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PETROLOGY, MINERALOGY AND GEOCHEMISTRY OF A MAFIC DIKE FROM MONTE CASTELLO, ELBA ISLAND, ITALY

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ABSTRACT

A mafic dike is intruded into two SW-NE trending normal faults, and crosscuts the Mt. Alpe Cherts and the Nisportino Fm. in the Monte Castello area, Elba Island, Tuscan Archipelago. The dike is dark grey to brownish in colour, it has a porphyritic texture with phenocrysts of plagioclase + clinopyroxene + olivine, and seldom xenocrysts of large k-feldspar. The original mineralogy is strongly altered and replaced by secondary minerals. Clinopyroxene and plagioclase in some cases are still preserved, whereas olivine is entirely replaced by smectite aggregates. Euhedral Mg-chromite inclusions occur in the olivine ghosts. In the freshest samples the groundmass is made up of clinopyroxene, k-feldspar, plagioclase, magnetite and apatite. Large k-feldspar xenocrysts probably scavenged from a monzogranite are also present. No olivine analyses are available due to strong weathering. Mg-chromites hosted by olivine ghosts have a mild residual character with a Cr# between 0.40 and 0.65. Plagioclases range in composition from An_{75} to An_{65}, although those enclosed in the k-feldspar xenocrysts have a compositional range from An_{39} to An_{35}. Clinopyroxenes are mainly sub-calcic diopside (augite) with an Mg# ranging from 0.88 to 0.83.

Step-heating $^{40}Ar/^{39}Ar$ dating was performed on the k-feldspar-rich groundmass of the less altered sample. The result establishes a date of 5.83±0.14 Ma (~70% of the released ^{39}Ar), although the slightly radiogenic initial Ar isotopic composition and the scatter observed during the release of Ar at low temperature make the result only indicative of the age.

Secondary minerals are ubiquitous even in the freshest samples, the whole rock compositions indicate that the parental magma has a shoshonitic composition, with a clear alkaline-potassic affinity. Mineral chemistry of k-feldspar and clinopyroxene crystals indicate that the magma belongs to the Italian Potassic Suites, with a strong resemblance to the potassic rocks cropping out at the Capraia Island and in the Southern Tuscany. The presence of olivine ghosts with euhedral Mg-chromite inclusions suggest that the magma has a strong primitive composition, with an alkaline character. Initial Sr-isotope values are in the range between 0.70878-0.70900, which indicate that the parental magma of the dike has not been contaminated with the monzogranite but the radiogenic Sr has been diluted by small scale magma-wall rock interaction. The presence of xenocrysts from a monzogranite, and lack of reaction paragenesis clearly indicates that the mafic magma intruded the monzogranite successively to its cooling.

The 5.8 Ma age of this dike constitutes a very important datum: in fact it indicates that block tectonics should began in the Island before this date, and could be contemporaneous or also older of the gravitational detachments triggered by the Monte Capanne pluton uplift.

INTRODUCTION

The Northern Apennine is an orogenic belt made up by a complex system of nappes piled up since Late Cretaceous to Mio-Pliocene times (e.g., Principi and Treves, 1984). The lowermost nappes pertain to the continental Adria Block (Tuscany and Umbria-Marche Domains), the uppermost ones, on the other hand, pertain to the Mesozoic Tethyan Ocean (Ligurian and Piedmont Domains). In the Ligurian Domain the Vara Supergroup succession constitute the only unit showing ophiolites at its base as its original basement (Abbate and Sagri, 1970).

In the Ligurian Units of the Elba Island magmatic bodies are intruded. Magmatism of the Elba Island is characterised by two plutonic masses cropping out in the eastern (La Serra - Porto Azzurro; Fig. 1) and western (Monte Capanne) sectors, along with microgranite, aplite and pegmatite dikes. Subvolcanic masses of rhyolitic porphyries do also occur in the central and eastern sectors of the island (Marinelli, 1959; Boccaletti and Papini, 1989; Poli, 1992). Subvolcanic porphyries and aplitic dikes are intimately associated to the main monzogranitic bodies. All igneous products are derived by highly silicic magmas with a clear crustal signature, although either mixing or mingling with sub-crustal magmas has been argued in the genesis of Monte Capanne magma (Poli, 1992). K/Ar, Rb/Sr and $^{40}Ar/^{39}Ar$ datings of the plutonic and subvolcanic rocks establish a range of cooling ages from ~8.5 to 5 Ma (e.g., Eberhardt and Ferrara, 1962; Evernden and Curtis, 1965; Saupé et al., 1982; Juteau, 1984; Juteau et al., 1984; Ferrara and Tonarini, 1985; Boccaletti et al., 1987; Dini and Tonarini, 1997; Dini and Laurenzi, 1999; Maineri et al., in prep.), generally decreasing eastwards.

The presence of sub-crustal magmas in the Elba magmatic system, coeval to the crustal anatectic magmas, is testified by rounded mafic enclaves occurring in plutonic bodies, which can reach diameters up to 15 m in size at Capo Sant'Andrea, on the northern edge of the Monte Capanne

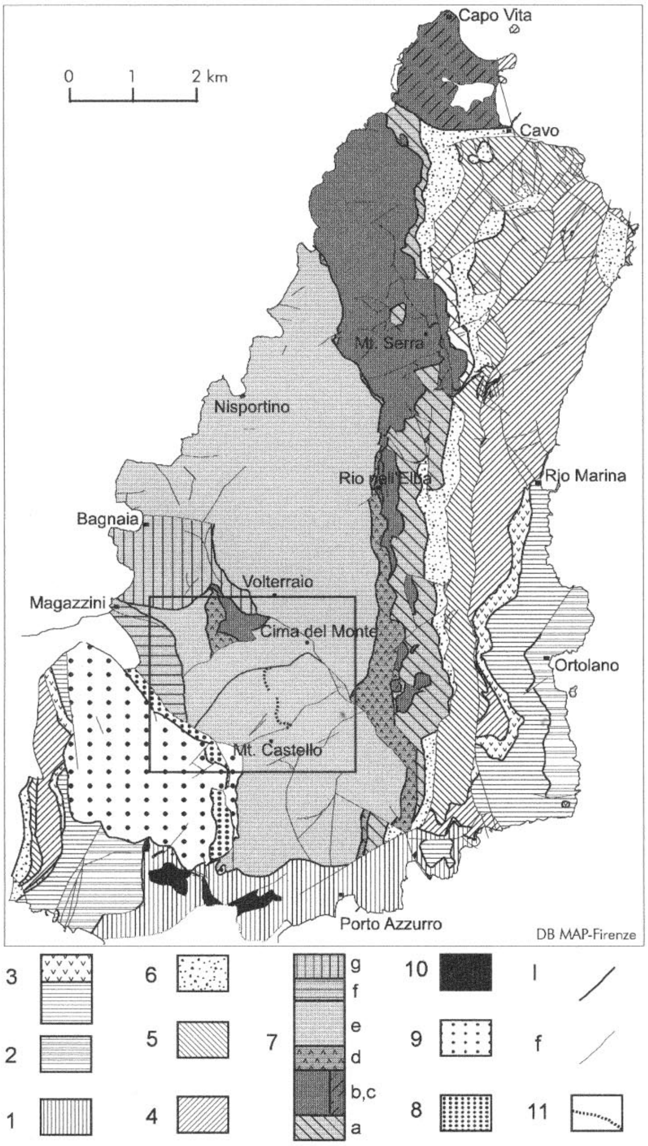

Fig. 1 - Structural map of eastern Elba Island. 1- Porto Azzurro Unit (Tuscan Domain); 2- Ortano U. (TD); 3- Acquadolce Unit (a- Porticciolo Subunit; b- Santa Filomena S.) (Piedmontese Domain); 4- Monticiano-Roccastrada U. (T.D.); 5- Tuscan Nappe (T.D.); 6- Gràssera U. (P.D.); 7- Ophiolitic U. (a- Acquaviva S.; b- Monte Serra S.; c- Capo Vita S.; d- Sassi Turchini S.; e- Volterraio S.; f- Magazzini S. g- Bagnaia S.) (Ligurian Domain); 8- Paleogene Flysch U. (L.D.); 9 Cretaceous Flysch U. (L.D.), 10- La Serra - Porto Azzurro monzogranite; 11- Mt. Castello mafic dike. The inset encloses the enlarged area of Fig. 3 (after Bortolotti et al., 2001).

pluton (Poli, 1992; Coli et al., 2001). Mafic enclaves, however, did not stock the original composition but interaction with the silicic host dramatically affected their chemical and isotopic compositions. Also the rare veins or mafic dikes intruding the Monte Capanne pluton in the NW edge (Colle d'Orano) did not preserve their original chemistry but diffusion processes with the host, which was not totally crystallised at the moment of intrusions, occurred. Unfortunately being the outcrops of Monte Capanne Pluton in the northern and western edges totally denudated and directly surrounded by the sea it is not possible to follow the dikes far away from the pluton in the country rock.

In the present paper we report mineralogical, isotopic, chronological and compositional data for a mafic dike, which intruded the sedimentary cover of the ophiolites, above the La Serra - Porto Azzurro pluton. These data would, possibly, furnish important informations on the subcrustal magmatism that pervaded the Elba area, but was not able to reach the surface having been intercepted by the large magmatic reservoirs represented by the Monte Capanne and La Serra - Porto Azzurro plutons. Furthermore, age and petrological data will be used in the frame of the geological evolution of the Elba Island. In addition, the possibility of dating the magmatic event is of paramount importance also for dating the beginning of the tensional block tectonics and the gravitational movements linked to this tectonic regime during the geological evolution of the Elba Island.

GEOLOGICAL AND PETROLOGICAL BACKGROUND

An intense magmatic activity, related to the post-collisional phase of the Apennine orogeny, took place during the opening of the Northern Tyrrhenian basin during the Late Miocene-Pleistocene. This caused the emplacement of a wide variety of rocks at different crustal levels (i.e., from volcanic to intrusive), with marked differences in petrologic affinities, from strongly alkaline (ultrapotassic) to calc-alkaline (Peccerillo et al., 1987; Poli et al., 1989; Innocenti et al., 1992; Conticelli, 1998a).

Crust- and mantle-derived magmatic rocks cropping out in the Tuscan Archipelago and Southern Tuscany were once grouped in a single magmatic province (Tuscan Magmatic Province) owing to their hypothetical consanguinity (Marinelli, 1961). Recently a number of authors have shown that only granites and rhyolites were originated in the crust, whilst calc-alkaline, potassic and ultrapotassic magmas were originated in a variably metasomatised lithospheric mantle source (Peccerillo et al., 1987; Conticelli and Peccerillo, 1992, Peccerillo, 1993).

Crust-derived magmas form (i) the plutons and subvolcanic bodies of Elba, Montecristo, and Giglio islands, (ii) the granite intrusion of the Vercelli Seamount (Northern Tyrrhenian Sea), (iii) the intrusive bodies of Gavorrano, Campiglia and Monteverdi, in Southern Tuscany, and (iv) the lava flows of San Vincenzo and Roccastrada-Roccatederighi, also in Southern Tuscany (Peccerillo et al., 1987; Pinarelli et al., 1989; Poli et al., 1989; Poli, 1992; Innocenti et al., 1992). These crust-derived magmas were emplaced between 8.5 and 2 Ma (e.g., Borsi et al., 1965, 1967; Borsi, 1967; Juteau, 1984; Juteau et al., 1984; Ferrara and Tonarini, 1985, 1992; Villa et al., 1987; Barberi et al., 1994; Maineri et al., in prep.), and become younger and younger eastwards (Barberi et al., 1971; Civetta et al., 1978).

Mantle-derived magmas overlap, in time and space, with crust-derived magmas (e.g., Peccerillo et al., 1987; Innocenti et al., 1992), although they were emplaced in a wider span of time, starting from 14.2 Ma (Sisco, Corsica) to 0.08 Ma (e.g., Ferrara and Tonarini, 1985; Fornaseri, 1985; Turbeville, 1992; Cioni et al., 1993; Barberi et al., 1994).

For what concerns the magmatic rocks associated to the Monte Capanne pluton, minor porphyritic dikes are present at the western margin of the pluton, but the most extended masses of rhyolitic porphyry crop out on the northern edge and intruded in the flysch units of central Elba.

In eastern Elba (Fig. 2) an Ophiolitic Unit (Vara Supergroup succession) has a peculiar tectonic position, lying on the Tuscan Nappe (Tuscan Domain) separated by a thin local tectonic unit, the Gràssera Unit, probably belonging to the Piedmontese Domain (possibly the upper section of an anchimetamorphic "*Schistes Lustrés*"-type succession; Bortolotti et al., 2001). The nappe pile of eastern Elba lies on a sub-horizontal tectonic structure called Zuccale Fault, along which the whole pile has had two successive gravitational movements: the first one east- southwestwards, due to the Mt. Capanne pluton uplift; the second one, of minor extension, northeastwards, due to the La Serra - Porto Azzurro pluton. The last movements of this fault are in fact younger than La Serra- Porto Azzurro pluton, being the monzogranitic stock itself, as well as the overall dikes to it related, abruptly cut by this tectonic discontinuity (Bortolotti et al., 2001). Finally, this pluton and the Zuccale Fault are cut by a north-south swarm of normal faults.

The pelagic cover stratigraphycally overlaying the ophiolite succession is made up by the Monte Alpe Cherts, the Nisportino Formation and by the Calpionella Limestones (Bortolotti et al., 2001). The Monte Alpe Cherts are an Upper Jurassic formation, made up by thin bedded red cherts, porcellanites, and siliceous shales, grading into the overlaying Nisportino Formation (Bortolotti et al., 1994). The Nisportino Formation (Berriasian) is a transitional formation, between the Monte Alpe Cherts and the whitish siliceous Calpionella Limestones (Valanginian). This formation is made up of siliceous siltstones and shales interbedded to siliceous and cherty limestones, grading upwards to a massive level of marly limestones (Rivercina Member), and then to marly siltstones and siliceous shales intercalated with more and more abundant micritic limestones. Upwards, a thick succession of whitish micritic limestones constitutes the Calpionella Limestones.

FIELD DATA

In the Monte Castello area (Fig. 3) a mafic dike (Fig. 4) intrudes the Nisportino Fm. and the Monte Alpe Cherts. The dike has a variable thickness from few to 140 cm, and can be followed from the Monte Castello zone northwards to the southern flank of Forcaccio Creek, 800 metres further on. In detail the dike at its southern edge is intruded into the SW-NE trending Monte Castello normal fault, which separates Monte Alpe Cherts by the Nisportino Fm., then it curves northwestwards, crossing sinuously the Monte Alpe Cherts and the Nisportino Fm. At its northern edge it follows the SW-NE-trending Acqua Cavalla normal fault, which separates the Nisportino Fm. and Calpionella Limestones from the Monte Alpe Cherts. Both Monte Castello and Acqua Cavalla normal faults are older than the NW-SE-trending faults (Casa Totano and Cima del Monte transfer faults; see Bortolotti et al., 2001), which cut their western and eastern edges (Fig. 3).

The dike shows its maximum thickness when crossing the Monte Alpe Cherts, whereas it gets narrower when it cuts the marly limestones and the siltstones of the Nisportino Fm. The contact with the country rocks is mainly sharp, with country rocks showing no macroscopic evidence of thermometamorphism. In some cases, when the dike intrudes the marly limestones of the Nisportino Fm., the country rock at the contact might present incipient melting features, suggesting the presence of chemical and isotopic mobilisations and transfer between magma and country rock.

The dike has a light grey, brownish to slightly greenish colour (reddish by weathering), with an aphanitic texture, scattered, seldom partially resorbed, large xenocrysts of karlsbad-twinned k-feldspar up to 10 cm in size (Fig. 4). Several minute crystals of plagioclase and clinopyroxene can be distinguishable if observed with an eyeglass.

PETROGRAPHY AND MINERAL CHEMISTRY

The mafic dike of Monte Castello has sub-aphyric textures with clinopyroxene and olivine ghost phenocrysts, with xenocrysts represented by plagioclase, quartz and large orthoclase, set in a groundmass made up of clinopyroxene, plagioclase, sanidine and oxides. Clinopyroxene is often replaced by either uralite or chlorite. Olivine is totally replaced by serpentine, smectite, and minor calcite, but euhedral chromite and anhedral clinopyroxene, pyrrothite, and amphibole inclusions are often still preserved. Secondary minerals are found in the most weathered portions of the dike, due to the different country rocks: calcite is the most important in the portions intruding marlstones.

Olivine. No analyses are available because no fresh olivine grains are found in the studied samples. Presence of olivine was inferred by morphology of serpentine pseudomorph after olivine.

Clinopyroxene. The entire population analysed have an Mg# [Mg/(Mg+Fe^{2+})] falling in the range 0.83-0.88 (Table 1). Following the Morimoto (1989) scheme of classification clinopyroxene from the Monte Castello dike has a homogeneous composition falling in the augite field (Fig. 5). Only the clinopyroxene enclosed in olivine ghosts has a diopsidic composition. Phenocrysts and groundmass crystals have a composition, in terms of quadrilateral component, similar to that of clinopyroxene crystals from lamproitic to transitional rocks from Southern Tuscany (Conticelli et al., 1992; Conticelli, 1994; 1998b). In comparison with lamproite, however,

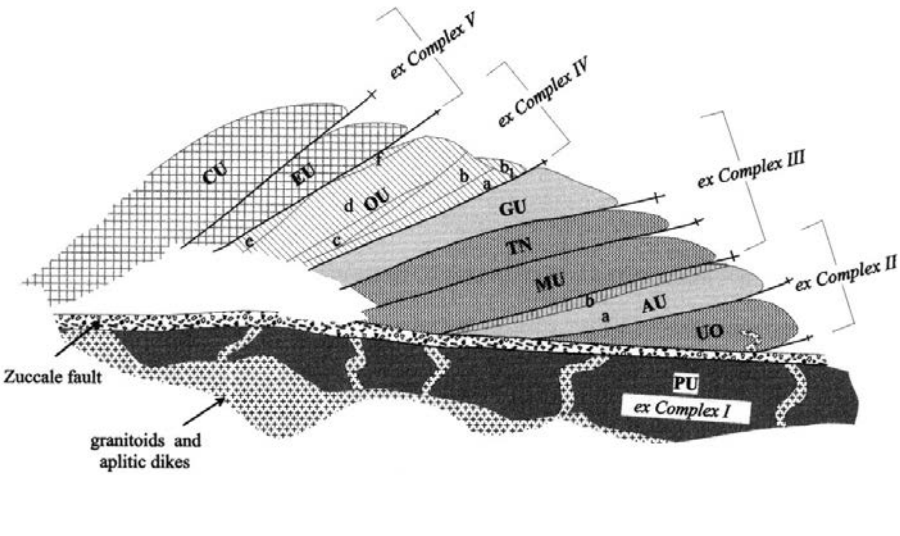

Fig. 2 - The tectonic pile of eastern Elba. PU- Porto Azzurro Unit; UO- Ortano U.; AU- Acquadolce U. (a- Porticciolo Subunit, b- Santa Filomena S.); MU- Monticiano-Roccastrada U.; TN- Tuscan Nappe; GU- Gràssera U.; OU- Ophiolitic U. (a- Acquaviva Subunit; b- Mt. Serra S.; b_1- Capo Vita S.; c- Sassi Turchini S.; d- Volterraio S.; e- Magazzini S.; f- Bagnaia S.); EU- Paleogene Flysch U.; CU- Cretaceous Flysch U. (after Bortolotti et al., 2001).

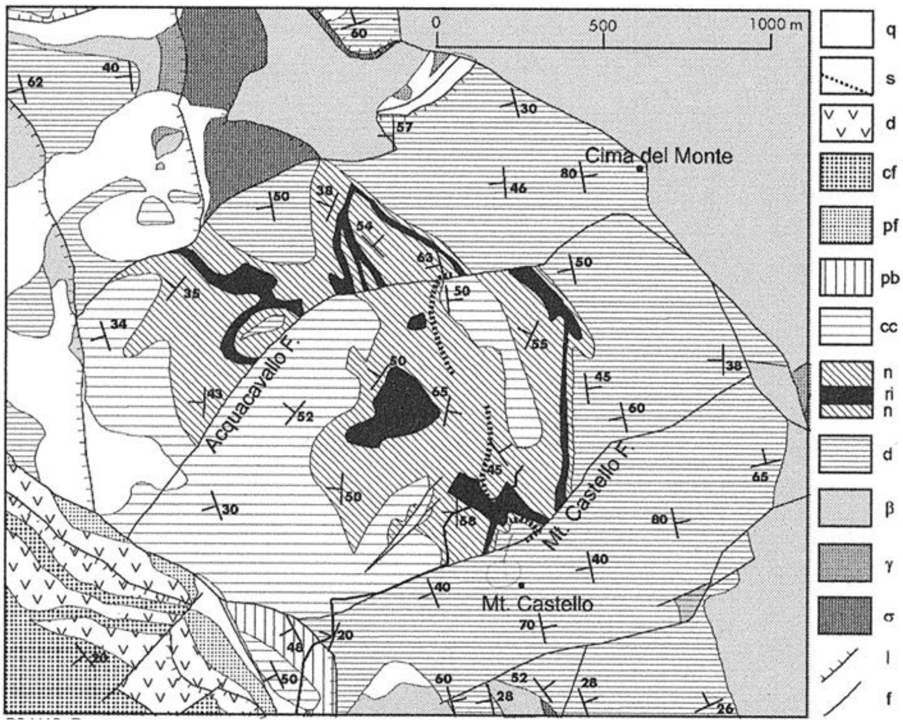

Fig. 3 - Sketch map of the Monte Castello-Cima del Monte area. q- Quaternary deposits; s- Mt. Castello mafic dike; d- Neogene aplite and pegmatite dikes ; Cretaceous Flysch Unit: cf- Marina di Campo Fm.; pb- Palombini Shales; cc- Calpionella Limestones (the south-westernmost outcrop). Paleogene Flysch Unit: pf- Colle Reciso Fm. Ophiolitic Unit: cc- Calpionella Limestones; n- Nisportino Fm, with ri- Rivercina Member; d- Mt. Alpe Cherts; β- Basalts; γ- Gabbros; σ- Serpentinites. l- Thrust; f- Fault (redrawn after Bortolotti et al., 2001).

Fig. 4 - The mafic dike near the Mt. Castello Fault. The arrow indicates a large k-feldspar xenocryst.

Al (a.f.u.) is higher and sufficient to compensate Si deficiency and therefore Si+Al completely saturated the tetrahedral site. In the Al versus Ti diagram (Fig. 6) the crystals from the mafic dike (with the exception of the crystal enclosed in the olivine ghosts), straddle the boundary between the field of clinopyroxene from transitional rocks and that of clinopyroxene from Roman type rocks.

Amphibole. Anhedral inclusions of amphibole crystals are often included in olivine ghosts. They have a Mg-hastingsitic composition with an Mg# in the range between 0.73 and 0.75 (Table 1). Amphibole is uncommon in potassic and ultrapotassic rocks but k-richterite is found in Corsica and South Tuscany lamproites (Wagner and Velde, 1986; Conticelli et al., 1992). Hornblende is common in high-potassium calc-alkaline rocks from Capraia Island, Tuscan Archipelago (Poli et al., 1996).

Plagioclase. Microphenocryst and groundmass plagioclase has a composition ranging from An_{65} to An_{75}, whereas rounded and resorbed large xenocrysts and plagioclase inclusions in orthoclase xenocrysts fall in the range between An_{35} to An_{39} (Fig. 7) The latter overlap in composition plagioclase from the La Serra - Porto Azzurro monzogranite. In addition authigenetic plagioclase crystals have higher Fe_2O_3 (0.4-0.7 wt.%), MgO (0.1-0.2 wt.%), and SrO (0.1-0.5 wt.%) than xenocrysts and plagioclase from the La Serra - Porto Azzurro monzogranite (Table 2).

Among potassic and ultrapotassic rocks from Italy, lamproite and kamafugites are plagioclase-free, but transitional rocks similar to the shoshonite from Radicofani are characterised by plagioclase restricted in the groundmass with sanidine (Conticelli and Peccerillo, 1992).

K-feldspar. Groundmass crystals are sanidine, whereas large sub-euhedral crystals are orthoclase varieties. The latter are plenty of crystalline inclusions of apatite and biotite. Sanidine is characterised by TiO_2 (0.1-0.2 wt.%), Fe_2O_3 (0.4-0.5 wt.%), BaO (0.5-1.1 wt.%), and SrO (0.1-0.5 wt.%) higher than orthoclase. Compositions of large orthoclase

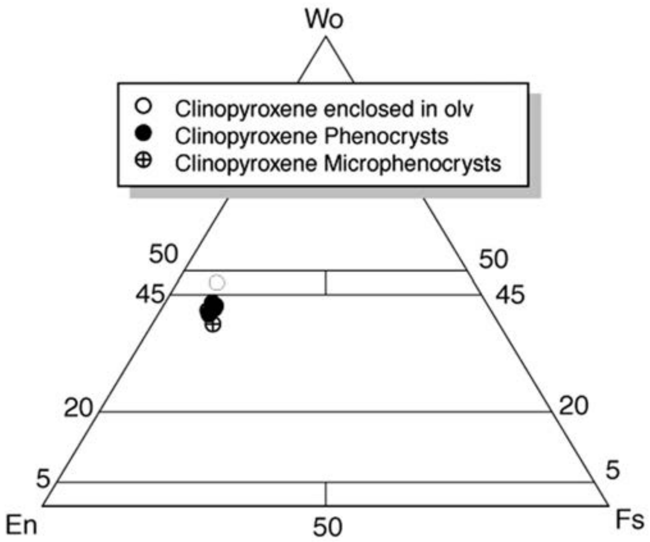

Fig. 5 - Composition of clinopyroxene in terms of quadrilateral components.

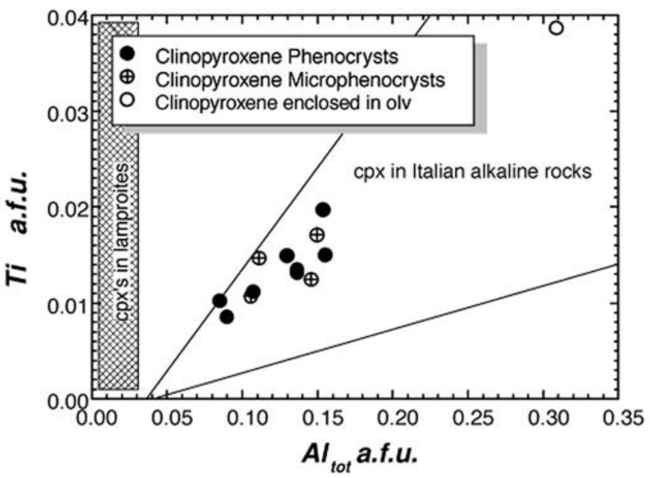

Fig. 6 - Ti vs. Al composition for clinopyroxene crystals from the Italian region (after Conticelli, 1998a), with reported the Monte Castello dike clinopyroxene and the fields for the Italian lamproite clinopyroxene and the Italian potassic alkaline clinopyroxene (data source: Conticelli et al., 1991; 1992; 1997; Conticelli 1998b; Conticelli and Poli, 1999; Perini and Conticelli, 1999).

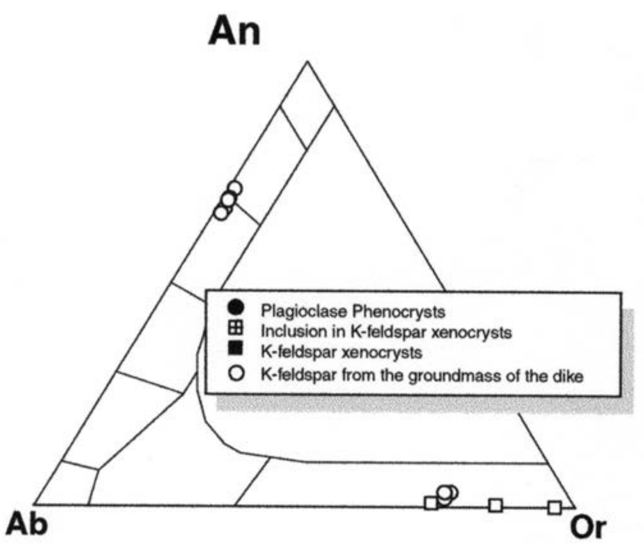

Fig. 7 - Classification diagram for ternary feldspar.

xenocrysts partially overlap in composition megacrysts from the La Serra - Porto Azzurro monzogranite (Table 2, Fig. 7). On the basis of minor elements, sanidine from the studied rocks are similar in composition to those from the groundmasses of Tuscan transitional rocks (e.g., Monte Cimino, Radicofani; Conticelli and Poli, 2001; author's unpublished data).

Oxide. Several oxide minerals of primary and secondary origin are present either as inclusions of main phenocryst phases or in the groundmass of the dike. Namely Ti-magnetite, chromite and anatase are the main oxide minerals found.

Mg-chromite is clearly a primary phase, and it has been found as euhedral inclusions in the olivine ghosts. It has a Cr# [Cr/(Cr+Al)] ranging between 0.40 and 0.65 (Table 3). Just from a speculative viewpoint, if Fo of original host olivine was between 89 and 90, when coupled to such Cr# values, they would have covered the values for near liquidus olivine-spinel pairs of the Central portion of the Roman Comagmatic Province (Conticelli 1998b; Perini and Conticelli, 2001); these values are significantly lower than those own by minerals in ultrapotassic primitive rocks from the Tuscan Region (i.e., lamproite-like, kamafugite and transitional; Conticelli, 1998a, 1998b; Conticelli and Poli, 2001).

Ti-magnetite has been found enclosed in the large orthoclase xenocrysts having a TiO_2 contents up to 9.5 wt.%, which was in equilibrium with the composition of the melts from which orthoclase crystallised.

Anatase, is mainly found as minute crystals as the products of the alteration of possible Ti-rich primary phases such as ilmenite.

Glass. Glass inclusions have been found in many phenocryst phases but only those in clinopyroxene were sufficiently large for being analysed (Table 4). They have a dacitic composition when plotted on a water-free basis in the Total Alkali-Silica diagram (Fig. 8).

CHEMICAL COMPOSITION AND ISOTOPE DATA OF WHOLE ROCK SAMPLES

The original bulk chemistry of the magma is not directly represented by the whole rock composition being the dike strongly modified by syn- and post emplacement alteration.

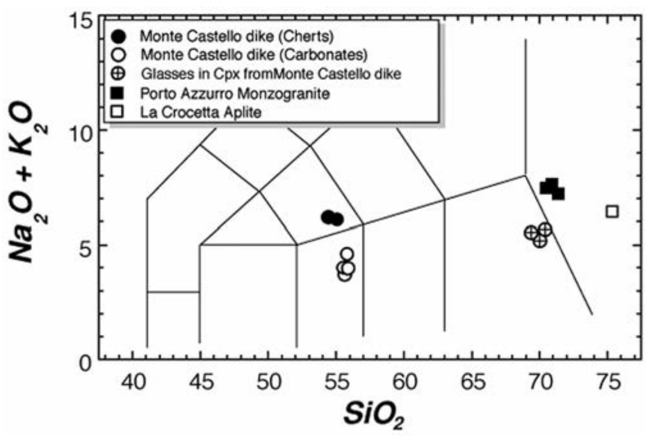

Fig. 8 - Total Alkali Silica classification diagram (Le Bas et al., 1986; Le Bas, 1989) for the samples of the Monte Castello dike, with reported the glass inclusions found in the clinopyroxene phenocrysts of the dike and the compositions of the La Serra - Porto Azzurro monzogranite and of a k-feldspar rich aplite ("Eurite") of La Crocetta quarry.

Table 1 - Selected analyses of clinopyroxene and amphibole

Sample	ST 10	ST 10	ST 10	ST 10	ST 10
Spot	8	3	4	23	10
Texture	enclosed in olivine	core	rim	gdm	enclosed in olivine
SiO_2	49.7	52.3	51.8	52.0	41.3
TiO_2	1.41	0.49	0.72	0.45	1.74
Al_2O_3	7.18	3.16	3.58	3.36	18.0
Cr_2O_3	0.32	0.83	0.12	0.71	bdl
FeO	4.53	5.33	5.72	5.25	9.88
MnO	0.03	0.03	0.17	0.20	0.19
MgO	15.4	16.9	17.0	16.8	15.7
CaO	21.3	20.5	21.0	20.3	9.51
Na_2O	0.33	0.28	0.23	0.26	2.48
K_2O	bdl	bdl	bdl	bdl	0.39
Sum	100.2	99.8	100.4	99.3	99.1
Si	1.813	1.914	1.886	1.911	5.850
Al	0.187	0.086	0.114	0.089	2.150
Al	0.121	0.051	0.040	0.057	0.851
Ti	0.039	0.013	0.020	0.012	0.186
Cr	0.009	0.024	0.003	0.021	0.000
Fe^{3+}	0.003	0.004	0.047	0.005	0.171
Mg	0.835	0.925	0.923	0.922	3.319
Fe^{2+}	0.135	0.159	0.127	0.157	1.001
Mn	0.001	0.001	0.005	0.006	0.023
Ca	0.834	0.803	0.818	0.802	1.445
Na	0.023	0.020	0.016	0.019	0.682
K	0.000	0.000	0.000	0.000	0.071
En	46.2	48.9	48.1	48.7	
Fe	7.7	8.7	9.3	8.9	
Wo	46.1	42.5	42.6	42.4	
Mg#	0.86	0.85	0.84	0.85	0.74

Analyses were performed by the senior author with a JEOL 8600 JXA microprobe at the "*C.N.R., Centro di Studio per la Minerogenesi e Geochimica dei Sedimenti*". The WDS equipment was operating with 15 kV accelerating voltage, and 10 nA beam current, with different counting times for major and minor elements. Errors were in agreement with those found by Vaggelli et al. (1999). Atomic proportions on the basis of 4 cations with Fe^{3+} estimated from stoichiometry for clinopyroxene and on the basis of 13 cations with Fe^{3+} estimated from stoichiometry. Core- phenocryst core; rim- phenocryst rim; gdm- crystal from the groundmass; bdl- below the detection limit.

The seven analysed samples indeed display slight but significant differences in the major and trace element concentrations correlated with the different country rocks cut by the dike (Table 5). Samples from the Monte Alpe Cherts, display lower contents of CaO (6.3-6.9 wt.% vs. 9.9-10.5 wt.%) and SiO_2 (49-50 wt.% vs. 51-52 wt.%), and higher contents of MgO (6.1-6.3 wt.% vs. 4.8-5.2 wt.%), K_2O (3.0-3.8 wt.% vs. 1.9-2.2 wt.%), Rb (161-191 ppm vs. 87-101 ppm), Ba (515-630 ppm vs. 327-441 ppm), with respect to those from the dike intruded in the Rivercina Member marly limestones. Significant differences are observed also among the initial Sr isotope values. The value of 0.70900 for the dike in the Monte Alpe Cherts, and the value of 0.70808 for that in the marly limestone of the Rivercina Member have been found.

These compositional differences are also found relative to the classification of the rocks, being the dike a shoshonite (basaltic trachyandesite) in the Monte Alpe Cherts and a basaltic andesite in the marly limestones and siltstones of the Rivercina Member (Fig. 8). Most differences observed depict a descent line pointing to the composition of the Rivercina Member marly limestones and siltstones, whereas the composition of the La Serra - Porto Azzurro monzogranite and related aplite fall far away from this trend (Fig. 9). In addition the Sr-isotope value of the dike intruded into the Rivercina Member (0.70808) is intermediate between the value of the Rivercina Member marly limestone, calculated at the age of the intrusion (0.70767), and that of the dike intruded into the Monte Alpe Cherts. On the other hand the La Serra - Porto Azzurro monzogranite has an initial Sr isotopic value which is significantly higher (0.71339) than those of the dike.

$^{40}Ar/^{39}Ar$ DATING

The isotopic analysis was performed on the groundmass separate of the less altered sample (sieved fraction between 160 and 100 μ), taken in the thickest part of the dike (~140 cm). The mineral separation was performed with conventional magnetic and gravimetric methods, with final handpicking under the binocular microscope, to avoid the altered portions, and to purify the sample. The analysed groundmass was made up of clinopyroxene, k-feldspar, plagioclase, magnetite and apatite.

The sample was irradiated for 9 hours long, in the core of the 250 kW TRIGA reactor at the "*Università degli Studi di Pavia*", using FCT biotite as age monitor and Ni wires as flux monitors. The age used for FCT Biotite is 27.55 Ma (Lanphere et al., 1990): it represents one of published ages for this standard, (for a detailed discussion, see Izett et al., 1992). A conventional step-heating analysis using an RF furnace was performed (Table 6). The obtained age spectrum is disturbed, with high ages on low temperature steps. Ca/K ratio matches age values for the majority of the spectrum, but it jumps to high values, compatible with the degassing of Ca-rich phases in the high temperature steps; K is due almost entirely to k-feldspar degassing. No statistically

Table 2 - Selected analyses of plagioclase and k-feldspar

	Plagioclase			***K-feldspar***			
	dike	dike	dike	dike	dike	dike	monzo granite
Sample	**ST 10**	**ST 10**	**ST 03**	**ST 10**	**ST 03**	**ST 03**	**ST 24**
Spot	6	26	4	37	9	2	3
Where	micro	gdm	enclosed in Kf #2	gdm	xeno core	xeno rim	mega
SiO_2	50.9	51.6	59.8	62.5	65.7	65.5	65.1
TiO_2	bdl	0.09	bdl	0.11	bdl	bdl	bdl
Al_2O_3	30.9	30.8	25.5	19.5	18.6	18.7	19.1
Fe_2O_3	0.57	0.39	bdl	0.45	0.08	bdl	bdl
MnO	bdl	bdl	bdl	bdl	bdl	bdl	bdl
MgO	bdl	0.15	bdl	bdl	bdl	bdl	bdl
CaO	14.2	13.7	7.15	0.95	bdl	0.17	0.08
Na_2O	3.03	3.31	6.63	0.53	0.41	2.82	1.53
K_2O	0.19	0.19	0.68	13.9	15.7	11.9	13.7
SrO	0.53	0.14	0.06	0.45	bdl	bdl	bdl
BaO	bdl	bdl	bdl	1.01	bdl	0.51	0.59
Sum	100.35	100.48	99.82	99.35	100.45	99.62	100.04
Cations on the basis of 8 oxygens							
Si	2.318	2.338	2.669	2.921	3.006	2.997	2.985
Al	1.659	1.645	1.341	1.074	1.004	1.011	1.031
Ti	0.000	0.003	0.000	0.004	0.000	0.000	0.000
Fe^{3+}	0.019	0.013	0.001	0.016	0.003	0.000	0.000
Mg	0.000	0.010	0.000	0.000	0.000	0.000	0.000
Ca	0.693	0.666	0.342	0.048	0.000	0.008	0.004
Na	0.267	0.291	0.574	0.048	0.036	0.250	0.136
K	0.011	0.011	0.039	0.826	0.917	0.697	0.800
Sr	0.014	0.004	0.002	0.012	0.000	0.000	0.000
Ba	0.000	0.000	0.000	0.018	0.000	0.009	0.011
Ab	27.53	30.01	60.12	5.11	3.82	25.95	14.32
An	71.34	68.85	35.83	5.06	0.00	0.86	0.41
Or	1.14	1.13	4.06	87.86	96.18	72.24	84.16
Cn	0.00	0.00	0.00	1.97	0.00	0.95	1.12

Details for EPMA as in Table 1. Fe was totally expressed as Fe_2O_3. Bdl- below the detection limit; Ab- albite; An- anorthite; Or- orthoclase; Cn- celsian.

Table 3 - Selected analyses of oxide minerals

	chromite			*magnetite*	*anatase*
Sample	**ST 10**	**ST 10**	**ST 10**	**ST 03**	**ST 03**
Spot	9	28	29	10	1
Texture	enclosed in olivine	enclosed in olivine	enclosed in olivine	Enclosed in KF # 9	gdm
SiO_2	0.17	0.14	0.08	0.24	0.75
TiO_2	0.94	0.88	0.88	9.15	96.8
Al_2O_3	31.9	17.8	17.8	0.20	0.18
Cr_2O_3	32.0	47.5	47.6	bdl	bdl
Fe_2O_3	3.89	3.99	3.20	60.9	-
FeO	18.3	18.9	18.8	26.3	1.94
MnO	0.12	bdl	bdl	0.71	bdl
NiO	bdl	0.07	bdl	bdl	bdl
MgO	12.9	10.9	10.7	0.37	0.12
CaO	0.05	0.12	0.10	0.54	0.16
ZnO	bdl	bdl	bdl	bdl	bdl
sum	100.2	100.3	99.1	98.4	100.0
Cr#	0.40	0.64	0.64		

Details for EPMA are reported in table 1. Fe^{3+} was estimated on the basis of stoichiometry. Bdl- below the detection limit; gdm- groundmass; KF- k-feldspar xenocrysts; Cr#- $Cr/(Cr+Fe^{3+}+Al)$.

acceptable plateau age is obtained (Fig. 10), while 6 steps (860-1250 °C), containing about 70% of ^{39}Ar release, identifies an isochron age of 5.83 ± 0.14 Ma (Fig. 11), with a slightly radiogenic initial $^{40}Ar/^{36}Ar$ ratio (317.6±4). All displayed errors are at the 1 σ level. This age would be 5.89 Ma toward an age of 27.84 Ma (Cebula et al., 1986) for FCT. The shape of the spectrum and the high L.O.I. of the sample, however, make the obtained result only indicative of the age of the dike.

DISCUSSION

The presence of coeval crustal anatectic magmas and subcrustal mafic magmas in Tuscany has been reported by several authors (Peccerillo et al., 1987; Innocenti et al., 1992; Conticelli 1998a). In particular, the Tuscan Archipelago displays volcanic apparata characterised by subcrustal magma (i.e., Capraia Island; Poli et al., 1995) beside more or less coeval magmatic intrusions of ultimate crustal origin (i.e., Montecristo, Giglio, Capanne, etc.; Poli, et al., 1987; Poli, 1992). In addition, the Monte Capanne intrusion (Elba Island) displays a clear evidence of mingling and mixing between magmas of strongly different natures. Mafic enclaves indeed have been interpreted as the witness of injection of hot mafic subcrustal magmas into the cooler crustal anatectic magma of the Monte Capanne intrusion (Poli, 1992; Coli et al., 2001).

The dike intruding the allochthonous terranes in the Monte Castello area, although strongly altered, has clear ev-

Table 4 - Selected analyses of glass inclusions

Sample	ST 10	ST 10	ST 10
Spot	33	35	37
Mineral	Glass	Glass	Glass
Where	enclosed in cpx # 34	enclosed in cpx # 36	enclosed in cpx # 38
SiO_2	66.3	65.1	66.6
TiO_2	bdl	0.09	0.05
Al_2O_3	17.9	18.3	17.8
Cr_2O_3	0.03	bdl	bdl
FeO	0.38	0.45	0.41
MnO	bdl	bdl	bdl
NiO	bdl	bdl	bdl
MgO	0.03	0.07	0.05
CaO	3.75	4.01	3.92
SrO	0.11	0.10	0.15
BaO	0.12	0.09	0.10
Na_2O	2.20	2.11	2.16
K_2O	2.32	2.65	2.44
P_2O_5	0.17	0.20	0.18
F	0.09	0.11	0.10
Cl	0.06	0.05	0.07
S	bdl	bdl	bdl
Sum	93.42	93.29	94.01

Details for EPMA are reported in Table 1. Bdl- below the detection limit; cpx- clinopyroxene phenocrysts.

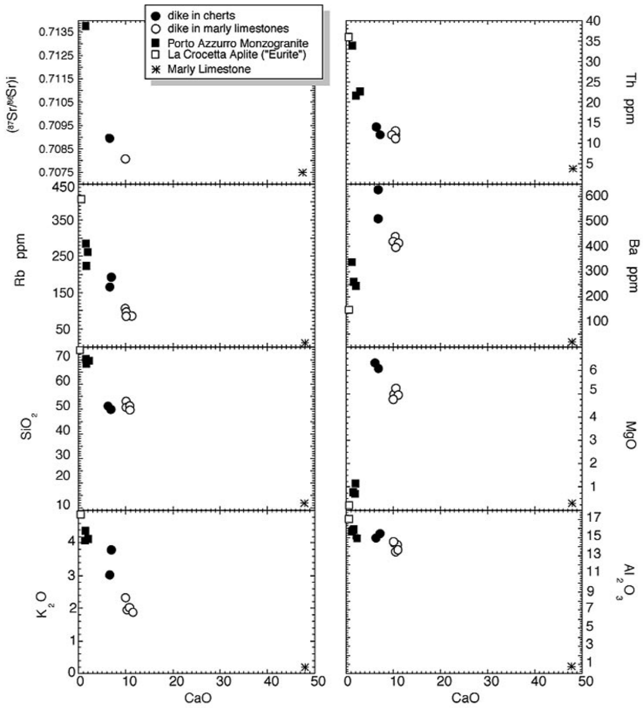

Fig. 9 - Variation diagram for some major and trace elements and initial Sr isotope values for the samples of Monte Castello dike intruding cherts and marly limestones of the Nisportino Fm., compared with the composition of La Crocetta Aplite and La Serra - Porto Azzurro crustal anatectic magmatic rocks.

idence for being originated by feeding of mafic hot magma of subcrustal origin. The concentrations of MgO, FeO_{tot}, Ni, Cr, V, Co, and of other compatible elements, together with the petrographic characteristics and the composition of mineral phases argue for a subcrustal origin of the parental magma feeding the dike of Monte Castello. The length, the small width and the shallow emplacement level allow to consider the obtained $^{40}Ar/^{39}Ar$ datum representative of the emplacement age of the dike.

The presence of large k-feldspar xenocrysts dotted by several mineral inclusions probably scavenged by an underlying monzogranite stock testify that when the parental magma was feeding the dike, the monzogranite would have been almost completely crystallised, or at least it had a fragile behaviour. If the monzogranite had been still molten the feeding mafic magma would have been injected into the stock with the result of mixing and/or mingling between the two magmas. In addition no evidence of compositional mixing is observed between the samples representing the dike and the composition of La Serra - Porto Azzurro monzogranite and its aplites (Fig. 9). In particular, the high $^{87}Sr/^{86}Sr$ value of the monzogranite would have strongly affected the initial $^{87}Sr/^{86}Sr$ of the mafic magma.

On the other hand, evidence of near surface contamination of the parental magma of the feeding dike is clear both on petrographic and compositional grounds. For many major and trace, compatible and incompatible elements, the samples from the dike in the Rivercina Member marly limestones and siltstones are intermediate between the composition of those in the Monte Alpe Cherts and the composition of the Rivercina Member itself (Table 5, Fig. 9). This holds true also for the initial Sr isotopes (Fig. 9 and 12), which, when plotted versus the concentrations of incompatible trace elements (Fig. 12), falls along a possible mixing line between the sample intruded into the Monte Alpe Cherts and the Rivercina Member, respectively. Petrographycally, the samples from the dike intruded into Rivercina Member display large amount of secondary calcite, whereas the samples intruded into the Monte Alpe Cherts have higher L.O.I.. This crustal contamination occurred before, near surface alteration, but was not overprinted by the latter process.

Although strong alteration and near surface crustal contamination occurred, we still can speculate about the original nature of the subcrustal magma feeding the Monte Castello dike. Taking into account the samples of the dike into the Monte Alpe Cherts, which did not suffered additional crustal contamination, the magma appears clearly to have an alkaline potassic signature (Fig. 8). Although, the alteration did strongly modify the original mineralogy and chemistry of the dike, olivine ghost with euhedral spinel inclusions, and the high Mg# of clinopyroxene phenocrysts speaks for a fairly primitive nature of the parental magma of the dike. This is also corroborated by the Mg-V [$100*Mg/(Mg+0.75*Fe_{tot})$] of the rocks, which was not strongly affected by alteration, being in the range 65.6-67.2, close to the equilibrium with the Mg# of clinopyroxene phenocrysts.

The distribution of incompatible trace elements normalised to the primordial mantle, provide, for this magma, a picture fairly close to that of Tuscan transitional magmas (Peccerillo et al., 1987; Conticelli and Peccerillo, 1992), with clear negative spikes at Nb, Sr, P and Ti (Fig. 13). Similar patterns, negative spikes at Sr beside those at each high field strength element, are peculiar of lamproite-like rocks, and of some Tuscan transitional rocks, but differ from those typical of Roman alkaline potassic and ultrapotassic rocks

Table 5 - Major, trace elements and Sr isotope analyses of samples of eastern Elba Island

Locality:	Monte Castello	Monte Castello	Monte Castello	Monte Castello	Monte Castello	Monte Castello	Cala Barbarossa	Porto Azzurro	Porto Azzurro	La Crocetta	Nisporto
	Dike	Dike	Dike	Dike	Dike	Dike	Monzo granite	Monzo granite	Monzo granite	"Eurite"	Marlst.
Sample:	**ST 135/12**	**ST 135/3**	**ST 135/8**	**ST 135/6**	**ST 135/7**	**ST 135/10**	**ST 135/24**	**PO 40**	**PO 42**	**ST 135/14**	**ST 135/26**
	in cherts	in cherts	in marlst.	in marls	in marlst.	in marlst.					
SiO_2	49.8	50.8	51.2	51.3	51.7	52.8	70.6	70.0	70.4	73.9	10.8
TiO_2	0.78	0.80	0.82	0.89	0.88	0.89	0.41	0.51	0.41	bdl	bdl
Al_2O_3	15.4	14.9	13.4	14.3	14.3	14.5	15.9	15.1	15.7	17.0	0.86
Fe_2O_3	2.22	2.34	2.68	2.51	2.64	2.89	1.78	0.61	0.95	0.16	0.53
FeO	4.28	4.86	4.45	3.96	4.04	4.16	0.84	2.28	1.56	0.40	0.48
MnO	0.12	0.14	0.19	0.12	0.13	0.14	0.03	0.05	0.05	0.02	0.31
MgO	6.13	6.33	5.22	4.94	4.95	4.84	0.74	1.10	0.81	0.16	0.52
CaO	6.94	6.31	10.5	10.5	10.1	9.95	1.37	2.07	1.63	0.07	48.3
Na_2O	1.86	2.61	1.47	1.67	1.72	2.12	3.05	3.27	3.20	1.39	0.01
K_2O	3.80	3.01	1.94	2.03	1.96	2.24	4.09	4.14	4.36	4.92	0.09
P_2O_5	0.14	0.16	0.14	0.15	0.15	0.16	0.10	0.22	0.17	bdl	0.02
L.O.I.	8.52	7.76	8.04	7.72	7.49	5.32	1.04	0.65	0.77	1.94	38.1
Mg-V	67.2	65.6	61.5	62.5	61.8	60.0	38.9	44.9	41.3	38.2	53.3
V	173	178	191	200	192	169	33	-	-	6	12
Cr	349	352	416	420	400	326	37	32	23	<3	1
Co	24	27	21	22	20	26	3	6	5	<3	<3
Ni	27	33	28	28	27	30	13	-	-	10	<3
Cu	<3	5	9	<3	<3	8	<3	-	-	<3	8
Zn	75	97	74	71	73	78	40	-	-	19	23
Rb	191	161	89	88	87	101	215	262	287	410	4
Sr	450	460	468	492	490	531	158	201	165	7	243
Y	19	17	14	14	14	15	22	20	18	29	20
Zr	132	135	133	134	132	136	108	157	142	39	26
Nb	6	6	6	5	5	7	5	12	8	10	<3
Ba	630	515	395	441	417	421	337	242	258	145	11
La	24	29	25	29	29	28	24	35	33	<3	14
Ce	51	59	53	53	55	56	50	73	67	25	13
Nd	21	22	22	24	23	24	25	28	29	8	14
Pb	38	19	26	23	21	31	47	na	na	15	10
Th	12	13	12	13	13	13	34	21	21	36	5
$(^{87}Sr/^{86}Sr)_m$	-	0.709084	0.708123	-	-	-	0.713720	-	-	-	0.707669
2σ	-	0.000011	0.000008	-	-	-	0.000012	-	-	-	0.000009
$(^{87}Sr/^{86}Sr)_i$	-	0.709001	0.708078	-	-	-	0.713385	-	-	-	0.707665

Major and trace elements were determined by XRF, although some major elements were determined by AAS (MgO and Na_2O), titritation (Fe_2O_3) and loss of weight on ignition (L.O.I.). Accuracy and precision were evaluated using international reference samples as unknown. Precision was evaluated to be better than 5% for most of the trace elements analysed. Sr isotopes were carried out at the "Università degli Studi Federico II" at Naples, using standard chemical separation techniques and a VG 354 Micromass spectrometer. $^{87}Sr/^{86}Sr$ values were corrected for mass fractionation by normalisation to $^{86}Sr/^{88}Sr = 0.1194$. Replicate measurement of NBS 987 reference sample gave mean values of $^{87}Sr/^{86}Sr = 0.71027 \pm 0.00002$. Samples PO 40 and PO 42 are from Poli (1992). Eurite is a local name for a k-feldspar rich aplite related to the Porto Azzurro Monzogranite Intrusion. bdl = below detection limit; Mg-V = Mg-value, $100*[Mg/(Mg+0.75*Fe_{tot})]$. $(^{87}Sr/^{86}Sr)i$ values were recalculate considering the determined age for the dike samples and for the marlstone, and a 6.5 Ma for the Porto Azzurro Monzogranite sample.

Table 6 - $^{40}Ar/^{39}Ar$ analytical data of the sample ST 135/10 gdm

J=$6.595\cdot10^{-4}$ Weight=0.07153 g

Temp (°C)	^{40}Ar Tot	Error	^{39}Ar	Error	^{38}Ar	Error	^{37}Ar	Error	^{36}Ar	Error	Age (Ma)	Error
580	$8.64\cdot10^{-7}$	$1.92\cdot10^{-9}$	$1.31\cdot10^{-9}$	$6.23\cdot10^{-12}$	$5.25\cdot10^{-10}$	$4.54\cdot10^{-12}$	$1.66\cdot10^{-9}$	$1.21\cdot10^{-10}$	$2.83\cdot10^{-9}$	$2.00\cdot10^{-11}$	26.724	5.2
640	$1.99\cdot10^{-7}$	$1.56\cdot10^{-10}$	$2.79\cdot10^{-9}$	$7.26\cdot10^{-12}$	$1.73\cdot10^{-10}$	$3.00\cdot10^{-12}$	$5.54\cdot10^{-9}$	$1.00\cdot10^{-10}$	$6.16\cdot10^{-10}$	$5.64\cdot10^{-12}$	7.23	0.707
700	$4.31\cdot10^{-7}$	$4.84\cdot10^{-10}$	$4.10\cdot10^{-9}$	$2.30\cdot10^{-11}$	$3.26\cdot10^{-10}$	$5.29\cdot10^{-12}$	$1.02\cdot10^{-8}$	$3.72\cdot10^{-10}$	$1.34\cdot10^{-9}$	$1.32\cdot10^{-11}$	10.393	1.129
760	$6.22\cdot10^{-7}$	$1.13\cdot10^{-8}$	$1.50\cdot10^{-8}$	$3.85\cdot10^{-11}$	$6.15\cdot10^{-10}$	$5.00\cdot10^{-12}$	$1.90\cdot10^{-8}$	$2.34\cdot10^{-10}$	$1.78\cdot10^{-9}$	$1.30\cdot10^{-11}$	7.695	0.302
860	$4.73\cdot10^{-7}$	$5.14\cdot10^{-10}$	$2.57\cdot10^{-8}$	$4.90\cdot10^{-11}$	$7.74\cdot10^{-10}$	$4.41\cdot10^{-12}$	$2.37\cdot10^{-8}$	$5.32\cdot10^{-10}$	$1.10\cdot10^{-9}$	$8.42\cdot10^{-12}$	6.998	0.115
920	$1.88\cdot10^{-7}$	$1.24\cdot10^{-10}$	$1.52\cdot10^{-8}$	$2.89\cdot10^{-11}$	$3.68\cdot10^{-10}$	$2.82\cdot10^{-12}$	$1.27\cdot10^{-8}$	$3.10\cdot10^{-10}$	$3.58\cdot10^{-10}$	$3.36\cdot10^{-12}$	6.549	0.078
1020	$1.03\cdot10^{-7}$	$1.15\cdot10^{-10}$	$9.50\cdot10^{-9}$	$2.04\cdot10^{-11}$	$2.11\cdot10^{-10}$	$2.37\cdot10^{-12}$	$1.18\cdot10^{-8}$	$2.43\cdot10^{-10}$	$1.83\cdot10^{-10}$	$2.74\cdot10^{-12}$	6.297	0.101
1080	$6.08\cdot10^{-8}$	$4.40\cdot10^{-11}$	$6.23\cdot10^{-9}$	$1.38\cdot10^{-11}$	$1.35\cdot10^{-10}$	$1.74\cdot10^{-12}$	$1.30\cdot10^{-8}$	$2.67\cdot10^{-10}$	$1.00\cdot10^{-10}$	$1.72\cdot10^{-12}$	6.149	0.095
1150	$2.68\cdot10^{-8}$	$3.92\cdot10^{-11}$	$2.11\cdot10^{-9}$	$7.05\cdot10^{-12}$	$4.90\cdot10^{-11}$	$1.74\cdot10^{-12}$	$6.68\cdot10^{-9}$	$2.45\cdot10^{-10}$	$5.50\cdot10^{-11}$	$1.83\cdot10^{-12}$	6.247	0.295
1250	$3.84\cdot10^{-8}$	$3.22\cdot10^{-11}$	$1.78\cdot10^{-9}$	$6.89\cdot10^{-12}$	$4.82\cdot10^{-11}$	$1.21\cdot10^{-12}$	$4.49\cdot10^{-9}$	$1.40\cdot10^{-10}$	$9.65\cdot10^{-11}$	$1.28\cdot10^{-12}$	6.843	0.251
1400	$2.62\cdot10^{-8}$	$2.53\cdot10^{-11}$	$2.72\cdot10^{-10}$	$2.51\cdot10^{-12}$	$1.93\cdot10^{-11}$	$7.47\cdot10^{-13}$	$4.12\cdot10^{-10}$	$4.83\cdot10^{-11}$	$7.88\cdot10^{-11}$	$1.42\cdot10^{-12}$	12.904	1.833
										Integrated age =	*7.38*	

Analytical data, in ml/g unit. Isotope concentrations are corrected for instrumental background, isotopic fractionation and ^{37}Ar decay. All other uncertainties are considered in the age calculation and error. Displayed errors are within $\pm 1\sigma$ analytical error. Correction factors for nuclear interferences: $(^{36}Ar/^{37}Ar)Ca = 2.6\cdot10^{-4}$; $(^{39}Ar/^{37}Ar)Ca = 6.7\cdot10^{-4}$; $(^{40}Ar/^{39}Ar)K = 8.0\cdot10^{-3}$.

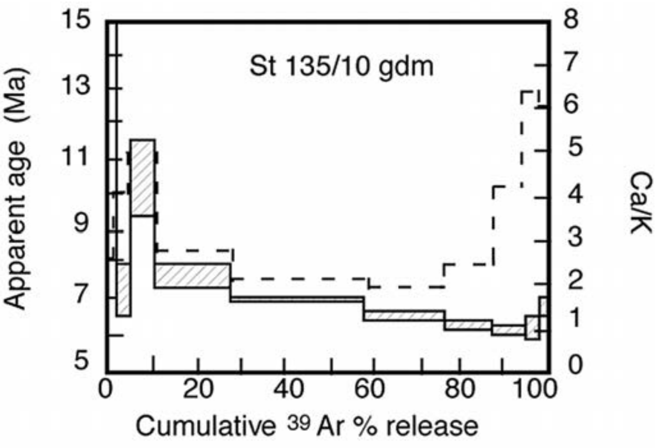

Fig. 10 - Age spectrum for the groundmass of the sample ST 135/10. Box width represents ±1 σ analytical error. The dashed line represents Ca/K variation, whose scale is on the right side of the graph.

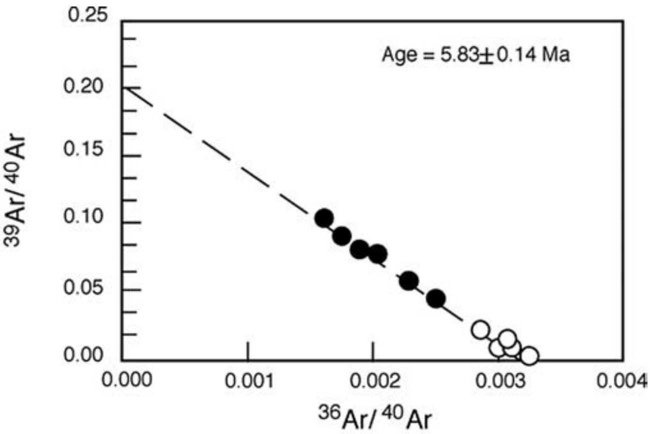

Fig. 11 - Isotope correlation diagram for the groundmass of the sample ST 135/10: solid circles represent points used to extrapolate the age, empty circles all the other points.

(Fig. 13). In particular, these rocks closely resemble, in terms of trace element distribution, the trachybasalts from Capraia Island, which were outpoured at 4 Ma few km NW in the Northern Tyrrhenian Sea (Barberi et al., 1986; Poli et al., 1995). These patterns, however, do not significantly differ from those typical of Mediterranean calc-alkaline rocks, and might be interpreted as the result of partial melting of an upper mantle source subsequently to a metasomatic event, which was related to fluid and/or melts releasing from a subducted slab, in the frame of the evolution of the Mediterranean Basin (Beccaluva et al., 1987; 1994).

The dike intruded at about 5.8 Ma the Rivercina Member and the Monte Alpe Cherts in the Monte Castello area, cutting an already crystallised large orthoclase-bearing granitic stock. Saupé et al. (1982) gave a wide range of Rb/Sr and K/Ar mineral and whole rock ages for the La Serra - Porto Azzurro monzogranite and to its dikes (4.9-5.9 Ma). It is worth to note, however, from a geochronological point of view that the majority of Saupé et al. (1982) data were obtained on whole intrusive rocks, and are almost all affected by high analytical uncertainties.

More recently, new $^{40}Ar/^{39}Ar$ dating of the La Serra - Porto Azzurro pluton gave an age of 6.0±0.1 (Maineri et al., in prep). Being the dating performed on biotite, this age refers to the isotopic closure of this mineral, occurring at be-

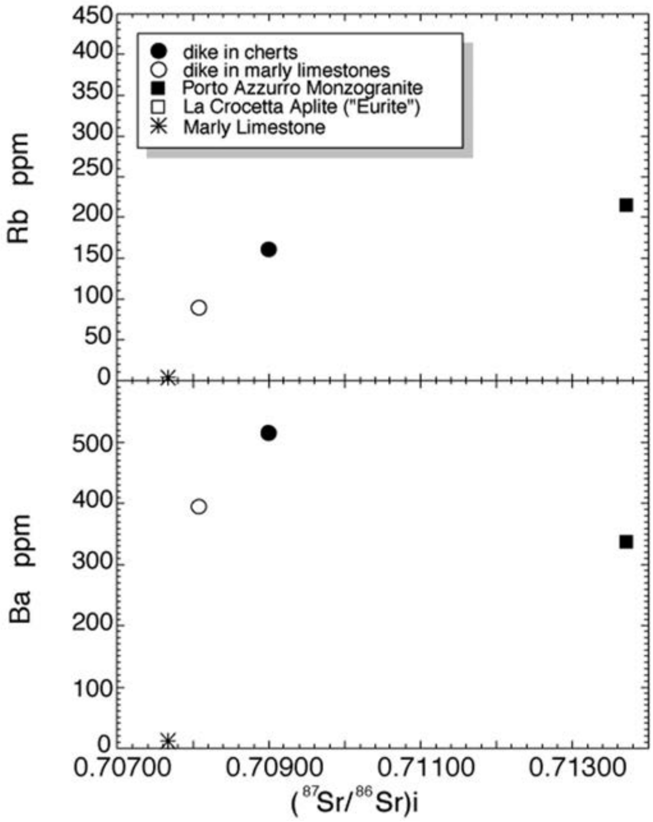

Fig. 12 - Sr-Isotope variations with Rb and Ba incompatible elements.

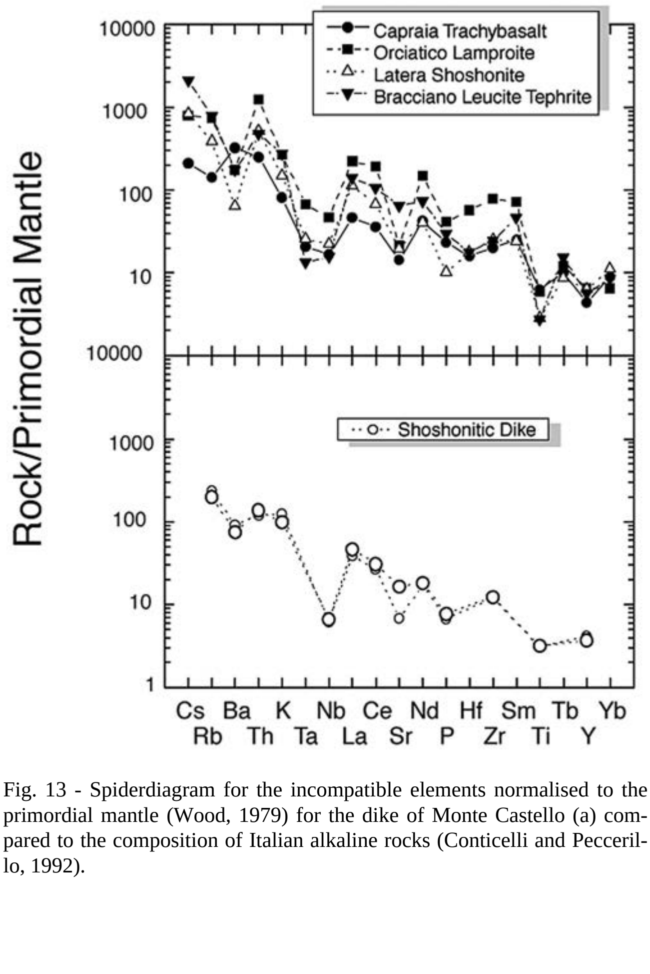

Fig. 13 - Spiderdiagram for the incompatible elements normalised to the primordial mantle (Wood, 1979) for the dike of Monte Castello (a) compared to the composition of Italian alkaline rocks (Conticelli and Peccerillo, 1992).

tween 300 and 450°C, when the pluton was already completely crystallised. Therefore, the parental magma of the shoshonitic dike was able to scavenge the large orthoclase crystals from La Serra Porto Azzurro monzogranite.

Other chronological informations are available for the hematite deposits of eastern Elba, younger than the La Serra - Porto Azzurro monzogranite, being linked to the N-S normal fault system cutting the monzogranite stock and the Zuccale Fault. A (U+Th)/He age of 5.39±0.46 Ma on specularite and a mean K/Ar age of 5.32±0.11 Ma on coexisting adularia are found (Lippolt et al., 1995). A $^{40}Ar/^{39}Ar$ age of 5.3 Ma was found on adularia from the same deposits (Laurenzi, unpublished datum).

The occurrence of the Monte Castello dike and its age of intrusion (compared with the ages of the La Serra - Porto Azzurro pluton and the ematite deposits), are very important for putting constraints on the ages of the block tectonics and gravitational movements in eastern Elba. The SW-NE trending Monte Castello and Acqua Cavalla faults (Fig. 3) in which the dike was intruded, are the older records of the extensional regime. In this area, in fact, three successive high-angle faulting can be recognised: the SW-NE normal fault system, which is cut by the NNW-SSE transfer system, probably linked to a gravitational movement of a portion of the Ophiolitic (VSU) and Flysch Units (Fig. 1). This faulting is in its turn cut by the last NS swarm of normal faults, which affects all the units and defines also the eastern coast of the Island. This swarm only, cuts the Zuccale Detachment Fault (Bortolotti et al., 2001).

Recently, Maineri et al. (in prep.), interpreted the 6.7 Ma old sericitisation of the aplitic and porphyritic dikes linked of the Monte Capanne pluton, and now sited in eastern Elba (La Crocetta quarry), as due to fluid circulation into a detachment fault (called CEF = Central Elba Fault), along which the Ligurian Units began their eastwards sliding. This detachment would be due to the pluton (6.8 Ma) uplifting and would be contemporaneous to its cooling.

On the ground of the previously reported radiometric ages and of the relationships between the various fault swarms, we could reconstruct this succession of events:

i. 7-6.7 Ma: intrusion of the Mt. Capanne Pluton, its uplift and the consequent first phase of gravitational movements of the cap rocks towards the continent. During, or perhaps immediately before (seen the Burdigalian age of the formation of the Corsica Channel, just west of Elba I), also the NW-SE trending fault system originated;
ii. between 6.7 and 6.0 Ma: second phase of gravitational movements towards the continent along the Zuccale Fault, and subsequent intrusion of the La Serra - Porto Azzurro Pluton;
iii. 5.8 Ma: intrusion of the Mt. Castello dike along the old fault system;
iv. between 5.8 and 5.3: last limited movements of the Zuccale Fault, probably northeastwards, and formation of the N.S trending high angle normal faults;
v. 5.3 Ma: emplacement of ore mineralisations along these faults

CONCLUSIONS

The mafic dike found in the Monte Castello area was intruded at about 5.8 Ma into the Nisportino Formation and Monte Alpe Cherts, penetrating also along two NE-SW faults, and cutting an already crystallised orthoclase-bearing monzogranitic stock as testified by the presence of abundant large orthoclases xenocrysts. Recent chronological data suggest that underlying La Serra - Porto Azzurro monzogranitic stock was already crystallised at the time of emplacement of the dike into the Ophiolitic Unit (5.9 Ma). The probably allochthonous position of these Unit might speak for a slightly westernmost position of the dyke with respect to the present day location.

Interaction between magma and wallrock caused some portion of the dike to have been diluted in incompatible trace elements and K and enriched in CaO and probably CO_2 and its Sr isotope values to be changed.

On the basis of present day composition and mineralogy it is possible to define the original nature of the parental magma feeding the dike. This magma was in equilibrium with an upper mantle source, but was also K and related elements enriched. On the basis of incompatible trace elements distribution the feeding magma was similar to the trachybasalt from Capraia, and can be classified as a Transitional magma between Lamproite-like magmas and potassic series magmas (KS).

Finally, the dating of this shoshonitic dike intruding the older system of high-angle normal faults, indicate that the first extensional phases precedes about 5.8 Ma, and may so be linked to the uplift of the Monte Capanne stock, or even be older of the magmatic events, seen the Burdigalian age of the formation of the Corsica Channel, just west of Elba I. Moreover, the 5.4 Ma age marks the end of the structural evolution of the Elba Island.

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REFERENCES

Abbate E. and Sagri, 1970. The eugeosynclinal sequences. Sedim. Geol., 4: 251-340.

Barberi F., Buonasorte G., Cioni R., Fiordelisi A., Foresi L., Iaccarino S., Laurenzi M.A., Sbrana A., Vernia L. and Villa,I.M., 1994. Plio-Pleistocene geological evolution of the geothermal area of Tuscany and Latium. Mem. Descr. Carta Geol. d’It., 49: 77-134.

Barberi F, Innocenti F. and Ricci C.A., 1971. Il magmatismo. In: “La Toscana Meridionale”, Rend. S.I.M.P., 27, Spec. Vol.: 169-210.

Beccaluva L., Coltorti M., Galassi B., Macciotta G. and Siena F., 1994. The Cainozoic Calc-alkaline magmatism of the Western Mediterranean and its geodynamic significance. Boll. Geofis. Teor. Appl., 36: 293-308.

Beccaluva L., Di Girolamo P. and Serri G., 1991. Petrogenesis and tectonic setting of the Roman Volcanic Province, Italy. Lithos, 26: 191-221.

Boccaletti M. and Papini P., 1989. Ricerche meso e microstrutturali sui corpi ignei neogenici della Toscana. 2: L’intrusione del M. Capanne (Isola d’Elba). Boll. Soc. Geol. It., 108: 699-710.

Boccaletti M., Papini P. and Villa I.M., 1987. Modello strutturale e cronologico del M. Capanne (Isola d'Elba). Rend. S.I.M.P., 42: 300-301.

Borsi S., 1967. Contributo alla conoscenza dell'età e dell'origine magmatica del vulcanismo dell'Isola di Capraia (Arcipelago Toscano). Atti Soc. Tosc. Sci. Nat., Mem., 71: 232-243.

Borsi S., Ferrara G. and Mazzuoli R., 1965. Studio petrologico e datazione con i metodi K/Ar e Rb/Sr di una roccia granitica presso Roccastrada (Grosseto). Atti Soc. Tosc. Sci. Nat., Mem., 72: 1-24.

Borsi S., Ferrara G. and Tongiorgi E., 1967. Determinazione con il metodo K/Ar delle età delle rocce magmatiche della Toscana. Boll. Soc. Geol. It., 86: 403-410.

Bortolotti V., Gardin S., Marcucci M. and Principi G., 1994. The Nisportino Formation: a transitional unit between the Mt. Alpe Cherts and the Calpionella Limestone (Vara Supergroup, Elba Island, Italy). Ofioliti, 19: 349-365.

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

Cebula G.T., Kunk M.J., Mehnert H.H., Naeser C.W., Obradovich J.D. and Sutter J.F., 1986. The Fish Canyon Tuff, a potential standard for the $^{40}Ar/^{39}Ar$ and fission track methods. Terra Cognita, 6: 139-140.

Cioni R., Laurenzi M.A., Sbrana A. and Villa I.M., 1993. $^{40}Ar/^{39}Ar$ chronostratigraphy of the initial activity of the Sabatini volcanic complex (Italy). Boll. Soc. Geol. It., 112: 251-263.

Civetta L., Orsi G., Scandone P., and Pece R., 1978. Eastward migrations of the Tuscan anatectic magmatism due to anticlockwise rotation of the Apennine. Nature, 276: 604-605.

Coli M., Conticelli S., Moratti G., Pandeli E., Papini P. and Tommasini, S., 2001. Pre-meeting transect Corsica-Elba Island-Southern Tuscany Guidebook: 2 - Elba. C. Western Elba. Ofioliti 26 (2a), this volume

Conticelli S., 1989. Genesi del magmatismo alcalino-potassico dell'Italia Centrale: evidenze petrologiche, geochimiche e petrologico-sperimentali. Doctoral Thesis, Dipartimento di Scienze della Terra, Università degli Studi di Firenze, Firenze, 404 pp.

Conticelli S., 1994. Relationships among lamproitic, kamafugitic and Roman Type magmas: mineralogical, petrological and experimental data. In: Proceed. Intern. Mineral. Ass., 16th General Meeting, p. 82.

Conticelli S., 1998a. Genesi ed evoluzione dei magmi alcalino-potassici dell'Italia Centrale. In: Metodologie e modellizzazione nella moderna petrologia magmatica, 2ª Scuola di Petrografia, Asiago, 15-19 Giugno 1998, Vol. bis, p. 1-20.

Conticelli S., 1998b. Effects of crustal contamination on ultrapotassic magmas with lamproitic affinity: mineralogical, geochemical and isotope data from the Torre Alfina lavas and xenoliths, Central Italy. Chem. Geol., 149: 51-81.

Conticelli S., Francalanci L., Manett P., Cioni, R. and Sbrana A., 1997. Petrology and geochemistry of the ultrapotassic rocks from the Sabatini Volcanic District, Central Italy: the role of evolutionary processes in the genesis of variably enriched alkaline magmas. J. Volcanol. Geoth. Res., 75: 107-136.

Conticelli S., Francalanci L. and Santo A.P., 1991. Petrology of final stage Latera lavas, Vulsini Mts.: mineralogical, geochemical and Sr-isotopic data and their bearing on the genesis of some potassic magmas in Central Italy. J.Volcan. Geoth. Res., 46: 187-212.

Conticelli S., Manetti P., Menichetti S. 1992. Petrology, chemistry, mineralogy and Sr-isotopic features of Pliocenic orendites from South Tuscany: implications on their genesis and evolutions. Europ. J. Mineral., 4: 1359-1375.

Conticelli S. and Peccerillo A., 1992. Petrology and geochemistry of potassic and ultrapotassic volcanism in Central Italy: petrogenesis and inferences on the evolution of the mantle sources. Lithos, 28: 221-240.

Conticelli S. and Poli G., 2001. Source heterogeneity versus crustal assimilation in the genesis of mafic high silica alkaline magmas: petrologic and isotope data from the Monte Cimino volcano, Central Italy. J.Petrol., submitted.

Dini A. and Laurenzi M.A., 1999. $^{40}Ar/^{39}Ar$ chronology of shallow-level granitic intrusions, Elba Island, Italy. Plinius, 22: 157-158.

Dini A. and Tonarini S., 1997. Evoluzione tettono-magmatica dell'Isola d'Elba centro-occidentale: nuovi dati geologici e geocronologici sulle rocce porfiriche. PH52, CROP Project, Trieste, June 1997.

Eberhardt P. and Ferrara G., 1962. Confirmation of the absolute age of the granodiorite outcrop in Elba Island with potassium-argon measurements. Nature, 196: 665-666.

Evernden J.F. and Curtiss G.H., 1965. The potassium-argon dating of late Cenozoic rocks in East Africa and Italy. Current Antropology, 6: 343-385.

Ferrara G. and Tonarini S., 1985. Radiometric geochronology in Tuscany: results and problems. Rend. S.I.M.P., 40: 111-124.

Ferrara G. and Tonarini S., 1993. L'Isola d'Elba: un laboratorio di geocronologia. Mem. Soc. Geol. It. 49: 227-232.

Fornaseri M., 1985. Geochronology of volcanic rocks from Latium (Italy). Rend. S.I.M.P., 40: 73-106.

Innocenti F., Serri G., Ferrara P., Manetti P. and Tonarini, S., 1992. Genesis and classification of the rocks of the Tuscan Magmatic Province: thirty years after Marinelli's model. In: Marinelli Volume, Acta Vulcanol., 2: 247-265.

Izett G.A., Dalrymple G.B. and Snee L.W., 1991. $^{40}Ar/^{39}Ar$ age of Cretaceous-Tertiary boundary tektites from Haiti. Science, 252: 1539-1542.

Juteau M., 1984. Les isotopes radiogéniques et l'évolution de la croûte continentale. C.N.R.S., Centre .Rech. Pétrogr. Géochim., Inst. Nat. Polytechnique Lorraine, p. 1-107.

Juteau M., Michard A, Zimmermenn J.-L. and Albarede F., 1984. Isotopic heterogeneities in the granite intrusion of Monte Capanne (Elba Island, Italy) and dating concepts. J.Petrol., 25: 532-545.

Lanphere M.A., Sawyer D.A., Fleck R.J., 1990. High resolution $^{40}Ar/^{39}Ar$ geochronology of Tertiary volcanic rocks, Western U.S.A. Geol. Soc. Australia Abstr., p. 27:57.

Le Bas M.J., 1989. Nephelinitic and basanitic rocks. J. Petrol., 30: 1299-1312.

Le Bas M.J., Streckeisen A. and Zanettin B., 1986. A chemical classification of volcanic rocks based on the total alkali-silica diagram. J.Petrol., 27: 745-750.

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

Maineri C., Benvenuti M., Costagliola P., Dini A., Lattanzi P.F., 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. In press.

Marinelli G., 1959. Le intrusioni terziarie dell'Isola d'Elba. Atti Soc. Tosc. Sci. Nat. Mem., Serie A, 68: 74-116.

Marinelli G., 1961. Genesi e classificazione delle vulcaniti recenti toscane. Atti Soc. Tosc. Sci. Nat., Mem., Serie A, 68: 74-116.

Morimoto N., 1989. Nomenclature of pyroxenes. Canad. Mineral., 27: 143-156.

Peccerillo A., 1985. Roman Comagmatic Province (Central Italy): Evidence for subduction related magma genesis. Geology, 13: 103-106.

Peccerillo 1993. Potassic and ultrapotassic rocks. Compositional characteristics, petrogenesis, and geologic significance. Episodes, 15: 243-251

Peccerillo A., Conticelli S. and Manetti P., 1987. Petrological characteristics and the genesis of the recent magmatism of Southern Tuscany and Northern Latium. Period Mineral., 56: 157-172.

Perini, G. and Conticelli. S., 2001. Crystallization conditions of Leucite-bearing rocks and their implications on the magmatological evolution of ultrapotassic magmas: The Vico Volcano, Central Italy. Mineral. Petrol., in the press.

Pinarelli L., Poli G. and Santo A.P., 1989. Geochemical characterization of recent volcanism from Tuscan Magmatic Province (Central Italy): Roccastrada. Period. Mineral., 58: 67-96.

Poli G., 1992. Geochemistry of Tuscan Archypelago granitoids, Central Italy: the role of hybridization and accessory phases crystallization in their genesis. J. Geol., 100: 41-56.

Poli G., Ghezzo C. and Conticelli S., 1989a. Geochemistry of granitic rocks from the Hercynian Sardinia Corsica Batholith: Implication for magma genesis. Lithos, 23: 247-266.

Poli G., Manetti P. and Tommasini S., 1989b. A petrological review on Miocene-Pliocene intrusive rocks from southern Tuscany and Tyrrhenian Sea (Italy). Period. Mineral., 58: 109-126.

Poli G., Prosperini N., Conticelli S. and Ogna M., 1995. Petrology and geochemistry of Capraia Island (Tuscan Archipelago - Italy): complex origin of a calc-alkaline volcano. Plinius, 14: 258-259.

Poli G., and Tommasini S., 1991. Model for the origin and significance of microgranular enclaves in calc-alkaline granitoids. J. Petrol. 32: 657-666.

Principi G. and Treves B., 1984. Il sistema Corso-Appenninico come prisma di accrezione. Riflessi sul problema generale del limite Alpi-Appennini. Mem. Soc. Geol. It., 28: 549-576.

Saupé F., Marignac C., Moine B., Sonet J. and Zimmermann, J.-L., 1982. Datation par les méthodes K/Ar et Rb/Sr de quelques roches de la partie orientale de l'Ile d'Elbe (province de Livourne, Italie). Bull. Minéral., 105: 236-245.

Turbeville B.N., 1992. $^{40}Ar/^{39}Ar$ ages and stratigraphy of the Latera Caldera, Italy. Bull. Volcanol., 55: 110-118.

Vaggelli G., Olmi F. and Conticelli S., 1999. Evaluation of analytical errors during microprobe analyses of silicate minerals international reference samples. Acta Volcanol., 11, in press.

Villa I.M., Gianelli G., Puxeddu M., Bertini G. and Pandeli E., 1987. Granitic dike of 3.8 Ma age from a 3.5 km deep geothermal well at Larderello (Italy). In: Granites and their surrounding, Abst. Vol., Verbania, p. 163-164.

Wagner C. and Velde D., 1986. The mineralogy of K-richterite-bearing lamproites. Am. Mineral., 71: 17-37.

Wood D.A., 1979. A variably veined sub-oceanic upper mantle - genetic significance for mid ocean ridge basalts from geochemical evidence. Geology, 7: 499-503.

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