Per. Mineral. (2003), *72*, SPECIAL ISSUE: *Miocene to Recent...*, **127-132** http://go.to/permin

PERIODICO di MINERALOGIA
established in 1930

An International Journal of
MINERALOGY, CRYSTALLOGRAPHY, GEOCHEMISTRY, ORE DEPOSITS, PETROLOGY, VOLCANOLOGY
and applied topics on *Environment, Archaeometry* and *Cultural Heritage*

CHAPTER 5
Campiglia Marittima and Gavorrano intrusive magmatism

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5.1 HISTORICAL PERSPECTIVE

From Etruscan times to the recent past, man has bored into the rocks of the Campiglia Marittima area to extract ore minerals. Here, deposits of ore minerals hundreds of metres thick blanket two porphyritic dykes. The ores are mainly mixed sulfides (argentiferous galena, chalcopyrite, sphalerite) and cassiterite. At the surface the deposits are composed of limonite, the so-called «cappellaccio». The occurrence of mineral resources influenced the location and development of settlements from Etruscan times onwards. In 1984, an archaeological research program started at Rocca San Silvestro, close to Campiglia Marittima, with excavation of the site. These studies unveiled a medieval village set up for ore exploitation and metal production. The fifteen mine workings linked with the Rocca were mostly vertical shafts a few to tens of metres deep. In Medieval times, copper and silver were used together with gold as the main components of coins, thus they were considered precious metals, and the revenues and political importance deriving from the control of their production was considerable. Rocca San Silvestro is a demonstration of the importance of the management of mineral resources and of the control of the whole metal production cycle. Indeed, the settlement was built with the aim of keeping the workers and all the phases of production under control. Within the village walls of Rocca San Silvestro, a whole area has been identified which was set up for the metallurgical processing of the local minerals of copper, lead and silver. Traces of smelting activity detected here include waste from metal working, blocks of the fire-proof stone used in the construction of kilns, baked clay, mineral fragments, and the remains of constructions used for smelting. Outside the walls of Rocca San Silvestro, the reduction furnace and the forge of an iron smelting and smithing complex have been discovered. Here, the production of iron was driven by great internal demand linked to the mining and production activities of the village rather than to any commercial exploitation of iron as such.

After being abandoned for over 200 years, mining activities were significant over two centuries. Exploration studies were undertaken at the beginning of the nineteenth century, leading to mining concessions to French then English companies during the second half of the century. The first scientific description of ore deposits from French, German and Italian engineers and geologists date back to these times. At the end of the 1950s, exploitation started again by Italian companies, and operated until 1976 when the mine was forced

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to close, and the area has since then been exploited principally for opencast limestone quarrying. Following the studies by the archaeological research team, the San Silvestro Archaeological Mines Park was sketched out in 1989. The aim was to give value to, and make a museum out of, a whole historic landscape arising from centuries of mining activity. Also included in the Park are the buildings, infrastructures, tunnels, washing plants, roasting and reduction furnaces set up from the beginning of the nineteenth century to 1976.

5.2 GEOLOGIC SETTING

The geological framework of the area (Fig. 1) consists of several stacked tectonic units producing a stratigraphy starting at the bottom with Tuscan Basement, successively overlain by the Tuscan nappe and the Ligurian nappe. The nappe pile resulted from eastward-directed thrusts associated with the convergence and collision between the European margin and the Adria microplate in late Oligocene time. Since late Tortonian time, the internal zone underwent post-collisional extension related to the opening of the northern Tyrrhenian Sea. In southern Tuscany, crustal extension was linked to the igneous activity of the Tuscan Magmatic Province.

5.3 THE INTRUSIVE UNITS

5.3.1 Botro ai Marmi pluton

In the area of Campiglia Marittima, intrusive rocks crop out over a limited area at Botro ai Marmi, and are found in boreholes at M. Spinosa and M. Valerio, 3 km south of the outcrop (Fig. 2). Samples from the pluton display a monzogranite or alkali feldspar granite composition (Fig. 3; Caiozzi *et al.*,

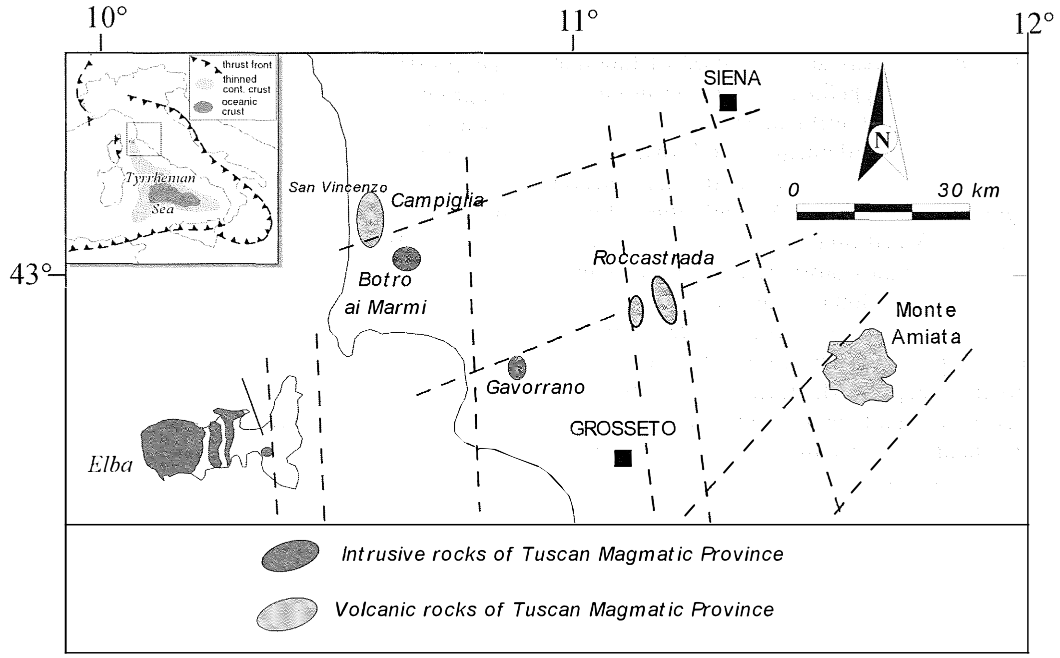

Fig. 1 – Location of intrusive and effusive rocks of the Campiglia area.

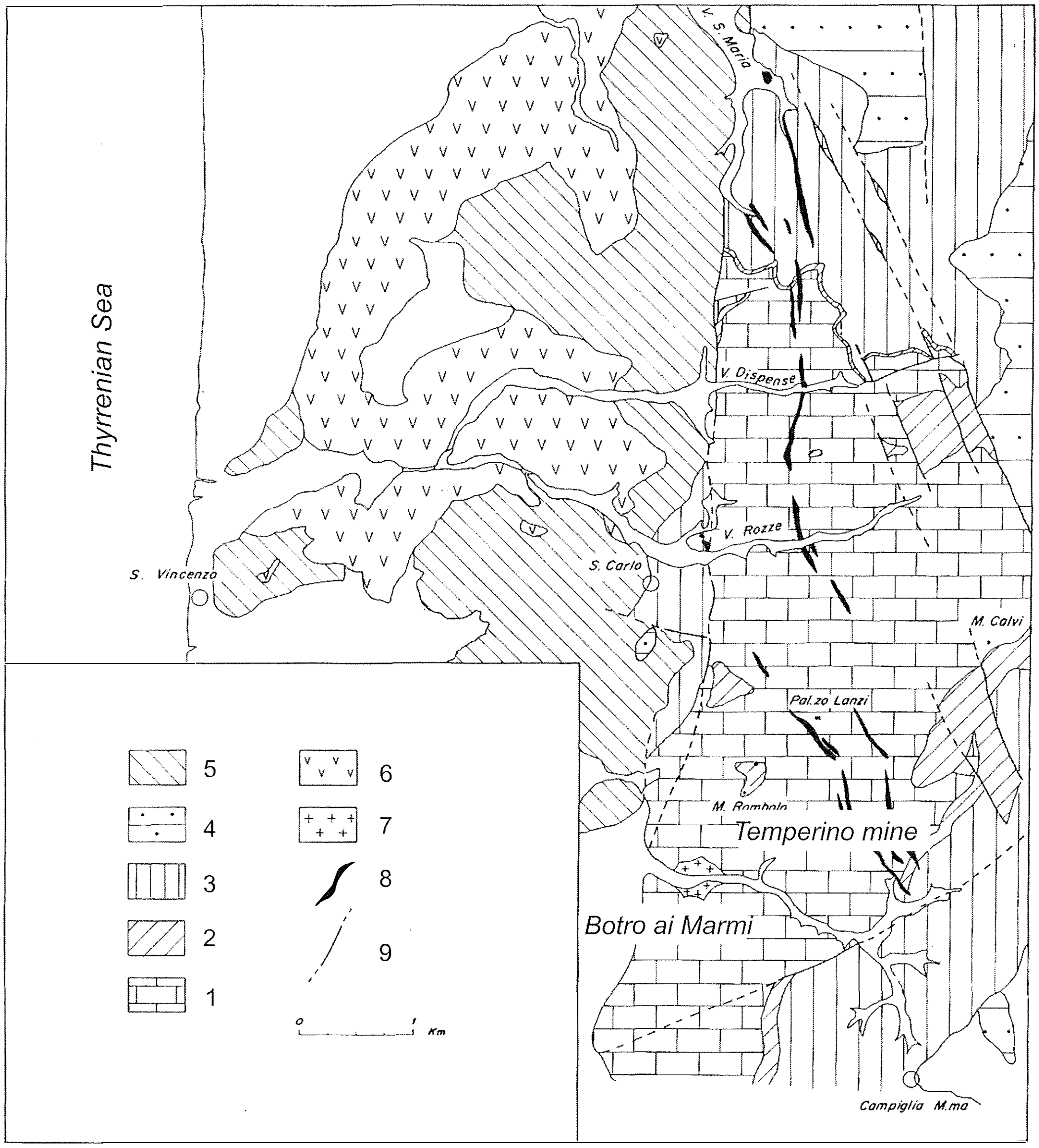

Fig. 2 – Schematic geological map of the area north of Campiglia Marittima. 1) Limestones (Lias); 2) Limestones (Lower Lias); 3) Marls and chert (Dogger-Oligocene); 4) Flysch (Oligocene); 5) Ophiolites s.l.; 6) Pliocenic volcanics; 7) Botro ai Marmi pluton; 8) porphyry dykes; 9) faults. Modified after Barberi *et al.* (1967b).

1998; Poli *et al.*, 1989). The mineralogical assemblage consists essentially of subhedral orthoclase and anhedral quartz. Plagioclase occurs rarely as small euhedral crystals, often replaced by K-feldspar. Mafic phases are almost lacking, with primary biotite replaced by chlorite and/or muscovite (Lattanzi *et al.*, 2001; Poli *et al.*, 1989). Botro ai Marmi rocks

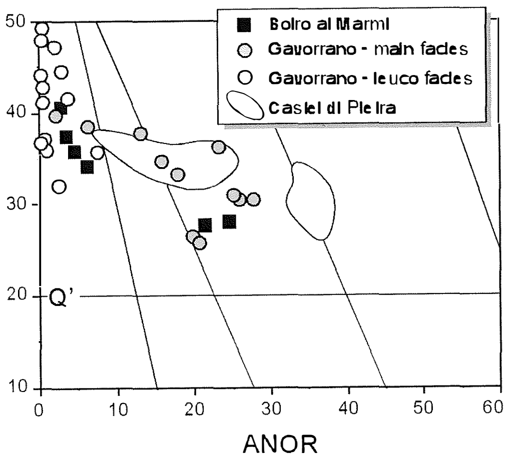

Fig. 3 – Normative Q' vs. ANOR classification diagram (Streckeisen and Le Maitre, 1979) for Gavorrano and Botro ai Marmi intrusions, and Type-3 porphyries. Data from Caiozzi *et al.* (1998), Peccerillo *et al.* (1987), and unpublished data from Innocenti. For comparison, variation fields for the Castel di Pietra subsurface intrusion are shown (data from Franceschini *et al.*, 2000).

plot in the leucocratic facies field of intrusives from TMP (Fig. 4).

Secondary phases have been generated in large part by autometasomatism involving late-stage hydrothermal fluids, with minor contributions from interaction with CO_2-rich fluids and carbonate country rocks (Barberi *et al.*, 1967b; Poli *et al.*, 1989). The role of hydrothermal chlorine brines exsolved from the magmas during the late stage of crystallisation is also considered essential as a carrier of metals (Fe, Cu, Sn, Zn, As) for the nearby ore deposits (Caiozzi *et al.*, 1998). The emplacement age of the pluton is poorly constrained at ca. 5 Ma (Serri *et al.*, 2001, and references therein). The apical part of the intrusion is quarried as a raw ceramic material (Lattanzi *et al.*, 2001).

5.3.2 Porphyry dykes

In the area of Campiglia Marittima, about 1-2 km ENE of the Botro ai Marmi pluton, several N to NW trending porphyry dykes crosscut the early Jurassic reef limestone of the Tuscan Nappe (Fig. 2). The dykes crop out discontinuously over a length of 7 km, with thicknesses ranging from a few cm to several tens of metres. Samples are invariably quite altered, but three different types of porphyry dykes can be recognised (Barberi *et al.*, 1967b). Type-1 are cordierite-bearing acidic dykes. Primary phenocrysts are: sericitised andesinic plagioclase, abundant strongly embayed quartz, scattered euhedral potassic feldspar, pseudomorphs after euhedral cordierite, and biotite deeply transformed to chlorite, muscovite, iron hydroxides and Ti-rich products. The groundmass shows a felsitic-microgranophyric texture with quartz-feldspathic phases. Type-2 are Na-poor, K-rich acidic dykes. Primary phenocrysts are: embayed quartz, potassic feldspar as both euhedral crystals and anhedral patches, and pseudomorphs after euhedral cordierite and biotite. The groundmass has variable grain size. These dykes represents Type-1 dykes that suffered K-metasomatism with secondary replacement of plagioclase by K-feldspar. Type-3 are pyroxene-bearing dykes of intermediate composition. Primary phenocrysts are: rare sanidine up to 5 cm, oscillatory-zoned plagioclase, strongly embayed quartz, diopsidic pyroxene almost completely replaced by a chlorite-epidote assemblage, and biotite transformed to chlorite + sphene. The groundmass shows a felsitic texture with plagioclase, sanidine and pyroxene. The age of dyke emplacement is constrained by the 4.3 Ma K-Ar age for a Type-2 metasomatised porphyry dyke (Serri *et al.*, 2001, and references therein). A close spatial link exists between these dykes and the extensive skarn and Cu-Pb-Zn ore mineralisation of the Campiglia area. Compositions of two samples of Type-3 are reported in Figure 3, however strong alteration impedes a deeper geochemical study.

5.3.3 Gavorrano intrusion

Data from mining activity, along with field work, indicate that the Gavorrano intrusion is a laccolith emplaced at the base of the Tuscan

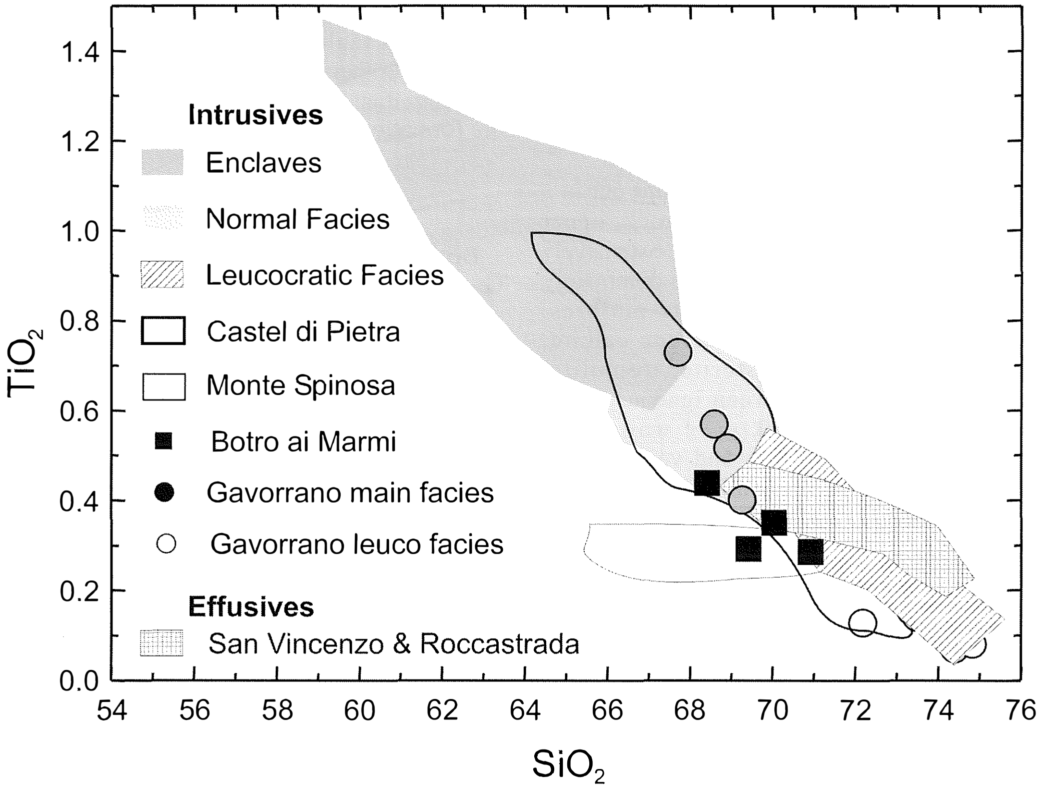

Fig. 4 – SiO_2 vs TiO_2 diagram for Botro ai Marmi and Gavorrano intrusions. Data from Poli (1992); Festoso (1989); Pinarelli *et al.* (1989); Barberi *et al.* (1967b).

nappe above the Verrucano units of the Tuscan basement. Mining data also show that maximum thickness of the laccolith is about 600 m, with a maximum width of about 4000 m (Mazzarini *et al.*, 2002). The Gavorrano intrusion is bounded by two main faults. The eastern side of the granite is cut and bounded by the NNW-SSE trending normal Monticello fault, while the western side is bordered by the Gavorrano fault. At Gavorrano, the brittle deformation in granite and host rocks is seen as fault surfaces with slickensides, the occurrence of slices of thermal aureole along the fault plane, and the occurrence of fault breccias containing clasts of granite. These characteristics suggest that brittle tectonics (Gavorrano and Monticello faults) acted after the emplacement and cooling of the Gavorrano laccolith. These faults are associated with ore sulfide deposits.

The Gavorrano intrusion was emplaced at 4.4. Ma (Serri *et al.*, 2001, and references therein) and crops out in a structural high consisting of a southward dipping monocline. New geologic investigation and review of numerous data from mining exploration have been merged. The intrusion consists of two main facies (Mazzarini *et al.*, 2002): (1) biotite-bearing monzogranite with large megacrysts of K-feldspar and (2) leucocratic tourmaline-rich microgranite. The latter intrudes the monzogranite, and the two facies depict a rough N-S magmatic structure. The two facies of the Gavorrano intrusion plot in the field of normal and leucocratic facies of TMP, respectively (Fig. 4).

5.4 COUNTRY ROCKS

At Botro ai Marmi, the pluton crops out in a window through the upper host rock, upper Triassic limestones that have been extensively metamorphosed by the intrusion to dominantly grey and minor pink and white marbles. Metamorphic paragenesis include calcite, dolomite, scapolite, forsterite, tremolite, diopside. Interaction between igneous fluids and carbonate host rock gave way to the formation of skarn pockets and veins, where scapolite, diopside, garnet, vesuvianite, adularia, allanite, and Cu-Fe-Pb-Zn sulfides can be found. At Gavorrano, the eastern Monticello fault is locally associated with cataclastic limestone, and no hornfels or calcsilicates are found close to the fault. Only minor expression of contact metamorphism is preserved along the western Gavorrano fault. The main outcrops of hornfels are at the north-northeastern and the southern terminations of the laccolith, and indicate a maximum temperature for thermal metamorphism of 550-600°C. Ore bodies are found along the western Gavorrano fault. The occurrence of quartz-pyrite hydrothermal veins in the intrusive body suggests that fluid circulation, leading to the ore formation, exploited magmatic joints.

5.5 EMPLACEMENT OF MAGMA

Both the Botro ai Marmi pluton and the Gavorrano laccolith were emplaced at a shallow crustal level at the base of the Tuscan Nappe, probably exploiting a mechanical discontinuity represented by the thrust between the Tuscan Nappe and the pre-Appenninic Tuscan Basement units. At Gavorrano, the flexure of the brittle overburden (about 5 km thick) at the borders of the intrusion generated a fractured zone where successive brittle deformation was localised (Mazzarini *et al.*, 2002). The use of tectonic or lithologic discontinuities as crustal magma traps is also envisaged for the Cainozoic intrusion of western-central Elba (Rocchi *et al.*, 2002). Alternatively, on the basis of structural data, both the intrusions are interpreted as emplaced in pull-apart voids related to the activity of a N-S right-lateral strike-slip fault zone (Rossetti *et al.*, 2000; 2001).