mineralization seemingly was accomplished by total metasomatism of carbonate lenses, leaving behind no relic trace of carbonate rocks. In addition, the high frequency of aplitic dikes observed at Sassi Neri and Ginevro may justify the larger extent and higher degrees of thermometamorphic effects with respect to Capo Calamita (Del Tredici, 1990). Of some interest is the presence at Ginevro and Sassi Neri of a relatively uncommon skarn mineral like ferropargasite, associated with grossularia-almandine garnet and only minor amounts of hedenbergite, ilvaite and epidote (Dimanche, 1971; Del Tredici, 1990). Finally, the Stagnone deposit was recognized through a drilling appraisal project, but it was never exploited; no detailed information is thus available.

### Ore mineralogy and textures

Primary ore mineralogy of Elba's Fe deposits is relatively simple (Table 2), being made up of Fe oxides (as a general rule, hematite is dominant in the northern, skarn-free deposits, whereas magnetite is enriched in the skarn-associated deposits of the Calamita Peninsula)±pyrite±(Cu,Pb,Zn,As,Bi…) sulphides.

Elba is especially famous worldwide for its beautiful crystals of hematite (variety "oligisto" = glaze iron)±pyrite, most coming from the Rio Marina stopes. Hematite may show either a typical lamellar-micaceous habitus, or flattened, rhombohedral crystals often covered by iridescent films of iron hydroxides; euhedral pyrite pyritohedra, octahedra or cubes have been observed in association with the Fe oxide (cf. Strüver, 1869; D'Achiardi, 1873; Panichi, 1909). Deschamps et al. (1983) suggest that the hematite±pyrite (±quartz) assemblage is paragenetically late, being derived from oxidative alteration and remobilisation of primary pyrite. Mining reports point to the general trend of increasing pyrite abundance with the deepening of mining exploitation. According to Debenedetti (1952), as a result of the tout-venant's increased sulphur contents (from 0.15% to 1.5% at Calamita over fifty years of exploitation) either the mining stopes were abandoned (as it happened at Rio Marina in the past century) or more expensive beneficiation processes had to be undertaken, as at Calamita in the '50s. This relative deficiency of pyrite in the topmost portions of the deposits can be likely ascribed to exogenous alteration, since Fe sulphides are largely more reactive than Fe oxides. The final alteration products of primary Fe minerals are limonitic aggregates of variable types and morphologies (earthy, massive, concretionary, sometimes stalactitic), which were actively exploited in the past, especially at Rialbano, Capo Bianco and Capo Calamita mines (cf. Calanchi et al., 1976).

Ore minerals from the skarn-bearing iron deposits of the Calamita Peninsula are mainly constituted by magnetite, which however was not the primary Fe mineral to form. The presence of magnetite with lamellar habitus is an evidence of pseudomorphic replacement after earlier hematite, as first suggested by vom Rath (1870) and more recently confirmed by Cocco and Garavelli (1954). Moreover, according to unpublished studies (Del Tredici, 1990; Torrini, 1990), etching of automorphic, euhedral magnetites from Capo Calamita and Sassi Neri deposits revealed the presence of relic lamellar structure, that may suggest once again a replacement of earlier hematite. The same authors evidence that crosscutting relationships between magnetite and skarn silicates like Fe-pargasite (Sassi Neri) or garnets (Capo Calamita) point to a pre-skarn formation of magnetite. The textural features shown by magnetite from these two deposits are not those typical of iron skarns worldwide, where magnetite is the primary Fe phase, and it is paragenetically later than skarn silicates (cf. Einaudi et al., 1981). At Ginevro, on the contrary, magnetite would be coeval with other skarn phases, namely Fe-pargasite and grossularia (Dimanche, 1971).

Sulphides, which are very rare or absent in the Rio Marina - Rialbano deposits, are significantly more abundant in the magnetite-type deposits, where they normally form at a late paragenetic stage. Masses of Fe-Cu sulphides (pyrrhotite, pyrite, chalcopyrite±malachite, azurite, chalcantite, etc.) were locally exploited at Capo Calamita at the contact between the garnet skarn and the magnetite lenses. (Torrini, 1990).

## OPEN QUESTIONS AND PERSPECTIVES FOR FUTURE RESEARCH

As briefly outlined in a previous chapter, several epigenetic models have been proposed for the Fe oxide and/or pyrite deposits of Elba Island and Maremma. Earlier scholars (e.g. De Launay, 1906; Lotti, 1928; 1929) conjectured that the late-Apenninic intrusions represented both the heat and the metal sources. More recently, new epigenetic models have been proposed (Wagner, 1980; Marinelli, 1983; Dechomets, 1985), according to which the intrusions acted as heat sources and promoted the circulation of hydrothermal fluids, although the source(s) of the fluids themselves and dissolved metals should be looked for elsewhere. Thus Marinelli (1983) suggested that Fe could derive from metasomatic reactions taking place at the peripheral portions of the intrusive bodies: chloride-rich metamorphic and/or connate waters would have been enriched in Fe through reaction with magmatic biotite. On the other hand, Dechomets (1985) proposes that hydrothermal fluids of dominant marine origin scavenged Fe from host rocks, while for Wagner (1980) large-scale bacterial reduction of sulphates would have taken place in low-temperature convective systems in the earliest stages of the granitic intrusion. Alternative syngenetic models for the pyrite-Fe oxide (barite) deposits of Tuscany maintain that the deposits, at least as protores, predate the Apenninic event and were formed in sedimentary and/or hydrothermal-sedimentary environments of Palaeozoic-Triassic age (Bodechtel, 1965; Deschamps et al., 1983; Cortecci et al. 1985a; Lattanzi and Tanelli, 1985; Zuffardi, 1990). According to these authors, the late-Apenninic extensional tectonics, magmatism and related hydrothermalism would be responsible for the more or less extensive reworking, metamorphism and remobilisation of the metal pre-concentrations. The physicochemical parameters of the hydrothermal fluids associated with the late-Apenninic event are relatively well constrained, at least for the pyrite-Fe oxide-barite deposits of the Apuane Alps (Benvenuti et al., 1992), the pyrite deposits of Maremma (Cortecci et al., 1983; Belkin et al., 1983; Cortecci et al., 1985b), the epithermal Au mineralization of Southern Tuscany (Ruggieri et al., 1993), and some industrial deposits of Elba and Southern Tuscany (Lattanzi et al., 2001). This is not the case, however, of the supposed (hydrothermal-) sedimentary, pre-Apenninic protores, whose environment and processes of deposition are still poorly known or unstated, excepting few cases (the Niccioleta pyrite deposit in Maremma: Lattanzi and Tanelli, 1985; the Rio Marina-Valle Giove Fe deposit at Elba: Deschamps et al., 1983).

As discussed more extensively elsewhere (cf. Tanelli and Lattanzi, 1986; Benvenuti, 1996), none of the genetic models so far proposed for iron deposits of eastern Elba Island is completely satisfactory. Descriptive models for the individual deposits are largely incomplete, so that inferred genetic models are obviously qualitative and poorly constrained. In the last ten years detailed research was carried out only on a few mineral deposits (Capo Calamita: Torrini, 1990; Sassi Neri: Del Tredici, 1990; Terranera: Seeck, 1998), and is still largely unpublished. Taking into account the regional framework, for which much more quantitative data are available (cf. Lattanzi et al., 1994), and the results obtained for the Calamita Peninsula deposits, we suggest that the stage of iron concentration could have preceded (at least in part) the emplacement of the Porto Azzurro intrusion and related aplitic dykes (5.9-5.1 Ma), as well as the formation of skarn bodies. This hypothesis is in agreement with:

– absolute dating of Terranera (7.3±0.4 Ma) and Rio Marina (6.4±0.4 to 5.32±0.11 Ma) hematite+adularia assemblages;
– textural relationships between iron minerals and skarn phases, which would point to the following paragenetic sequence (Capo Calamita, Sassi Neri): hematite → magnetite → skarn silicates;
– field evidences: relatively large iron ores (Rio-Marina, Rialbano) are apparently devoid of both skarns and intrusive bodies;
– petrologic evidences: the largest Fe skarn deposits worldwide are typically associated with distinctly more mafic intrusions than any known at Elba (cf. Einaudi et al., 1981).

However, still many aspects of both the genesis of these primary, pre-magmatic concentrations, and the process(es) of their mobilization need to be better defined on a quantitative basis. This was the state of the art almost fifteen years ago (Tanelli and Lattanzi, 1986), and is not much different nowadays. However, new perspectives for a well thought-out research on ore geology of Elba Island are provided by the continuously increasing knowledge of the geologic framework. Thus the basis can be laid for a new, multidisciplinary approach to the study of iron deposits, which could hopefully unravel:

a) the lithostratigraphic, structural, mineralogical and compositional features of the host rocks, including a careful investigation of alteration assemblage(s) around the ore bodies (if any);
b) the ore setting(s), mineralogy, textures and petrology, including relative (and radiometric) dating of mineralization types with different stratigraphic/structural controls;
c) genetic and chronological relationships of the skarn bodies and intrusions (if present) with iron ores;
d) the possible source(s) of fluids and iron, on the basis of geochemical modelling, mass balance calculations, characterization of hydrogeologic regimes and likely fluid pathway(s).

All these are fundamental clues to any reconstruction of genetic processes and evolution of Elba's iron deposits on an up-to-date, quantitative basis. Quoting Tanelli and Lattanzi (1986, p. 304): "such results may well prove of not merely academic interest, and of significance not only for ore deposit studies. […] They could be helpful in contributing to the palaeogeographic and palaeotectonic reconstruction of the Tuscan basement, and in general to the understanding of the geological evolution of the region".

## REFERENCES


Aurisicchio C, Ottolini L. and Pezzotta F., 1999. Electron- and ion-microprobe analyses and genetic inferences of tourmalines of the foitite-schorl solid solution, Elba Island (Italy). Europ. J. Mineral., 11: 217-225.

Belkin H.E., De Vivo B. and Lattanzi P., 1983. Fluid inclusion studies on ore deposits of Tuscan Maremma. Mem. Soc. Geol. It., 25: 273-284.

Beneo E., 1952. Sulle ricerche minerarie nella costa orientale dell'Isola d'Elba. Boll. Serv. Geol. It., 74: 9-24.

Benvenuti M., 1996. I giacimenti ferriferi dell'Isola d'Elba. In: G. Tanelli (Ed.), Atti I Convegno "I fiori della Terra", Rio Elba, p. 29-48.

Benvenuti M., Costagliola P., Lattanzi P. and Tanelli G., 1992. The metamorphic-hosted precious and base metal deposits of the Bottino-Valdicastello region (Apuane Alps, Tuscany): an overview. Acta Vulcanol., "Marinelli" Vol., 2: 45-54.

Benvenuti M., Guideri S. and Mascaro I., 1991. Inventario del patrimonio minerario e mineralogico in Toscana. Aspetti naturalistici e storico-archeologici. Vol. 1 (Schede e bibliografia). Ed. Regione Toscana, Firenze, 240 pp.

Benvenuti M., Mascaro I., Corsini F., Costagliola P., Parrini P., Lattanzi P. and Tanelli G., 1999. Environmental problems related to sulfide mining in Tuscany. Chronique Rech. Min., 534: 29-45.

Bodechtel J., 1965. Zur Genese des Eisenerze der Toskana und der Insel Elba. N. Jb. Miner. Abh., 103: 147-162.

Bortolotti V., Fazzuoli M., Pandeli E., Principi G., Babbini A. and Corti S., 2001. Geology of central and eastern Elba Island. Ofioliti, 26 (2a), this issue.

Calanchi N., Dal Rio G. and Prati A., 1976. Miniere e minerali dell'Elba orientale. Ed. Cacciari, Bologna, 102 pp.

Cipriani C. and Tanelli G., 1983. Le risorse minerarie della Toscana: note storiche ed economiche. Acc. Tosc. Sci. Lett. "La Colombaria", 48: 241-283.

Cocco G. and Garavelli C., 1954. Studio di alcuni problemi geochimici relativi al giacimento di ferro di Capo Calamita (Elba). Rend. S.I.M.P., 10: 269-350.

Corretti A., 1988. Indagine preliminare sull'attività di riduzione del ferro in età romana all'Isola d'Elba. Geo-Archeologia, 1: 7-39.

Corretti A. and Benvenuti M., 2000. The beginning of iron metallurgy in Tuscany; with special reference to *Etruria Mineraria*. Proceed. Vol. Int. Congr. on "Afrique et le bassin méditerranéen: aux origines de la métallurgie du fer", Genève (submitted).

Cortecci G., Klemm D.D., Lattanzi P., Tanelli G. and Wagner J., 1983. A sulfur isotope study on pyrite deposits of southern Tuscany, Italy. Mineral. Deposita, 18: 285-297.

Cortecci G., Lattanzi P. and Tanelli G., 1985a. Barite-iron oxides-pyrite deposits from Apuane Alps (northern Tuscany, Italy). Mem. Soc. Geol. It., 30: 337-345.

Cortecci G., Lattanzi P. and Tanelli G., 1985b. C- and O- isotope and fluid inclusion studies on carbonates from pyrite and polymetallic mineralizations and associated country rocks, southern Tuscany, Italy. Chem. Geol. (Isot. Geosci. Sect.), 58: 121-128.

Corti S., Dini C., Pandeli E. and Principi G., 1996. Le unità tettoniche dell'Isola d'Elba orientale (Toscana): nuovi dati e ipotesi di correlazione. In: 78ª Riunione Estiva S.G.I. "Geologia delle Dolomiti", San Cassiano (BZ), Riass., p. 65-66.

D'Achiardi A., 1873. Mineralogia della Toscana, 2 vol., Ed. Nistri, Pisa, 678 pp.

Debenedetti A., 1952. Osservazioni geologiche nelle zone minerarie dell'Isola d'Elba. Boll. Serv. Geol. It., 74: 53-85.

Dechomets R., 1985. Sur l'origine de la pyrite et des skarns du gisement, en contexte evaporitique, de Niccioleta (Toscane, Italie). Mineral. Deposita, 20: 201-210.

De Launay L., 1906. La metallogenie de l'Italie et des regions avoisinantes: notes sur la Toscane miniere et l'Ile d'Elbe. Imprenta y fototipia de la Secretaria de Fomento, Mexico, 143 pp.

Del Tredici F., 1990. Studio del giacimento a skarn di Sassi Neri, Isola d'Elba. Unpubl. Tesi di Laurea, Univ. Firenze, 200 pp.

Deschamps Y., Dagallier G., Macaudière J., Marignac C., Moine B. and Saupé F., 1983. Le gisement de pyrite-hématite de Valle Giove (Rio Marina, Ile d'Elbe, Italie). Schweiz. Mineral. Petrogr. Mitt., 63: 149-165.

Dimanche F., 1971. Les minerais de magnetite et les skarns du Ginevro (Ile d'Elbe - Italie). Mineral. Dep., 6: 356-379.

Duranti S., Palmieri R., Pertusati P.C. and Ricci C.A., 1992. Geological evolution and metamorphic petrology of the basal sequences of eastern Elba (Complex II). Acta Vulcanol., "Marinelli " Vol., 2: 213-229.

Einaudi M., Meinert L.D. and Newbberry R.J., 1981. Skarn deposits. In: Econ. Geol. 75° Anniv. Vol.: 317-391.

Fabri A., 1887. Relazione sulle miniere di ferro dell'Isola d'Elba. Mem. Descr. Carta Geol. It., 11, 162 pp.

Gillieron F., 1959. Osservazioni sulla geologia dei giacimenti di ferro dell'Elba orientale. L'Ind. Miner., 10 (1): 1-10.

Juteau M., Michard A. and Albarede F., 1986. The Pb-Sr-Nd isotope geochemistry of some recent circum-Mediterranean granites. Contrib. Mineral. Petrol., 92: 331-340.

Keller J. and Pialli G., 1990. Tectonics of the Island of Elba: a reappraisal. Boll. Soc. Geol. It., 109: 413-425

Lattanzi P., Benvenuti M., Costagliola P., Maineri C., Dini A., Mascaro I., Ruggieri G. and Tanelli G., 2001. Magmatic versus hydrothermal processes in the formation of raw ceramic material deposits in southern Tuscany. 10th Intern. Symp. Water-Rock Interaction, Villasimius, Italy, June 2000, Abstr., (in press).

Lattanzi P., Benvenuti M., Costagliola P. and Tanelli G., 1994. An overview on recent research on the metallogeny of Tuscany, with special reference to the Apuane Alps. Mem. Soc. Geol. It., 48: 613-625.

Lattanzi P., Benvenuti M., Gale N.H., Hansmann W., Koeppel V. and Stos Gale Z., 1997. Pb-isotope data on ore deposits of Southern Tuscany. Plinius, 18: 123-124.

Lattanzi P., Hansmann W. and Koeppel V. 1991. Preliminary data on the Pb-isotope composition of mineral deposits in Southern Tuscany. In: M. Pagel and J.L. Leroy (Eds), Source, transport and deposition of metals. Proceed. 25 years SGA Anniv. Meeeting, Balkema, Rotterdam, p. 317-320.

Lattanzi P.F., Hansmann W., Koeppel V. and Costagliola P., 1992. Source of metals in metamorphic ore-forming processes in the Apuane Alps (NW Tuscany, Italy): constraints by Pb-isotope data. Mineral. Petrol., 45: 217-229.

Lattanzi P. and Tanelli G., 1985. Le mineralizzazioni a pirite, ossidi di Fe e Pb-Zn(Ag) della zona di Niccioleta , Grosseto. Rend. S.I.M.P., 40: 385-408.

Lippolt, H.J., Wernicke, R.S., Bähr, R., 1995. Paragenetic specularite and adularia, Elba Island, Italy: Concordant, U+Th-He and K-Ar ages. Earth Planet. Sci. Lett., 132: 43 - 51.

Lotti B., 1877. Premessa alla traduzione dal tedesco di: I Monti di Campiglia nella Maremma Toscana, di G. Vom Rath. Boll. R. Com. Geol. It., 8: 187-188.

Lotti B., 1886. Descrizione geologica dell'Isola d'Elba. Mem. Descr. Carta Geol. It., 12: 3-254.

Lotti B., 1929. I depositi dei minerali metalliferi. Ed. L'Industria Mineraria, Genova, 236 pp.

Maineri C., Benvenuti M., Costagliola P., Dini A., Lattanzi P., Ruggieri G. and Villa I.M., 2000. Alkali - metasomatic processes at La Crocetta raw ceramic material mine, Elba Island, Italy): interplay between magmatism, tectonics and mineralization. Miner. Deposita, (submitted).

Maineri C., Costagliola P., Benvenuti M., Tanelli G., Dini A., Lattanzi P., Ruggieri G., Villa I.M., 1999. The deposit of raw ceramic material at La Crocetta, Elba Island, Italy. Proceed. 5th Biennial S.G.A. Meeting, London, p. 1121-1124.

Marinelli G., 1983. Il magmatismo recente in Toscana e le sue implicazioni minerogenetiche. Mem. Soc. Geol. It., 25: 111-124.

Pandeli E. and Puxeddu M., 1990. Palaeozoic age for the Tuscan upper metamorphic sequences of Elba and its implications for the geology of the Northern Apennines. Ecl. Geol. Helv., 83: 123-142.

Panichi U., 1909. Sulla pirite dell'Elba. Riv. di Mineral. Cristall. It., 38: 3-26.

Pertusati P., Raggi G., Ricci C.A.., Duranti S, and Palmeri R, 1993. Evoluzione post-collisionale dell' Elba centro-orientale. Mem. Soc. Geol. It., 49: 223-312.

Pullè G., 1921. Le miniere dell'Elba. In: A. Stella (Ed.), Le miniere di ferro dell'Italia. Lattes, Torino, p. 181-259.

Routhier, P., 1980. Ou sont les metaux pour l'avenir? Mem. B.R.G.M., 105: 1-409.

Ruggieri G. and Lattanzi P., 1992. Fluid inclusion studies on Mt. Capanne pegmatites, Isola d'Elba, Tuscany, Italy. Eur. J. Mineral., 4: 1085-1096.

Ruggieri G., Lattanzi P. and Tanelli G., 1993. Carbonate-hosted epithermal gold mineralization in southern Tuscany, Italy: the examples of Frassine and La Campigliola. In: P. Fenoll Hach-Ali, J. Torres-Ruiz and F. Gervilla (Eds.), Current research in geology applied to ore deposits, Balkema, Granada, p. 551-554.

Seeck I., 1998. Die Genese der Eisenerzlagerstätte Laghetto di Terra Nera auf Ostelba und deren geologischer Rahmen. Diplomarbeit und Diplomkartierung, Eberhard-Karls-Universität Tübingen.

Strüver G., 1869. Studi sulla mineralogia italiana. Pirite del Piemonte e dell'Elba. Mem. R. Accad. Sci. Torino, Serie 2, 26, 51 pp

Tanelli G., 1977. I giacimenti a skarn della Toscana. Rend. S.I.M.P., 33 (2): 875-903.

Tanelli G., 1983. Mineralizzazioni metallifere e minerogenesi in Toscana. Mem. Soc. Geol. It., 25: 91-109.

Tanelli G., 1995a. Carta geomineralogica dell'Isola d'Elba alla scala 1:50.000. Selca, Firenze.

Tanelli G., 1995b. Il Parco dei minerali dell'Isola d'Elba. In: Atti Conv. Intern."Parchi culturali in Toscana", Ed. Regione Toscana, Portoferraio, p. 1-16.

Tanelli G. and Benvenuti M., 1996. Minerals and mines from Elba Island (Italy): conservation of an outstanding heritage and its use as an educational tool towards the growth of a "geologic culture". In: Atti 2º Conv. Int. Progeo, Mem. Serv. Geol. It., (in press).

Tanelli G. and Benvenuti M., 1997. Guida ai minerali dell'Isola d'Elba e del Campigliese. Il Libraio Ed. Portoferraio, 164 pp.

Tanelli G. and Lattanzi P., 1983. Pyritic ores of Southern Tuscany, Italy. Spec. Publ. Geol. S. Afr., 7: 315-323.

Tanelli G. and Lattanzi P., 1986. Metallogeny and mineral exploration in Tuscany: state of the art. Mem. Soc. Geol. It., 31: 299-304.

Tanelli G., Lattanzi P., Ruggieri G. and Corsini F., 1991. Metallogeny of gold in Tuscany, Italy. In: E.A. Ladeira (Ed.), Brazil Gold '91. Balkema, Rotterdam, p. 109-114.

Torrini G., 1990. Studio del giacimento a skarn e magnetite di Capo Calamita, Isola d'Elba (cantieri settentrionali). Unpubl. Tesi di Laurea, Univ. Firenze, 163 pp.

Trevisan L., 1950. L'Elba orientale e la sua tettonica di scivolamento per gravità. Mem. Ist. Geol. Univ. Padova, 16: 5-39.

Vollmer R., 1977. Isotopic evidence for genetic relations between acid and alkaline rocks in Italy. Contrib. Mineral. Petrol., 60: 109-118.

Vom Rath G., 1870. Die Insel Elba. Geognostich-mineralogische Fragmente aus Italien. III Theil. Zeitschrift der Deutschen geologischen Gesellschaft., B, 22: 591-732.

Wagner, J., 1980. Die Eisen- und Kupfersulfidlagerstätten der Toskana in ihrem geologischen Rahmen. Dokt. Dissert., München.

Westerman D.S., Dini A., Innocenti F., Rocchi S., Tonarini S., 2000. Emplacement and tectonic evolution of a nested Christmas-tree laccolith complex, Elba Island (Italy). Geol. Soc. Am. Bull., (submitted).

Zuffardi P., 1990. The iron deposits of the Elba Island (Italy): remarks for a metallogenic discussion. Mem. Lincee Sci. Fis. Nat., Serie IX, 1 (4): 97-128.

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