Geological Field Trips

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The Elba Island: an intriguing geological puzzle in the Northern Tyrrhenian Sea

85° Congresso Nazionale della Società Geologica Italiana, Pisa 6-8 settembre 2010

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The Elba Island: an intriguig geological puzzle in the Northern Tyrrhenian Sea

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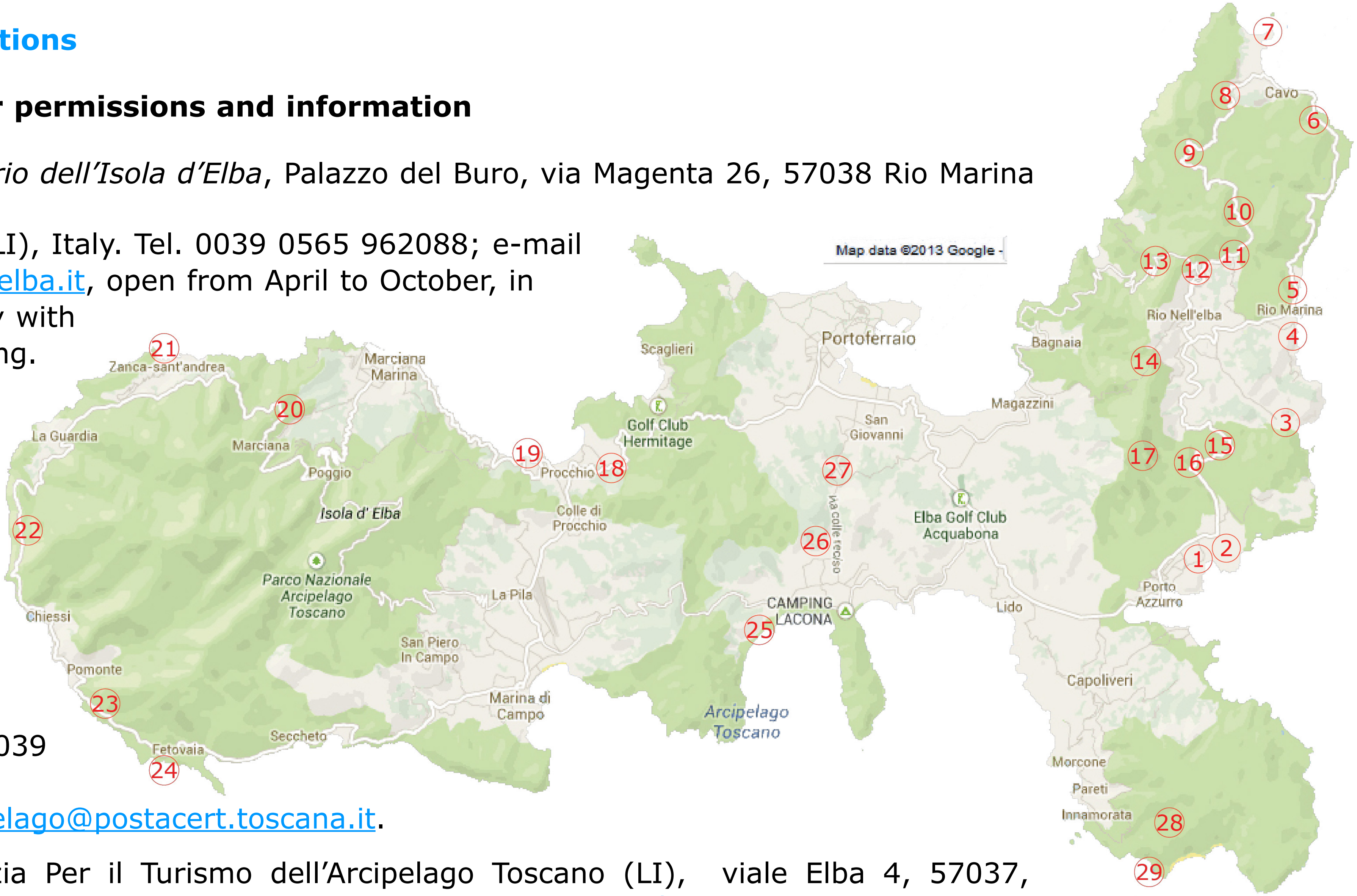
Addresses for permissions and information

- *Parco Minerario dell'Isola d'Elba*, Palazzo del Buro, via Magenta 26, 57038 Rio Marina

- *Elba Island* (LI), Italy. Tel. 0039 0565 962088; e-mail info@parcominelba.it, open from April to October, in the Winter only with previous booking.

- *Parco Nazionale Arcipelago Toscano*, Enfola (Portoferraio) Elba Island (LI), Italy Tel. 0039 0565 919411; Fax 0039 0565 919428; e-mail pnarcipelago@postacert.toscana.it.



- APT - Agenzia Per il Turismo dell'Arcipelago Toscano (LI), viale Elba 4, 57037, Portoferraio, Elba Island (LI), Italy. Tel 0039 0565; e-mail info@isoleditoscana.it. Or: Via Carducci, 150 - 57037 – Portoferraio – (LI), Tel. +39 0565 914671 - Fax +39 0565 914672 (Touristic Information) ; Tel. +39 0565 930727 - Fax +39 0565 916350 (Administrative Bureau); Secretary's Office: segreteria@aptelba.it; Touristic Information: info@aptelba.it. Or: Calata Italia, 43 - 57037 - Portoferraio Elba Island (LI), Italy; Tel. 0039 0565 914671, Fax 0039 0565 914672, Internet Address: www.aptelba.it.

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Periods

These excursions can be made in all seasons. For the climate and daylight hours the best season would be the summer but it is not recommended due to the excessive influx of tourists. In spring and autumn the tourist pressure is much lower, the climate is still good but more rainy. Winter is usually less rainy and sufficiently mild but the daylight is definitely shorter.

Equipment

For these excursions a big rig is not necessary, good soled shoes and grippy clothing appropriate to the season are sufficient. To collect samples it would be advisable gloves and goggles. Below escarpments the helmet would be appropriate. In the mine galleries (e.g. il Ginevro, Capoliveri) are absolutely necessary both sturdy shoes (preferably boots) and helmet.

Riassunto

L'Isola d'Elba è ubicata nel Mar Tirreno Settentrionale a metà strada fra la Toscana (Appennino Settentrionale) e Corsica (Corsica Alpina). Il complesso edificio tettonico dell'Isola d'Elba, che è considerato l'affioramento più occidentale della catena nord-appenninica, è anche noto per i suoi giacimenti minerari a ferro e per gli evidenti rapporti tra la messa in posto di corpi magmatici mio-pliocenici e le ultime fasi tettoniche tangenziali.
Il rilevamento alla scala 1:10.000 e 1:5.000 nell' ambito del Progetto di Cartografia Nazionale CARG – Foglio Isola d'Elba (già parzialmente pubblicato da Babbini et al., 2001 e da Bortolotti et al., 2001a) ha portato alla ricostruzione di un panorama stratigrafico e strutturale dell'Isola d'Elba centro-orientale più articolato rispetto al classico schema dei cinque "Complessi" di Trevisan (1950) e Barberi et al. (1969). Sono stati infatti distinte nove unità tettoniche appartenenti ai domini paleogeografici Toscano, Ligure e Piemontese. Prima della loro definitiva messa in posto, alcune di queste unità sono state intruse da plutoni granitoidi (monzogranito del M. Capanne e di La Serra-Porto Azzurro) e da filoni di varia tipologia (aplitici, shoshonitici, calcalcalini e lamprofirici) tra 8-2 Ma e 5.4 Ma.

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1- **Unità Porto Azzurro** (PU). E’ costituita da filladi, quarziti, micascisti e anfiboliti (formazione di M. Calamita), probabilmente di età paleozoica, che presentano una intensa ricristallizzazione a causa del metamorfismo termico indotto dall’intrusione di La Serra-Porto Azzurro e dal relativo corteo filoniano aplitico (6.0-5.9 Ma). Localmente sono stati riconosciute anche metasedimenti silicoclastici quarzosi (Verrucano s.l.) e dolomie e calcari dolomitici cristallini, verosimilmente attribuibili alla originaria copertura carbonatica mesozoica di tipo toscano della formazione del M. Calamita. I filoni aplitici si interrompono sul contatto con le soprastanti unità tettoniche.

2- **Unità Ortano** (UO). Questa unità include formazioni metavulcaniche (porfiroidi) e metasedimentarie quarzitico-filladiche (es. gli scisti di Capo d’Arco) correlabili con formazioni di età ordoviciana della Sardegna centrale e della Toscana (Alpi Apuane). Alcuni filoni aplitici sono stati osservati anche in questa unità lungo la costa tra Capo D’Arco e Ortano.

3- **Unità Acquadolce** (AU). E’ costituita da marmi passanti in alto a calcescisti e quindi a filladi, metasiltiti e metaarenarie con livelli di metacalcari e calcescisti con fossili del Cretacico inferiore. Al tetto è presente una lama tettonica di serpentiniti. Questa unità è stata attribuita al Dominio Piemontese e correlata con i calcescisti con ofioliti dell’Isola di Gorgona. Nell’area del residence di Capo d’Arco sono presenti alcune intrusioni filoniane lamprofiriche (dicchi di Casa Carpini). E’ tipica la locale trasformazione dei litotipi carbonatici in corpi di skarn a silicati e minerali metallici (es. skarn di Torre di Rio).

4- **Unità Monticiano-Roccastrada** (MU). E’ in gran parte costituita dai metasedimenti silicoclastici carbonifero-triassici (formazione di Rio Marina del Permo-Carbonifero e gruppo del Verrucano triassico). Ad essa appartengono anche le successioni giurassico-oligoceniche epimetamorfiche (da calcescisti e calcari diasprini allo Pseudomacigno) affioranti lungo la costa nell’area di Cavo (Capo Castello, Capo Pero) e presso l’area mineraria di Valle del Giove.

5- **Falda toscana** (FT). A Sud della Parata è rappresentata solo da brecce calcareo-dolomitiche spesso a «cellette» (calcare cavernoso Auctt.), mentre verso Cavo, a queste segue parte della tipica Successione toscana comprendente carbonati di mare sottile del Triassico superiore-Hettangiano e sedimenti calcareo-siliceo-marnosi pelagici del Sinemuriano-Dogger.

6- **Unità Gràssera** (GU). E’ composta da argilloscisti varicolori con scarse intercalazioni calcareo-silicee e radiolaritiche (formazione di Cavo). Tra Cavo e la Parata, alla base di questa unità è presente un orizzonte decametrico di calcescisti (membro dei calcescisti). L’unità Gràssera, forse di età cretacica, è stata attribuita al Dominio Piemontese per le sue litologie poco confrontabili con quelle della Falda Toscana e per la sua tipica impronta metamorfica anchizonale.

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7- **Unità Ofiolitica** (OU). Questa unità di provenienza ligure, è stata suddivisa in 7 subunità, (Acquaviva - ASU, Mt. Serra - SSU, Capo Vita - CSU, Sassi Turchini - TSU, Volterraio- VSU, Magazzini - MSU and Bagnaia - BSU) caratterizzate da successioni di età giurassico-cretacica inferiore sensibilmente diverse, ma che comunque includono ultramafiti serpentinizzate, oficalciti, Mg-gabbri ed una copertura vulcano-sedimentaria (basalti, diaspri M. Alpe, formazione di Nisportino, calcari a Calpionella e Argille a Palombini). Un filone shoshonitico (filone di M. Castello: 5,8 Ma) riempie faglie normali nella subunità Volterraio presso Porto Azzurro. Alcuni filoni a composizione calc-alcalina (filoni di M. Capo Stella) attraversano i basalti liguri dalla parte occidentale del Golfo Stella.

8- **Unità del flysch paleogenico** (EU). E’ costituita da argilliti con scarse intercalazioni calcareo-marnose, calcarenitiche, arenacee e localmente anche di brecce carbonatico-ofiolitiche (formazione di Colle Reciso). Il contenuto fossilifero dei litotipi carbonatici indica un’età medio eocenica. Questa unità rappresenterebbe una successione oceanica sintettonica (epiligure) sul tipo della formazione di Lanciaia della Toscana meridionale. Filoni aplitici (apliti di Capo Bianco: 8-8.5 Ma) talora sericitizzati (“Eurite” Auctt.), e porfidi (porfido di Portoferraio e porfido di di S. Martino: rispettivamente circa 8 e 7.4-7.2 Ma) intrudono i suddetti litotipi, ma verso il basso non proseguono nell’unità ofiolitica.

9- **Unità del flysch cretacico** (CU). Questa unità ligure presenta alla base scarsi lembi di una successione analoga a quella dell’unità ofiolitica (ofioliti, vulcaniti e copertura sedimentaria) che passano a argilliti varicolori di età cretacica, ed infine ad una potente sequenza torbiditica da arenaceo-conglomeratica (arenarie di Ghiaieto) a calcareo-marnoso-arenacea (formazione di Marina di Campo) di età Cretacico superiore. Anche questa unità, come la precedente, presenta frequenti ed estese intrusioni di filoni e laccoliti, spesso porfirici, a composizione acida.

Il presente assetto strutturale dell’edificio elbano è caratterizzato, specialmente nella parte orientale e centrale dell’isola, dalla presenza di numerose superfici tettoniche a basso angolo (thrusts e detachments), che delimitano le varie unità, con un generale trasporto tettonico verso Est. Alcuni di questi limiti sono chiaramente dei thrust (unità Gràssera su Falda Toscana; u. del flysch cretacico su u. del flysch paleogenico), altri (Falda Toscana su u. Monticiano-Roccastrada; u. del flysch cretacico su u. ofiolitica; u. Ortano su u. Porto Azzurro; u. ofiolitica -subunità Cavo- su u. Gràssera; u. Ofiolitica -sub. Volterraio- su u. del flysch paleogenico; u. ofiolitica -sub. Bagnaia- su u. ofiolitica -sub. M. Serra, Sassi Turchini e Volterraio-, e infine le unità 2-9 sulla u. Porto Azzurro, tramite la faglia dello Zuccale sottolineata da un orizzonte cataclastico decametrico) sono faglie normali a basso angolo prodotte dalla tettonica estensionale (attiva probabilmente in questo settore fin dal Burdigaliano-Langhiano), in tempi precedenti o penecontemporanei ai fenomeni magmatici messiniano-pliocenici; altri ancora (u. Acquadolce su u. Ortano; u. Monticiano-Roccastrada su u. Acquadolce; u. Ofiolitica su u. Gràssera) sono di complessa interpretazione, avendo agito in tempi diversi sotto regimi tettonici diversi. Anche numerose faglie normali ad alto angolo caratterizzano la fase distensiva. Un primo sciame, con andamento NE-SO (postdatato da un filone shoshonitico di 5.8 Ma) interessa la subunità Volterraio (unità ofiolitica) nella zona tra Magazzini e Porto Azzurro. Questo sciame viene tagliato da un sistema di faglie di trasferimento NO-SE che la delaminazione della faglia dello Zuccale sembra interrompere. Un ultimo evento deformativo, che ha interessato l'intero edificio strutturale, è rappresentato da faglie prevalentemente NS, che tagliano la superficie suborizzontale della faglia dello Zuccale e che localmente ospitano i noti giacimenti ad ematite.

I rapporti tra le diverse unità tettoniche e le loro relazioni con gli eventi magmatici messiniano-pliocenici hanno permesso di ricostruire la seguente evoluzione dell'edificio strutturale elbano:

Eventi pre-magmatici (>8.5 Ma). La lunga storia geologica dell'Isola d'Elba inizia nel Paleozoico, quando le successioni pre-carbonifere associate alle unità toscane inferiori furono oggetto delle deformazioni tettono-metamofiche varisiche, cui sono riconducibili i relitti di scistosità pre-alpina (evento sudetico dell'Orogenesi Varisica) presenti nelle rocce metamorfiche delle unità Porto Azzurro e Ortano, alle quali seguirono eventi sedimentari permo-carboniferi legati a bacini estensionali tardo-ercinici. Successivamente nel Trias medio-superiore ebbe inizio il ciclo sedimentario alpino (Successione toscana). A fine Triassico-inizio Giurassico iniziò la fase di rifting che portò all'apertura della Tetide giurassica. L'evoluzione tettonica iniziata nel Cretacico superiore-Terziario inferiore con la consunzione della Tetide (Bacino Ligure-Piemontese), portò alla fine della sedimentazione "oceanica" nell'Eocene superiore e alla successiva collisione tra il blocco sardo-corso e l'Adria. Da questo momento fino al Miocene inferiore si ha la deformazione polifasica dei margini europeo (Corsica) e adriatico (Dominio Toscano). In particolare le fasi magmatiche sono precedute da: i- la massima parte dei fenomeni plicativi e dei thrust riconosciuti nelle unità ofiolitica, del flysch paleogenico e del flysch cretacico, assieme alla genesi di brecce ofiolitiche nell'unità del flysch paleogenico (eventi deformativi intraoceanici dell'Eocene); ii- la strutturazione tettono-metamorfica principale delle unità toscane (Porto Azzurro, Monticiano-Roccastrada e Falda Toscana) e Piemontesi (Acquadolce e Gràssera; S_1 e S_2 nell'Acquadolce datate 19 Ma), nonché, iii- l'impilamento delle unità liguri e piemontesi su quelle toscane (eventi collisionali e di serraggio dell'Eocene sup./Oligocene-Miocene inferiore); iv- i fenomeni di ripiegamento delle suddette unità tettoniche e, infine, v- l'intercalazione dell'unità Acquadolce tra le unità Ortano e Monticiano-Roccastrada. Le fasi magmatiche sono precedute anche dai primi eventi estensionali con faglie a basso angolo, come la sovrapposizione della Falda Toscana sull'unità Monticiano-Roccastrada (Miocene inferiore-medio).

Eventi sin-magmatici (8.5-5.4 Ma). In questo periodo si ha lo sviluppo e la risalita di magmi anatettici connessi alla risalita dell'astenosfera e all'assottigliamento crostale. Durante la risalita del plutone del M. Capanne (6.8 Ma) parte della sua copertura, costituita dalle unità dei flysch, già intrusi da apliti e porfiriti, si scolla e scorre verso oriente utilizzando una superficie a basso angolo (faglia dell'Elba centrale - CEF). Durante questo movimento avvengono i processi di euritizzazione delle apliti (6.7 Ma). Poco più ad est, a 5.8 Ma, si intrude un filone basico nell'unità ofiolitica e probabilmente anche quelli lamprofirici nell'unità Acquadolce. Il prosieguo della risalita del M. Capanne permise poi un ulteriore avanscorrimento verso est delle unità dei flysch sull'unità ofiolitica e di tutte le unità già impilate sulla unità Porto Azzurro, e lo sviluppo delle faglie di trasferimento NW-SE, probabilmente legate a rampe laterali delle unità in movimento. A 6.0-5.4 Ma la messa in posto del monzogranito di La Serra-Porto Azzurro e del suo complesso filoniano produsse l'estesa aureola termometamorfica attraverso le unità Porto Azzurro, Ortano, Acquadolce, Monticiano-Roccastrada e, localmente, anche gli skarn.

Eventi post-magmatici (< 5.4 Ma). La risalita del plutone La Serra-Porto Azzurro dette luogo alla separazione e all'allontanamento dell'embrice tettonico dell'Elba orientale dalle corrispondenti unità dell'Elba centrale, sfruttando una già esistente superficie tettonica a basso angolo (faglia dello Zuccale) al tetto dell'unità Porto Azzurro. In questa fase, sempre legato al sollevamento del plutone di La Serra-Porto Azzurro, si ebbe anche il retroscorrimento dell'unità ofiolitica sull'unità del flysch paleogenico nell'area di Colle Reciso. La pila tettonica dell'Elba centro-orientale ha così raggiunto il suo completamento. Come ultimo evento tettonico si sviluppò un sistema di faglie normali ad alto angolo con orientazione N-S che hanno prodotto la frammentazione a horst e graben dell'edificio orogenico, permettendo così ai fluidi mineralizzanti di costituire i corpi minerari ad ematite (5.3 Ma).

Questa ricostruzione degli eventi relativa all'Isola d'Elba è stata poi inquadrata nel contesto dell'evoluzione del sistema Corsica-Appennino Settentrionale, e illustrata da una serie di schemi tettonici relativi all'intervallo Cretacico superiore - Attuale.

Parole chiave: *Appennino settentrionale, Arcipelago Toscano, Isola d'Elba, stratigrafia, assetto strutturale, magmatismo, metamorfismo, giacimenti a ferro, geodinamica.*

Abstract

The Elba Island is located in the Northern Tyrrhenian Sea at midway between Tuscany (Northern Apennines Chain) and Corsica (Alpine Corsica structural pile). The complex Elba I. stack of nappes, which is considered the innermost outcrop of the Northern Apennines Chain, is also well known for its Fe-ore bodies and the relationships between the emplacement of the Mio-Pliocene magmatic bodies and tectonics.
The CARG geological survey of Elba I. performed at a scale of 1:10.000 and 1:5.000 , partially published by Babbini et al. (2001) and Bortolotti et al. (2001a) allowed a revision of the stratigraphic and structural setting of the central and eastern Elba I. This new scheme results more complex compared to Trevisan's classical one, which was based only on five tectonic "Complexes" (Trevisan, 1950; Barberi et al., 1969). Nine tectonic units were defined, and they all pertain to the Tuscan and Ligurian (including the Ligurian-Piedmontese units) paleogeographic domains. Before their final emplacement the Elba's tectonic pile, some of these units were intruded by two acidic plutons (Mt. Capanne and La Serra-Porto Azzurro monzogranites), and by dikes of variable composition during the 8.5 to 5.4 Ma time interval.

A total of nine units were recognised, from bottom to top:
1- **Porto Azzurro Unit** (**PU**). It is made up of phyllites, quartzites, micaschists and amphibolites (Mt. Calamita fm.), probably of Paleozoic age. It shows a strong static recrystallisation due to the La Serra-Porto Azzurro intrusion and the related aplitic dike network (6.0-5.4 Ma). On top of the Mt. Calamita fm., quartzitic metasiliciclastics (Verrucano s.l.) and crystalline dolostones and dolomitic marbles were recognised and were attributed to its Mesozoic cover. The aplitic dikes are cut along the tectonic contact (Zuccale fault) with the overlying units described below.
2- **Ortano Unit** (**UO**). It includes metavolcanites (porphyroids) and quartzitic-phyllitic metasediments (e.g. Capo d'Arco schists) which can be correlated to the Ordovician formations of Central Sardinia and Tuscany (Apuan Alps). A few aplitic dikes were also recognised, and they occur along the coast between Capo d'Arco and Ortano.
3- **Acquadolce Unit** (**AU**). It is composed of marbles, grading upwards into calcschists and, finally, into phyllites, metasiltstones and metasandstones with intercalations of calcschists which contain fossils of Early

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Cretaceous age. This Unit has been attributed to the Ligurian Domain (Ligurian-Piedmontese units) and can be correlated with the "calcschists with ophiolites" of the Gorgona Island. Near Capo d'Arco residence, some lamprophyric dikes (Casa Carpini dikes) also occur. Locally, the carbonate lithotypes are transformed into Fe-skarn bodies.

4- **Monticiano-Roccastrada Unit** (**MU**). This Tuscan Unit largely consists of Upper Carboniferous-Triassic metasiliciclastic rocks (the Permian-Carboniferous Rio Marina fm. and the triassic "Verrucano" group). It also includes a Jurassic to Oligocene epimetamorphic succession (from the calcschists and cherty limestones of the Capo Castello calcschists, to the Pseudomacigno) which crops out along the coast between Capo Pero and Capo Castello, and in the Valle Giove mining area.

5- **Tuscan Nappe** (**TN**). South of the locality La Parata, this unit is composed only of calcareous-dolomitic, at times vacuolar, breccias ("Calcare Cavernoso"), while northwards these rocks are overlain by Upper Triassic to Hettangian shallow marine carbonates, and Sinemurian to Dogger carbonatic, siliceous and marly pelagic sediments.

6- **Gràssera Unit** (**GU**). It mostly consists of varicoloured slates with rare carbonate-siliceous and radiolarian cherts intercalations (Cavo fm.). Between Cavo and La Parata, a basal decametric calcschist member also occurs. This anchimetamorphic unit, possibly of Cretaceous age, could have been originated in the Ligurian Domain: because of its peculiar lithologic association and metamorphic overprint it is considered a Ligurian-Piedmontese Unit.

7- **Ophiolitic Unit** (**OU**). This Ligurian Unit is composed of seven tectonic subunits (Acquaviva "**ASU**", Mt. Serra "**SSU**", Capo Vita "**CSU**", Sassi Turchini "**TSU**", Volterraio "**VSU**", Magazzini "**MSU**" and Bagnaia "**BSU**"), which are characterised by serpentinites, ophicalcites, Mg-gabbros, and by their Jurassic to Lower Cretaceous volcanic-sedimentary cover (Basalts, Mt. Alpe cherts, Nisportino fm., Calpionella limestones and Palombini shales). A shoshonitic dike (Mt. Castello Dike: 5.8 Ma) fills two ENE-WSW-trending normal faults cutting **VSU** in the Porto Azzurro area. Some calc-alkaline dikes (Mt. Capo Stella dikes) were also identified in the Ligurian basalts along the western coast of Golfo Stella.

8- **Paleogene flysch unit** (**EU**). It is constituted by shales with calcareous-marly, calcarenitic and arenaceous intercalations and, locally, by ophiolitic-carbonate breccias (Colle Reciso fm.). The fossiliferous content of the carbonate lithotypes points to a Middle Eocene age. This unit can be interpreted as a syn-tectonic oceanic unit (Epiligurian Unit), which has the same paleogeographic origin of the Lanciaia fm. in Southern Tuscany. aplites

(Capo Bianco aplites: 8-8.5Ma), locally sericitised (the so-called "Eurite"), and porphyries (Portoferraio porphyries and San Martino porphyries: about 8 Ma and 7.4-7.2 Ma, respectivelly) intrude the sedimentary succession, but do not crosscut the basal contact with the underlying Ophiolitic Unit.
9- **Cretaceous flysch unit** (**CU**). It is a Ligurian, Helminthoid-type, oceanic succession. It consists of a basal tectonised complex, similar to **OU** (ophiolites, basalts and Jurassic-Cretaceous sedimentary cover slices), and of a sedimentary succession formed by Cretaceous Palombini shales and Varicoloured shales, which grade upwards into an arenaceous-conglomeratic (Ghiaieto sandstones) and then to a calcareous-marly-arenaceous (Marina di Campo fm.) flysch of Upper Cretaceous Age. Similar to the EU, this unit is frequently intruded by locally thick acidic dikes and laccoliths.

The structural setting of central and eastern Elba is characterised by a pile of eight structural units (units 2-9), separated by low angle tectonic surfaces (thrusts and detachments), which lays onto the lowermost Porto Azzurro Unit (Unit 1) by a low-angle detachment fault marked by a decametric cataclastic horizon (Zuccale fault and related cataclasite). The thrust surfaces (Upper Eocene-Early Miocene) have been tentatively distinguished from the low-angle detachments, due to the extensional tectonics, which probably began during Burdigalian-Langhian, and continued during Messinian-Pliocene times, and was accompanied by magmatic intrusions. Other low angle tectonic surfaces are of complex interpretation because they derived from the superposition of tectonic events which occurred in different times and/or in different tectonic regimes. Among the high-angle faults, we recognised a NW-SE trending transfer fault system, which was preceded and followed by two generations of normal faults, with WSW-NNE and N-S trends, respectively. The N-S-trending faults cut the whole tectonic pile, comprising all the detachment faults.

The study of the tectonic relationships between the previous nine tectonic units and between these tectonic units and the Messinian-Pliocene magmatic events, suggests the following geological scenario for the evolution of the Elba Island:
1) Pre-magmatic stages (>8.5 Ma). They are recorded by: a- relics of the pre-Alpine schistosity within **PU** and **UO**, which can be attributed to the Sudetic phase of the Variscan orogeny; b- folding and thrusting of the **OU**, **EU** and **CU**, with production of ophiolitic-carbonate breccias within **PU**, possibly related to Eocene intra-oceanic deformation events; c- main deformation and metamorphic events of Tuscan (**PU**, **UO**, **MU**) and Ligurian-

Piedmontese units (S_1 relics and 19 Ma S_2 in **AU**) and overthrusting of the oceanic units (**AU**, **OU**, **GU**, **EU**+**CU**) onto the Tuscan ones, probably related to the Oligocene-Early Miocene collisional events; d- refolding of the tectonic units and emplacement of **AU** between **OU** and **MU**, and of **TN** onto **MU**. The superposition of **TN** onto MU can be considered the older extensional event by low-angle detachments (Middle Miocene).

2) Syn-magmatic stages (8.5-5.4 Ma). This phase begins with the genesis and rise of anatectic melts due to the uplift of the asthenospheric mantle, within the stretched inner part of the Apenninic orogenic belt. During the uprise of the Mt. Capanne granitoid (6.8 Ma), the most of its cover, that was constituted by **EU** and **CU** (already injected by acidic dikes), was detached and shifted eastwards along a low-angle fault (Central Elba fault, “**CEF**”). During this event the acidic dykes of the basal part of the flysch were sericitised (“eurite”: 6.7 Ma). Farther east, a shoshonitic dike intruded OU at 5.8 Ma and, possibly, lamprophyric dikes were emplaced within AU. A new uplift of the Mt. Capanne caused a further glide eastwards of **EU**+**CU** onto **OU** in the central Elba, and the development of transfer faults (as lateral ramps of detachments) within the Ligurian units and, probably, the onset of the Zuccale fault. At 6.0-5.4 Ma the emplacement of the La Serra-Porto Azzurro granitoid produced a wide thermometamorphic aureola and local skarn bodies within the host **PU**, **UO**, **AU** and **MU**. The uplift of this granitoid caused, or completed, the separation of the eastern and central Elba tectonic pile through the Zuccale detachment fault. During this stage, the back-gliding of **OU** onto **EU**+**CU** in the Colle Reciso area, and the gliding north- or north-eastwards of CSU, completed the present tectonic frame of central and eastern Elba.

3) Post-magmatic events (<5.4 Ma). High-angle, N-S trending normal faults dismembered the orogenic pile and allowed the final circulation of idrothermal-mineralising fluids, with the formation of the hematite-rich ores of eastern Elba, dated ~5.3 Ma.

Thus, our reconstructions of Elba I. relate the tectonic evolution of the Island to the geodynamic context of the orogenic system Corsica-Northern Apennines. Furthermore, we offer a series of tectonic sketches starting from the Upper Cretaceous to Recent.

Key words: *Northern Apennines, Tuscan Archipelago, Elba Island, stratigraphy, structural setting, magmatism, metamorphism, Fe-ores, geodynamics.*

INTRODUCTION

The geology of the Elba Island is very interesting for the structural complexity, for the relationships between the Mio-Pliocenic magmatism and tectonics and for being placed between Corsica and Northern Apennine. In fact, it is the south-westernmost outcrop of the Northern Apennines. Its long-living geologic history takes roots in the Palaeozoic; its tectonic evolution begins in the Upper Cretaceous - Early Tertiary and goes up till the Late Miocene-Pliocene, starting with the consumption of the Mesozoic Western Tethys (Liguria-Piedmont Basin) and going up to the collision and successive polyphase deformation of the European (Corsica) and Adriatic (Tuscany Domain) margins (Boccaletti et al., 1980; Abbate et al., 1980; Bortolotti et al., 1998a; 1998b, 2001a).

New stratigraphical and structural data (Babbini et al., 2001; Bortolotti et al., 2001a; CARG Project Sheet Isola d'Elba) modify and complicate the geological frame proposed first by Trevisan (1950), and successively slightly modified (Barberi et al, 1967a; 1969), which divides the nappe pile into five complexes (Figs. 1a and 1b).

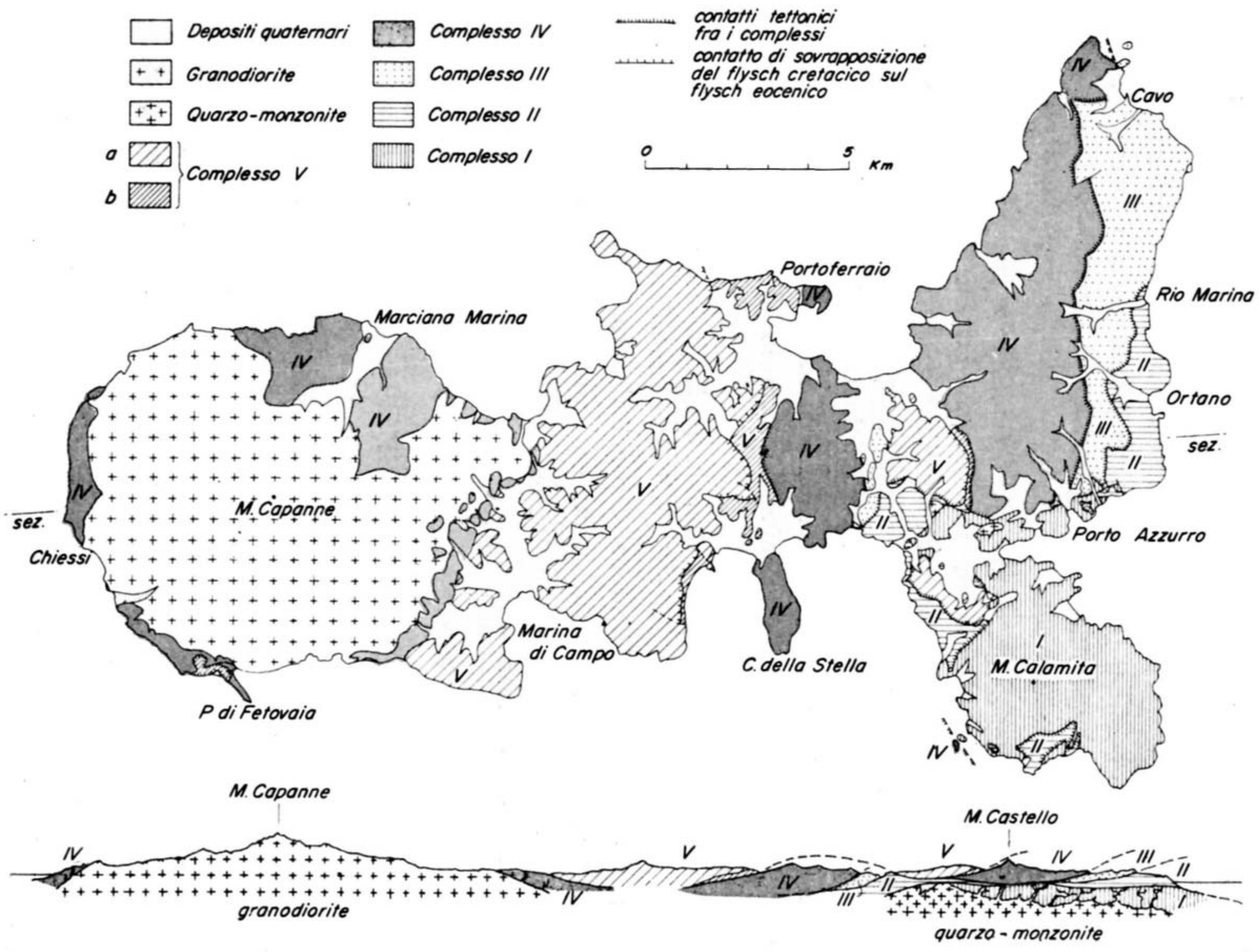

Fig. 1a - Geological sketch of the Elba Island (after Barberi et al.,1969).

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The new scheme we propose (Bortolotti et al., 2001a) (Figs. 2 and 3), comprises nine tectonic units, built up of Tuscan (Adria continental margin), Ligurian and Ligurian-Piedmont (Jurassic-Eocene oceanic domains) successions complexly piled up.

The last domain is represented by phyllites, calcschists and meta-ophiolites which can be correlated with the "Schistes Lustrés" of the "Alpine" Corsica.
This frame is complicated by post-orogenic extensional events, which produced the thinning of the Tuscan crust, the uplift of the Moho and the birth and evolution of the Tyrrhenian basin (Boccaletti et al., 1985; Bartole et al., 1991; Bartole, 1995; Carmignani et al., 1995).
To these events is linked the emplacement of Late Miocene monzogranitic bodies (Marinelli, 1975; Serri et al., 1993; Dini et al., 2002; Westerman et al., 2004) and the formation of ore deposits and skarns (Tanelli, 1977; 1983; Tanelli et al., 2001) that constitute one of the best known geological characteristic of the Island.

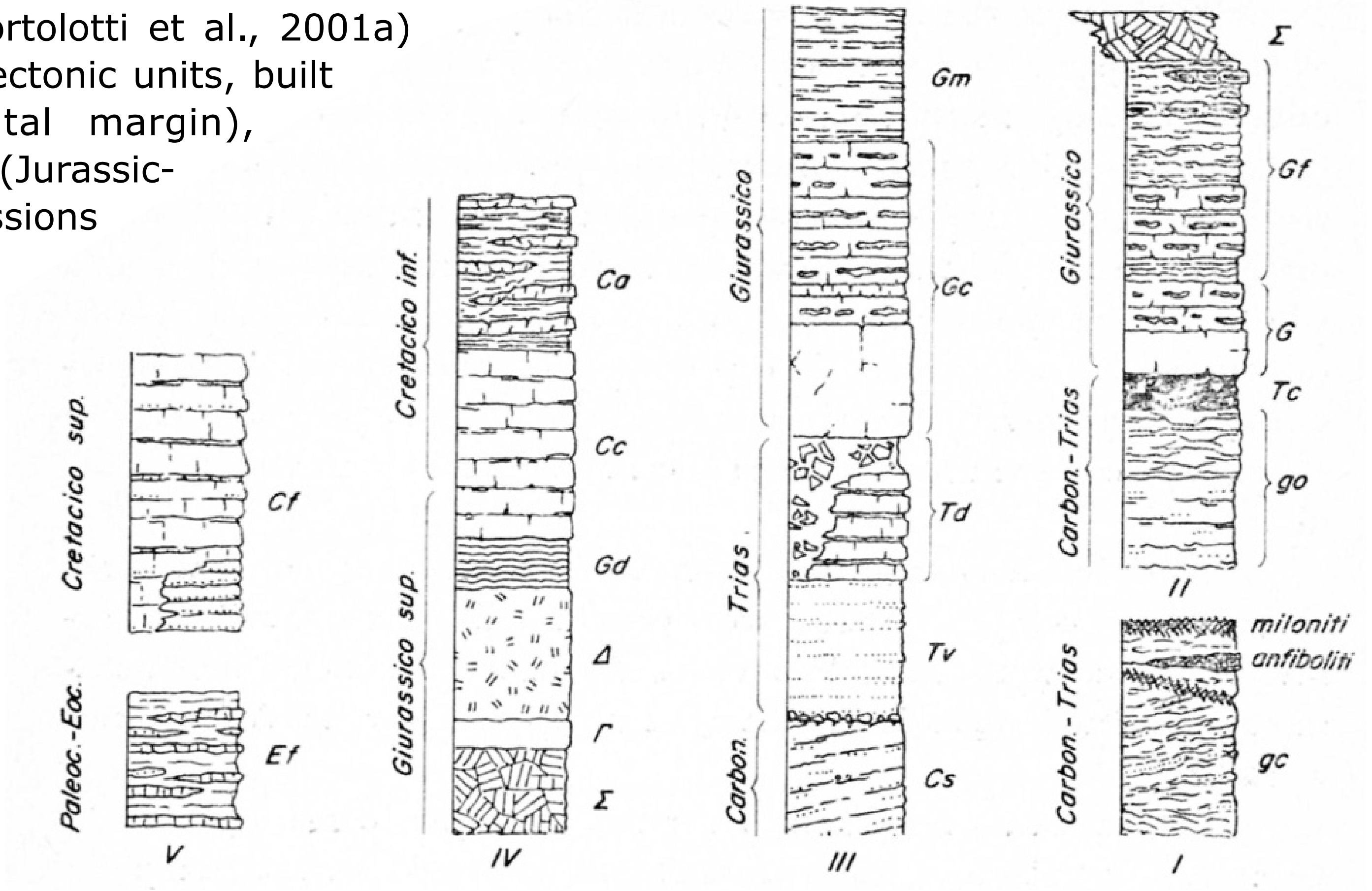

Fig. 1b - Stratigraphic columns of the five complexes (after Barberi et al.,1969).

THE TECTONIC UNITS OF THE ELBA ISLAND

The model of Trevisan

The first organic geological map and related monograph of the Elba Island was performed by Lotti (1884, 1886). Termier (1910) was the first to individuate allochthonous units in the Elba Island. Afterward, in the 50's Trevisan (1950; 1951) and Barberi et al. (1967a; 1969) proposed their model of five thrust complexes, which was, till now, the starting point for any geological study on Elba Island. For a more complete statement of the evolution of the geological interpretations see Bortolotti et al. (2001b). As already mentioned, according to Trevisan's model, the Tuscany units (Complexes I, II and III) are overlain by Ligurian units (Complexes IV and V) (Fig. 1a).
Complex I *(Calamita gneiss Auctt).* This Complex includes a sequence built up of muscovite-biotite schists with andalusite and plagioclase, and quartzitic and amphibolitic levels, which is attributed to the Paleozoic (Permo-Carboniferous?). The upper part is made of quartzites (Verrucano) and crystalline dolomitic limestones of Triassic-Liassic age. They are extensively thermally metamorphosed and intruded by aplitic dykes linked to the La Serra-Porto Azzurro monzogranite.
Complex II. This complex comprises a metamorphic tuscan sequence similar to the Apuan Alps one. From the base we can recognise: **a**. "scisti macchiettati" (thermometamorphic schists with biotite and andalusite spots), often graphitic, probably of Permo-Carboniferous age; **b**. yellowish thermometamorphic vacuolar dolomitic and calcareous-dolomitic rocks of Norian-Rhaetian; **c**. Marbles, passing upward to calcschists and "cipollini" (Lias); **d**. Calcareous phyllites (Dogger). At the top of the complex a sheet of tectonitised serpentinite crops out.
Complex III. This tuscan succession is made up of from the base: **a**. quartzarenites, arenaceous schists, quartzitic conglomerates and locally thermometamorphic schists (Late Carboniferous); **b**. transgressive quartzitic sandstones, conglomerates and schists, which can be correlated with the Ladinian-Carnian "Verrucano" of the Monte Pisano; **c**. vacuolar more or less dolomitic limestone, eteropic with black limestones with intercalations of marls with *Rhaetavicula* (Norian-Rhaetian); **d.** massive limestones (Hettangian); **e.** cherty limestones (Lias); **f**. varicoloured marly shales and rare cherty calcareous levels (Dogger).

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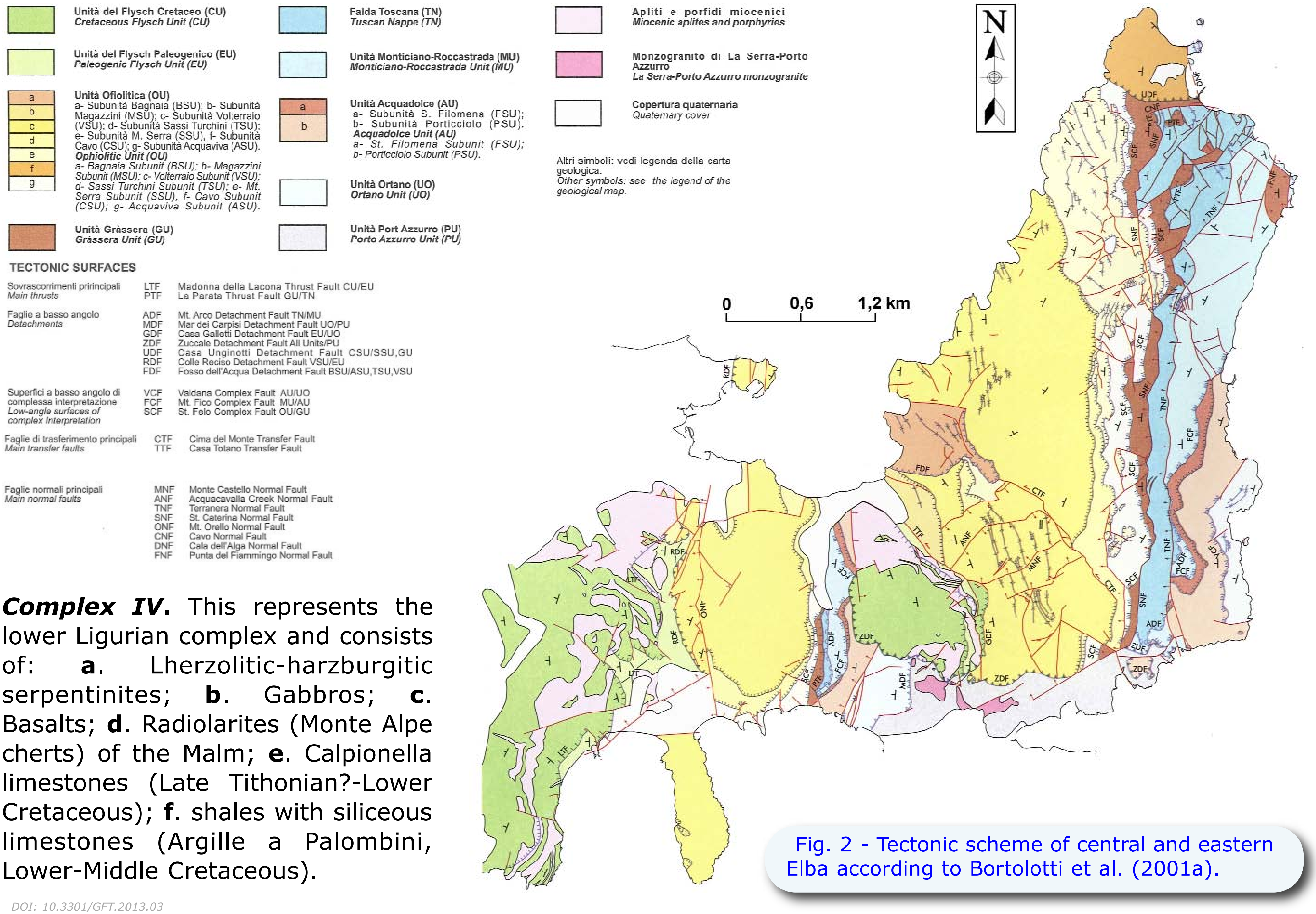

Fig. 2 - Tectonic scheme of central and eastern Elba according to Bortolotti et al. (2001a).

Complex IV. This represents the lower Ligurian complex and consists of: **a**. Lherzolitic-harzburgitic serpentinites; **b**. Gabbros; **c**. Basalts; **d**. Radiolarites (Monte Alpe cherts) of the Malm; **e**. Calpionella limestones (Late Tithonian?-Lower Cretaceous); **f**. shales with siliceous limestones (Argille a Palombini, Lower-Middle Cretaceous).

Complex V. It includes two flysch formations, tectonically superimposed. From the base: **a**. Paleocene-Eocene shales with intercalations of limestones and subordinately sandstones and ophiolitic breccias; **b**. Upper Cretaceous quartz-feldspatic sandstones and conglomerates, grading upward to a marly-calcareous succession.

For their imbricated structure, in eastern Elba all the four upper complexes lie directly on the substantially autochthonous Complex I.

The Authors consider this particular frame as due to a polyphase E-verging tectonics which first piled up, in a compressive regime, the Ligurian units on the Tuscan ones; afterwards, the tectonic pile on the Complex was reorganised by gravity tectonics due to the uplift of the Mio-Pliocenic stocks of Monte Capanne and La Serra-Porto Azzurro.

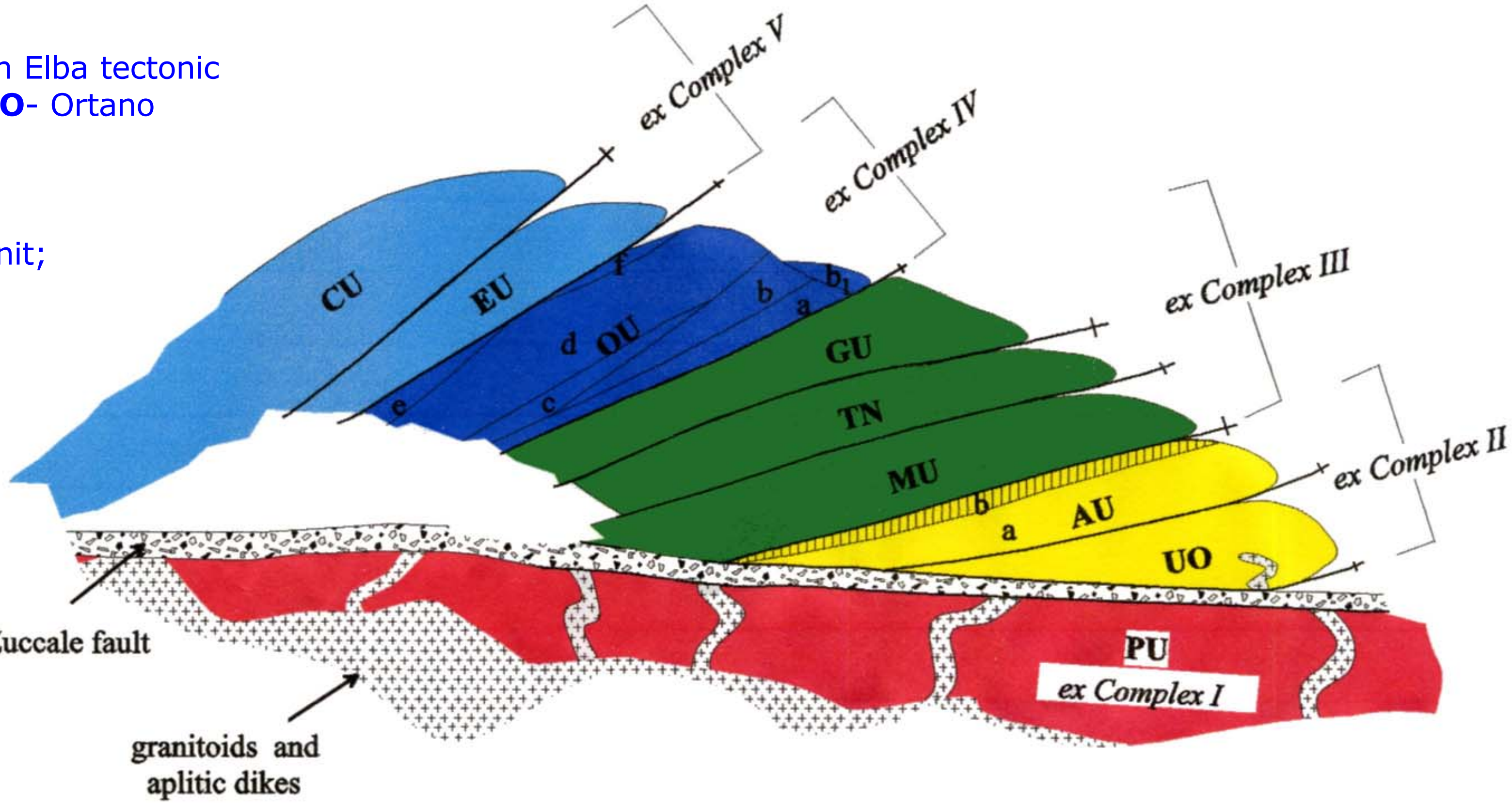

Fig. 3 - The central and eastern Elba tectonic pile. **PU**- Porto Azzurro unit; **UO**- Ortano unit; **AU**- Acquadolce unit (**a**. Porticciolo subunit, **b**- Santa Filomena S.); **MU**- Monticiano-Roccastrada unit; **TN**- Tuscan Nappe; **GU**- Gràssera unit; **OU**- Ophiolitic unit (**a**- Acquaviva subunit; **b**- Monte Serra S.; **b_1**- Capo Vita S.; **c**- Sassi Turchini S.; **d**- Volterraio S.; **e**- Magazzini S.; **f**- Bagnaia S.); **EU**- Paleogene flysch unit; **CU**- Cretaceous flysch unit (after Bortolotti et al., 2001a).

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The new model

During the last twenty years the tectono-stratigraphical frame of the Elba has been significantly improved (Perrin, 1975; Bouillin, 1983; Deschamps et al., 1983; Puxeddu et al., 1984; Pandeli and Puxeddu, 1990; Keller and Pialli, 1990; Deino et al., 1992; Daniel & Jolivet, 1995; Duranti et al., 1992; Pertusati et al., 1993; Bortolotti et al., 1994; Pandeli et al., 1995), as reported by Bortolotti et al. (2001b).
On the base of their data and our mapping on western and central-eastern Elba we have elaborated a more complex tectono-stratigraphical model (Figs. 2 and 3). The five Complexes of Trevisan, have been re-interpreted and re-named.

In particular, we recognised, from the base upward, nine tectonic units:
1. Porto Azzurro unit (“PU”) = Complex I
2. Ortano unit (“UO”)= Complex II pp.
3. Acquadolce unit (“AU”)= Complex II pp.
4. Monticiano-Roccastrada Unit (“MU”) = Complex III pp.
5. Tuscan Nappe (“TN”) = Complex III pp.
6. Gràssera unit (“GU”) = Complex III pp.
7. Ophiolitic unit (“OU”) = Complex IV
8. Eocene flysch unit (“EU”) = Complex V pp.
9. Cretaceous flysch unit (“CU”) = Complex V pp.

Porto Azzurro unit “AU” (Complex I)
It shows a complex tectono-metamorphic history, which ends with the thermometamorphic processes linked to the Serra-Porto Azzurro monzogranitic intrusion (Messinian: ~~5.9 Ma in Saupé et al. 1982; Maineri et al., 2003) which obliterated the primary textures. The Porto Azzurro Unit mainly consists of the Monte Calamita formation (micaschist and quartzose phyllitic successions with local amphibolites intercalations) which represents the Tuscan basement, and probably includes Cambro-Ordovician and Carboniferous-Permian formations (Puxeddu et al., 1984; Garfagnoli et al., 2005). The amphibolite intercalations result to be intraplate metabasites similar to those found in the Late Cambrian-Early Ordovician of the continental Tuscany (e.g. in the Apuan Alps metamorphic core). The affinity to the Tuscan Metamorphic Sequence is further on

strengthened by the presence of a transitional stratigraphical unit between the Verrucano and the overlying Mesozoic carbonate succession, very similar to the Tocchi fm. (Carnian), which has the same stratigraphical position in the successions of Southern Tuscany.

A low-angle fault associated with an about ten m thick cataclastic horizon (Zuccale fault) constitutes the contact with all the overlying tectonic units (Keller e Pialli, 1990; Pertusati et al., 1993; Bortolotti et al., 2001a; Collettini et al., 2006a, 2006b; Garfagnoli et al., 2005*).* East of Porto Azzurro the aplitic dykes, cutting the Porto Azzurro Unit, do not cross this low angle tectonic surface and the fault breccias includes thermometamorphic clast surrounded by a non-recrystallized cataclastic matrix. Moreover it. Consequently, the fault post-dates the intrusions. Finally, this cataclasite is somewhere (e.g. Reale-Terranera area) affected by the later, post-intrusion Fe mineralisations (hematite and limonite).

Ortano unit "UO" (Complex II pro parte)

It corresponds to the successions of the Complex II below the "calcare a cellette" (= vacuolar limestone) of Trevisan (1951).

It comprises at the base thermally metamorphosed phyllites, quartzites (Capo d'Arco schists) locally crosscut by rare and thin aplitic dykes (similar to those intruded in the Porto Azzurro Unit). At their top porphyroids and porphyritic schists which grade upward to phyllites and quartzitic metasandstones and metaconglomerates. This succession can be correlated with the Hercynian, Early Paleozoic basement of the Apuan Alps and central Sardinia (Pandeli and Puxeddu, 1990; Pandeli et al., 1994*).* Probably, this unit is a kilometric isoclinal fold with Ordovician metavolcanites at the core.

Acquadolce unit "AU" (Complex II pro parte)

It corresponds to the Complex II successions from the top of the "calcare a cellette" (here considered a cataclasite horizon) upwards. The complete succession begins with massive marbles, partly dolomitic; they grade upwards to (sometimes cherty) calcschists with, at their top, a metapelitic siliciclastic succession with local calcschist intercalations. In the latter Duranti et al. (1992) found a Lower Cretaceous microfauna; so they consider all the succession as a metamorphosed Liguride, which was deformed and recrystallised by the Mio-Pliocene intrusions. On the other hand Deino et al. (1992) obtained a 19-20 Ma for the main schistosity which rules out its link with the granitoid intrusions. As suggested by Termier (1910) , Corti et al. (1996), Bortolotti et al. (2001a) and Pandeli et al. (2001a) these terrains probably correspond to a Liguria-Piedmont oceanic sequence as the *Schistes Lustrés* of Corsica (e.g. Inzecca units, Durand Delga, 1984) and the calcschists of the Gorgona island (cfr. Capponi et al., 1990; Orti et al., 2002). Also the presence of a serpentinite sheet at its top agrees with this interpretation.

Monticiano-Roccastrada unit "MU" (Complex III pro parte)

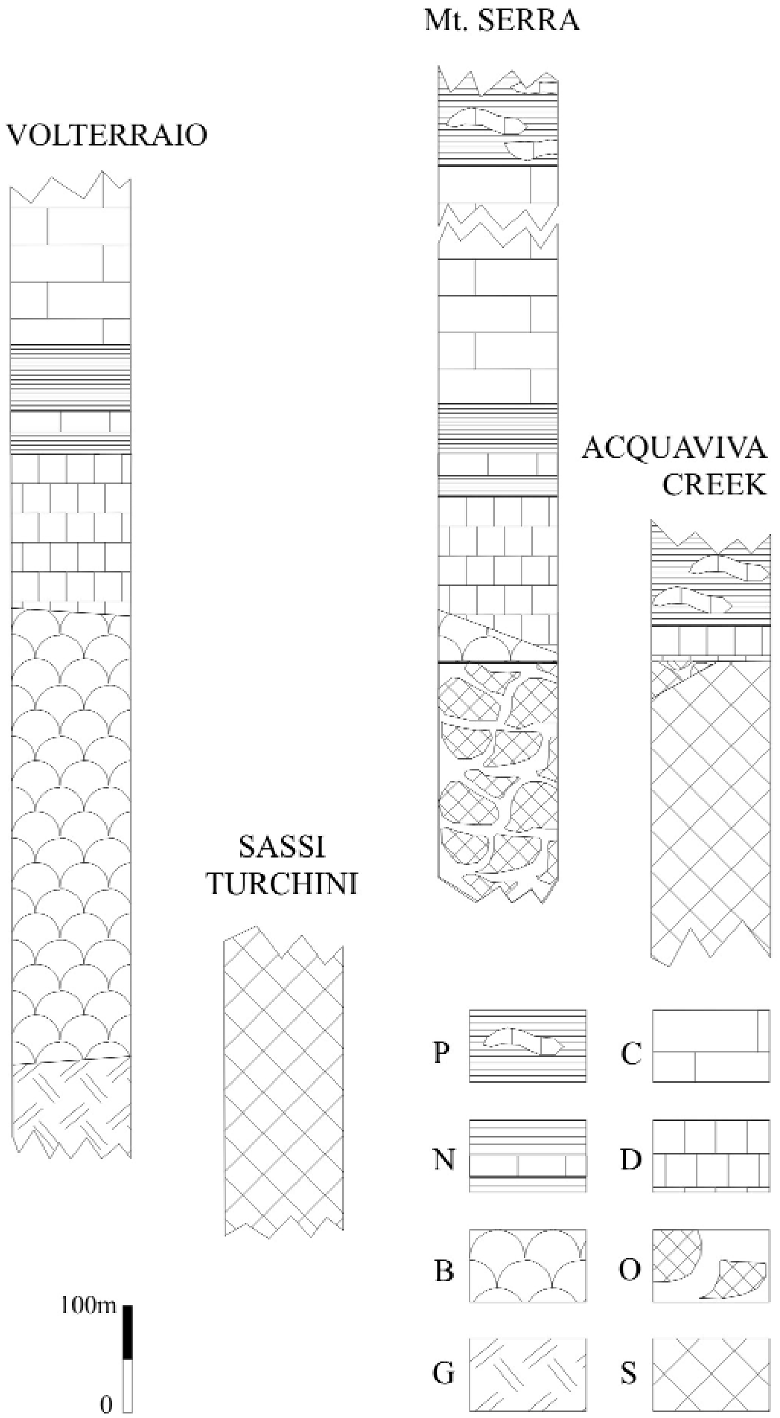
The base of this Unit is made of fossiliferous graphitic metasediments of Late Carboniferous-Early Permian (Rio Marina fm. Auctt.), on which the detrital triassic Verrucano successions are deposited (Deschamps et al., 1983; Bortolotti et al., 2001a; Pandeli, 2002). To this Unit we ascribe also the epimetamorphic successions of Capo Castello-Isola dei Topi and of Capo Pero (north and south of Cavo, respectively) which includes formations from Late Jurassic (siliceous metalimestones) to the Oligocene (Pseudomacigno) (Pandeli et al., 1995; Bortolotti et al., 2001); they could represent part of the Verrucano cover.

Tuscan Nappe "FT" (Complex III pro parte)

In the Porto Azzurro-Rio Marina, and Norsi-La Valdana areas, it is represented only by calcareous-dolomitic breccias (calcare cavernoso Auctt.); northwards, also the overlying carbonatic (*Rhaetavicula* Limestone and Calcare Massiccio - Late Triassic-Hettangian), carbonatic-cherty (Limano fm. and "Ammonitico Rosso" - Middle-Late Lias) and marly-carbonate formations (Posidonia marlstones - Dogger) crop out.

Grassera unit "GU" (Complex III pro parte)

It represents a unit of doubtful paleogeographic position. Its terrains were considered as Posidonia marlstones, at the top of the Tuscan Nappe (Barberi et al., 1969). It comprises at the base calcschists, sometimes with cherts, but most of the unit is made up of varicoloured slates and siltstones with rare manganiferous, recrystallized siliceous and calcareous beds (Bortolotti et al., 2001a; Pandeli et al., 2001b). Its lithofacies are different from those of all the formations of both Tuscan and Ligurian Domains. Moreover, they show a slight metamorphism (anchizone/epizone?), completely lacking in the Tuscan Nappe and in Ligurian formations at its base and top, respectively. It lies in tectonic unconformity on different terrains of the Tuscan Nappe. These facts let Bortolotti et a. (2001a) and Pandeli et al. (2001b) propose a provenance from a paleogeographic domain west of the Tuscan one, possibly the Ligurian-Piedmont domain, as the AU.



Ophiolitic unit "OU" (Complex IV)

Its succession pertains to the Vara Supergroup (Abbate and Sagri, 1970). It is built up of some thrust sheets (subunits), characterised by ophiolites of the oceanic basement of the Western Tethys (serpentinites and gabbros -cropping out only in the lower ones) on which is generally present a more or less complete volcanic (basalts) and sedimentary (Monte Alpe cherts, Nisportino fm., Calpionella limestones and Palombini shales) cover of Late Jurassic-Early Cretaceous age. This unit can be interpreted as a relic of a trapped oceanic crust originally near the Corsica European margin.

Within this thick Unit we identified four main subunits (Fig. 4); from the bottom they are: (a) the *Acquaviva subunit* (ASU), constituted mainly by serpentinites (or ophicalcites), and Palombini shales with rare, thin, cherty levels at their base; b) the *Monte Serra subunit* (SSU), in which the sequence begins with an ophicalcitised serpentinite level, whose contact with the volcanic cover is almost tectonised, but in some outcrops the contact seems stratigraphical; this cover includes, on the basalts, cherts (from few to some tens m), the Nisportino fm. (some tens m) and the Calpionella limestones covered, north of Cavo, by Palombini shales; c) the *Sassi Turchini subunit* (TSU), composed exclusively by serpentinised lherzolites and harzburgites;d) the *Volterraio subunit* (VSU). This is the more complete and thick sequence. From the bottom it comprises gabbro, basalts (3-400 m), Monte Alpe cherts (100-150 m), Nisportino fm. (100-120 m) and Calpionella limestones (at least 100 m).

Fig. 4 - Columns of the ophiolitic subunits in eastern Elba (after Bortolotti et al., 2001a).

Eocene flysch unit "EU" (Complex V pro parte)

It is represented by a shaly-marly succession with turbiditic calcilutites, sandstones and ophiolitic breccias of Eocenic age.

Cretaceous flysch unit "CU" (Complex V pro parte)

In this second turbiditic unit we can distinguish, on top of the Palombini shales and varicoloured shales, a lower section, represented by siliciclastic sandstones and conglomerates (Ghiaieto Sandstones) and an upper one with marly limestones (Marina di Campo fm.). The age of the siliciclastic and calcareous-marly flysch is Campanian-Maastrictian. According our interpretation the minor ophiolitic slabs, the Calpionella limestones and Palombini shales cropping out north-east of Porto Azzurro could be the tectonised basal terms of the subunit.
These flysch units -and particularly the second one- are cut by Tortonian to Messinian aplitic and porphyritic dykes, sills and laccoliths (e.g the 8.4 Ma Capo Bianco aplite, the 8 Ma Portoferraio porphyry, the 7.4 Ma S.Martino porphyry: Dini et al., 2002; Westerman et al., 2004, see later) that pre- date the about 6.9 Ma Monte Capanne monzogranite intrusion (Ferrara and Tonarini 1993, Rb/Sr; Juteau et al., 1984, U/Pb; Dini et al., 2002; Westerman et al., 2004). All the pre-MonteCapanne magmatic bodies are cut along the tectonic contact with the underlying OU.

In the western Elba, the Monte Capanne monzo-granite and its thermometamorphic aureole crop out (Fig. 5). The latter, tectonically separated from the flysch units of central Elba by the Eastern Border fault, is made up of a recrystallised ophiolitic sequences (ophiolites and volcano-sedimentary cover) intruded by the pre-MonteCapanne dykes and laccoliths (e.g. Capo Bianco aplite and Portoferraio porphyry). This meta-ophiolitic succession was related by Marinelli (1959), Barberi and Innocenti (1965; 1966), and Bouillin (1983) to the Ophiolite Unit to the Trevisan's Complex IV. On the contrary, other Authors (Perrin, 1975; Spohn, 1981; Reutter and Spohn, 1982; Coli & Pandeli,2001) referred them to Ligurian tectono-metamorphic rocks (similar to the Schistes Lustrés) which were later thermally metamorphosed and deformed by the Monte Capanne granitoid. In the Fetovaia area, a weakly recrystallised or non metamorphic flysch unit (similar to those of the Trevisan's Complex V: Barberi et al., 1969), tectonically lies on the thermally metamorphosed oceanic rocks (Bouillin, 1983; Spohn, 1981; Reutter and Spohn , 1982). This flysch unit is made up of a basal serpentinite body which is overlain by a marly-calcareous sequence with an olistostrome and ophiolitic breccias at the base. Moreover, serpentinite and gabbro olistoliths are locally present in the marly-calcareous sequence. In the ruditic levels, Paleocene-Eocene fossils were found (Bouillin, 1983; Spohn, 1981).

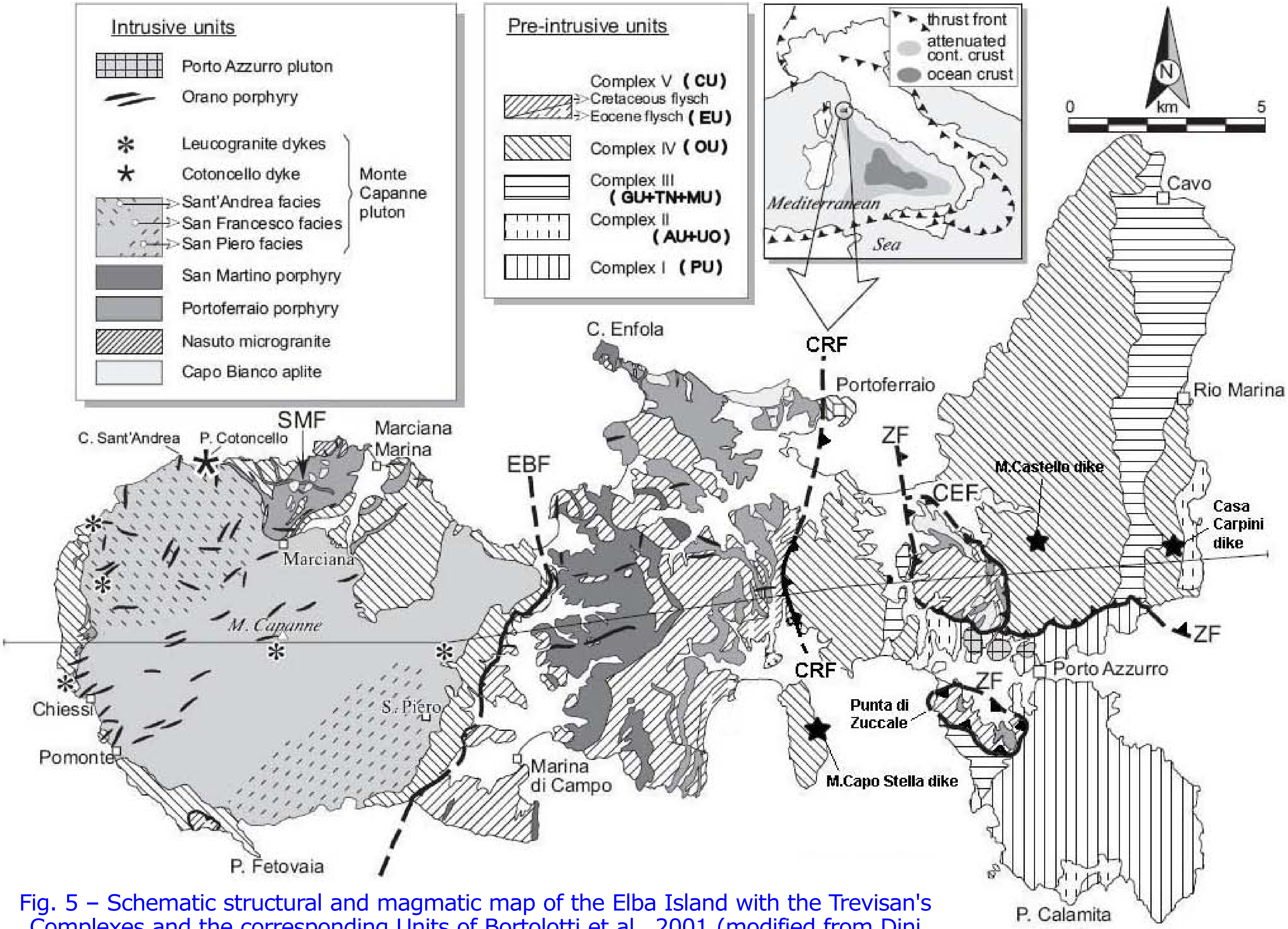


Fig. 5 – Schematic structural and magmatic map of the Elba Island with the Trevisan's Complexes and the corresponding Units of Bortolotti et al., 2001 (modified from Dini et al., 2002); EBF, Eastern Border fault; CEF, Central Elba fault; ZF, Zuccale fault; CRF, Colle Reciso fault.

MIO-PLIOCENE MAGMATISM IN THE NORTHERN APENNINES AND IN THE TUSCAN ARCHIPELAGO

Tuscan Province Magmatic Rocks

An intense magmatic activity, related to the post-collisional phase of the Apennine orogeny, took place along the Tyrrhenian border of the Italian Peninsula during the Late Miocene-Pleistocene (Peccerillo, 1985; 1990; 1993). 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, 2001; Poli et al., 1989; Innocenti et al., 1992; Serri et al., 1993; Poli, 2004).

Crust- and mantle-derived igneous rocks cropping out in the Tuscan Archipelago and Southern Tuscany (Fig. 6) were once grouped in a

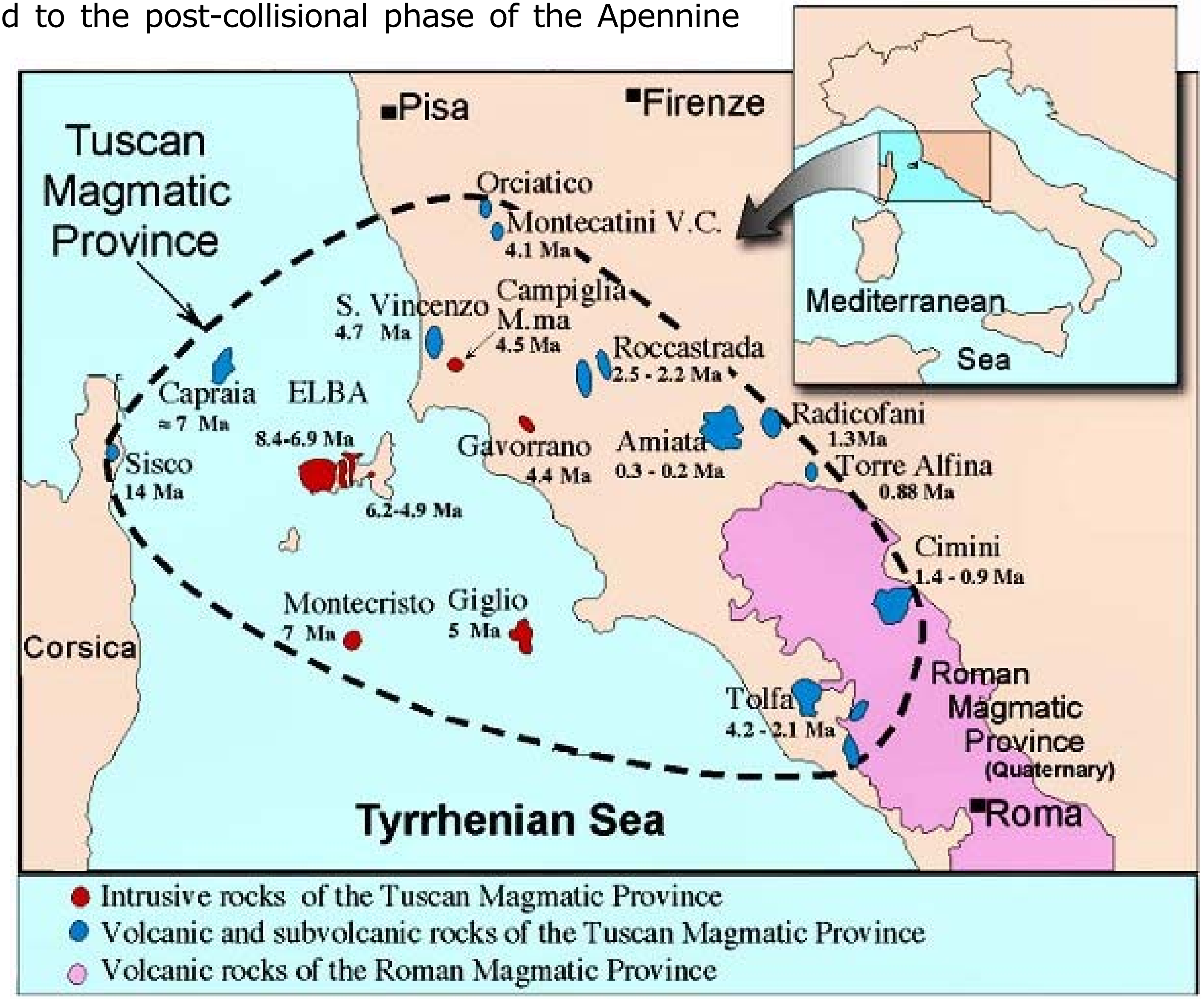


Fig. 6 – Regional distribution map of the magmatic bodies of the Tuscan Magmatic Province = TMP (after Dini et al., 2002).

single magmatic province (Tuscan Magmatic Province) owing to the consanguineity attributed to them (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 (similar to those those of the Roman Magmatic Province) were originated in a 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 Lago-Monteverdi, in Southern Tuscany, and (iv) the lava flows of San Vincenzo and Roccastrada-Roccatederighi, also in Southern Tuscany (Fig. 5; Peccerillo et al., 1987; Pinarelli et al., 1989; Poli et al., 1989b; Poli, 1992; Innocenti et al., 1992; Poli, 2004; Dini et al., 2005). These crust-derived magmas were emplaced between 8 and 2 Ma (e.g., Borsi et al., 1965, 1967; Borsi, 1967; Borsi and Ferrara, 1971; Juteau, 1984; Juteau et al., 1984; Ferrara and Tonarini, 1985; Villa et al., 1987; Barberi et al., 1994; Dini et al., 2002; Westerman et al., 2004), and have a general westward aging (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; Serri et al., 1993), although they were emplaced in a wider span of time, from 14 Ma (Sisco, Corsica) to 0.2 Ma (Monte Amiata) (Ferrara and Tonarini, 1985, 1993; Fornaseri, 1985; Turbeville, 1992; Cioni et al., 1993; Barberi et al., 1994).

Elba Island

Two monzogranitic plutonic masses crop out in the western (Monte Capanne, 6.9 Ma) and eastern (La Serra-Porto Azzurro, 5.9 Ma) sectors of the Elba Island (Fig. 5), along with their microgranite, aplite and pegmatite dyke swarms (Marinelli, 1959; Saupé et al. 1982; Jateau et al., 1984; Ferrara & Tonarini, 1985, 1993; Boccaletti & Papini, 1989; Maineri et al. 2003; Rocchi et al., 2003). The Monte Capanne intrusion post-dates the emplacement of a subvolcanic multilayer “Christmas-tree” laccolithic complex (Fig. 7) including four intrusive units that were emplaced between ca. 8 and 7.4 Ma (Dini et al. 2002) into the ophiolitic successions around the Monte Capanne and in the Cretaceous and Paleogene flysch units of central Elba. The oldest intrusive units are represented by the small outcrop of Nasuto microgranite and by two sills of the Capo Bianco aplite (ca. 8 Ma).

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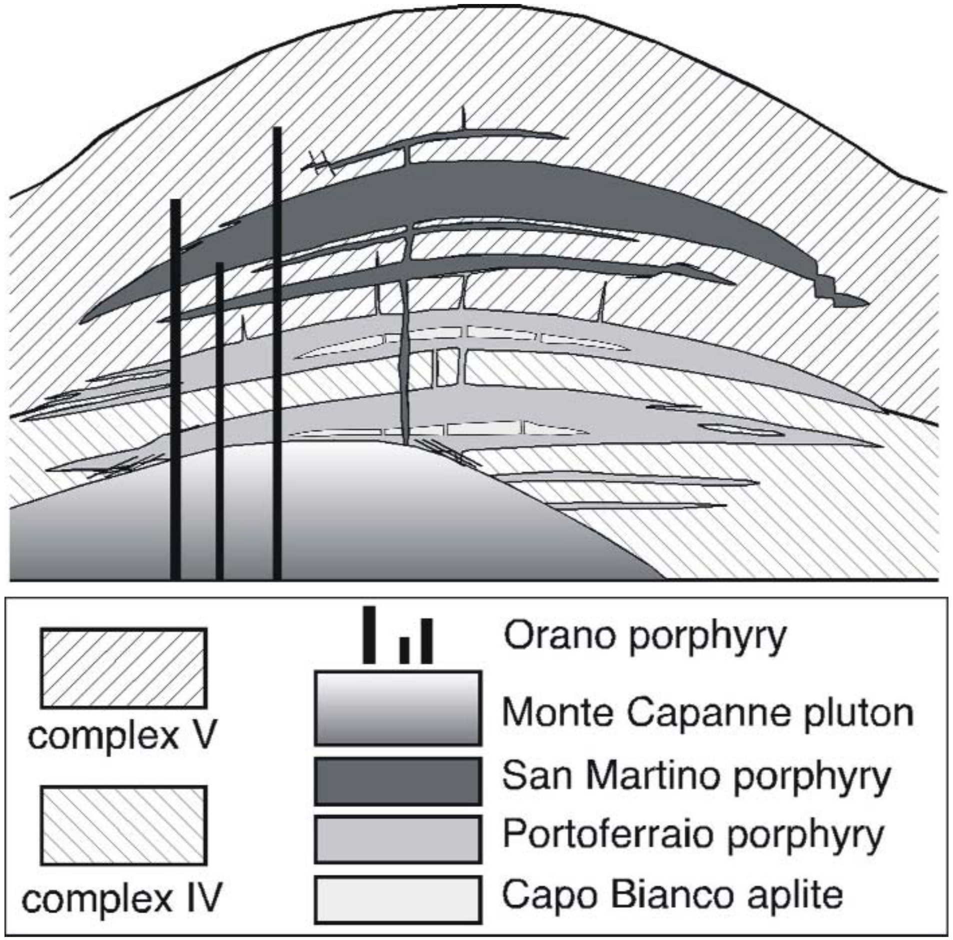

Fig. 7 - Sketch of the geometrical relationships between the magmatic bodies of central and western Elba Island at 6.8 Ma (after Dini et al., 2002).

The latter rocks, typically cropping out in a marine cliff at Capo Bianco, west of Portoferraio, is a very-fine grained alkali-feldspar-granite with tiny phenocrysts of quartz, feldspars and muscovite locally showing magmatic banding and concentrations of tourmaline (orbicules). The slightly younger monzogranitic-syenogranitic Portoferraio porphyry (ca. 8 Ma) consists of four main layers characterized by many small phenocrysts of quartz, feldspars and biotite. The monzogranitic San Martino porphyry (7.4 Ma), that is instead characterized by prominent sanidine megacrysts and by quartz, plagioclase, biotite phenocrysts, was emplaced into three main layers.

The monzogranitic Monte Capanne pluton (Dini et al., 2002; Gagnevin et al., 2004, 2005, 2008, 2010; Westerman et al., 2004) was fed by several magma pulses that coalesced into a single intrusion (Farina et al., 2010). Three main facies can be detected in the pluton but the first two are more important: 1) the monzogranitic Sant'Andrea facies, characterized by numerous large K-feldspar megacrysts and mafic enclaves; 2) the granodioritic-monzogranitic San Piero facies, typically quarried for its homogeneous texture almost devoid of large megacrysts and mafic enclaves; 3) San Francesco facies show intermediate features between the 1) and 2) facies (Dini et al., 2002; Westerman et al., 2004). The patchy distribution of the Sant'Andrea facies, dominantly around the margin of the pluton, suggests that it arrived first and was then disturbed by arrival of the San Piero facies. Both the facies are hybrid products and their geochemical/isotopic features can be modeled by the interaction of a mafic component geochemically similar to K-andesites of the

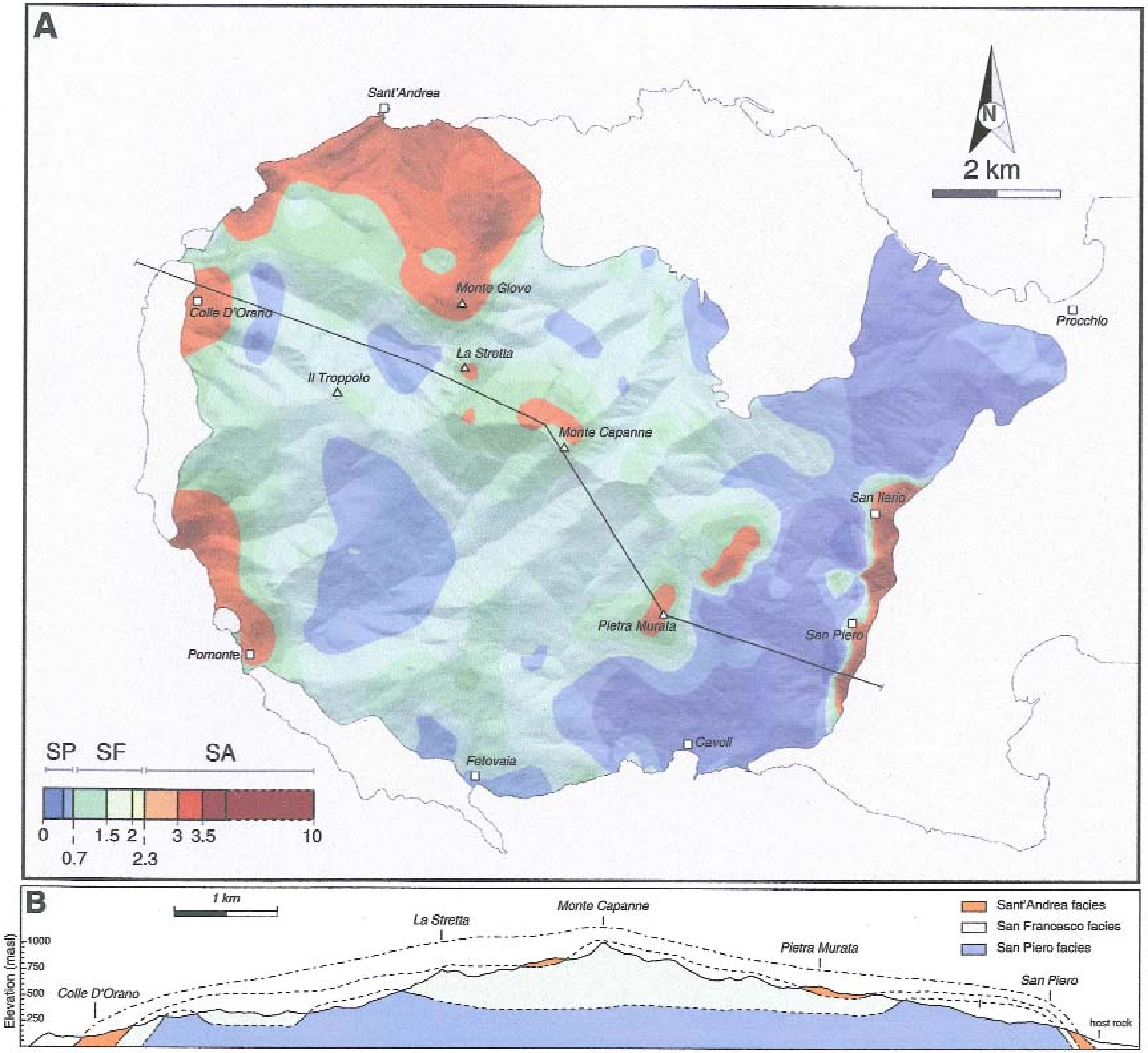

Fig. 8 – **A)** Contour map of Monte Capanne pluton showing the variability of megacrysts content (area %). **B)** Interpretative NW-SE geological cross-section of the Monte Capanne pluton. The Sant'Andrea facies (SA), S.Francesco facies (SF) and S.Piero facies (SP) are geometrically represented as three sheet extending across the whole pluton with overall slightly upward-convex shapes (after Farina et al., 2010).

Island of Capraia and crustal melts like the leucogranitic Cotoncello dyke at Elba (Dini et al., 2002). The leucogranite dyke swarm (including the Cotoncello dyke) is associated to the Monte Capanne magmatic event. In particular, these dykes have syenogranitic compositions, and they occur mainly close to the pluton's contact, within both the pluton and its thermometamorphic aureole. They commonly have a thickness of up to tens of metres. These dykes were emplaced late in the crystallization sequence of the Monte Capanne pluton, and are locally cut by dykes of the Orano porphyry (see below). Their isotopic age is indistinguishable from that of the Monte Capanne pluton. The leucogranites are interpreted as a series of fractionation products from a magma having characteristics similar to those of the San Piero facies of the

Monte Capanne pluton, a hypothesis further supported by the overlapping Sr and Nd isotopic compositions of the Monte Capanne pluton and the leucogranite dykes. Aplites and pegmatites occur commonly as thin (0.1 to 2 m) and short (up to a few metres) veins and dykes, cross-cutting the pluton, its thermometamorphic rocks and, in some places, the leucogranite dykes. Finally, the dyke swarm of the monzodioritic to granodioritic Orano porphyry intruded the pre-Monte Capanne laccolithic complex, the Monte Capanne pluton and its contact metamorphic aureole, and part of the flysch units of central Elba at 6.9-6.8 Ma (Dini et al., 2002; Rocchi et al., 2003) (Fig. 7). Orano porphyries are typically dark and contain an olivine, clinopyroxene, phlogopite assemblage that, coupled with geochemical and isotopic data, suggest a genesis from strongly modified mantle, as products intermediate between Capraia K-andesites and Tuscan lamproites. They are distinctly different than those involved in the earlier main hybridization process (San Martino, Monte Capanne).

La Serra-Porto Azzurro monzogranite in eastern Elba is similar to the Monte Capanne pluton (Marinelli, 1959; Saupé et al. 1982; Maineri et al., 2003). Particularly, in the Porto Azzurro area and eastern Monte Calamita promontory, its complex network of microgranite, leucogranite and aplite dykes crop out in the thermally metamorphosed rocks of the Monte Calamita formation. Typical felsic tourmaline-bearing dykes are also present (Dini et al., 2008).

Mafic dykes are also present in central-eastern part of the Elba Island. In particular, the occurrence of a 5.8 Ma mantle-derived shoshonitic dyke (Monte Castello dyke) has been recorded by Conticelli et al. (2001) in the Ophiolitic Unit outcropping north-west of Porto Azzurro. Moreover, quartz-dioritic dykes of likely Messinian age are also present in the Capo Arco area, east of Porto Azzurro, in the Acquadolce Unit (Case Carpini dyke in Pandeli et al., 2006) and in the Ophiolitic Unit of the Monte Capo Stella promontory, between the Lacona and Stella Gulfs (Pandeli & Santo, in preparation); both dykes show petrographic and geochemical evidence of mixing between a calcalkaline mafic-intermediate magma similar to that of Capraia and a crustal anatectic melt.

Petrogenesis of the Elba Island granitoids

Mineralogical, geochemical and petrological data of the Monte Capanne and Porto Azzurro rocks point to an origin by partial melting (anatexis) of a crustal source, similar to the garnet-bearing micaschists of Palaeozoic Tuscan basement (Giraud et al., 1986; Poli et al., 1989) that crops out in the southern part of the Calamita promontory (Garfagnoli et al., 2005).

The relatively high temperature (800-850°C), required to accomodate the degrees of melting experienced by this crustal source (35-45 wt.% on the basis of trace element modelling, Poli et al., 1989), is difficult to reconcile only with isostatic re-adjustments following the collisional event of the Apennine orogeny. In this respect, underplating of mantle-dfigerived magmas could have acted as an additional supply to the heat budget required to achieve high degrees of melting under the general fluid-absent conditions prevailing in middle- to lower-crust levels (Clemens and Vielzeuf, 1987).

At Elba Island the rock composition closest to that of parental magma has been recognised to be the rocks where mafic microgranular enclaves are absent (LF=leucocratic facies in Poli et al., 1989; Poli, 1992). On the other hand, the chemical composition of the MF (MF=main facies in Poli et al., 1989; Poli, 1992) has been modified by the physico-chemical interaction with mantle-derived magmas and the LF parental magma (CFC= contamination and fractional crystallization process, Poli and Tommasini, 1991). The occurrence of such a process is testified by the ubiquitous ME (=microgranular enclaves) found in the MF of the Monte Capanne pluton. The extent of such modification, however, is difficult to quantify because is directly dependent upon the relative amount of basic and acid magma: the more the basic magma the higher the equilibrium temperature and the more the "residual" basic magma available for mixing with the surrounding acid magma (stage 3, Poli and Tommasini, 1991). To complicate things further, disruption and mingling of the basic magma, as testified by the ME, during the attainment of the thermal equilibrium with the acid magma (stage 2, Poli and Tommasini, 1991) likely modified the composition of the surrounding granite magma owing to the incorporation of fragments from the basic magma (schlieren-like texture exhibited by some ME).

ORE DEPOSITS OF SOUTHERN TUSCANY AND ELBA ISLAND: AN OVERVIEW

Tuscany has been representing for about three millennia one of the most important mining regions of Italy and the whole Mediterranean region. Apart from economic aspects, the Tuscan metallogenic province remains of primary scientific relevance due to the occurrence of diverse hydrothermal deposits associated with volcano-sedimentary, magmatic, metamorphic and geothermal environments (Lattanzi et al., 1994). They include, among the others, the Fe oxides deposits of Elba Island (Tanelli et al., 1991, 2001). Fig. 9 and Fig. 10 provide sketch maps of the distribution of major ore deposits and mineral belts of Elba Island and of Southern Tuscany, respectivelly.

A description and discussion of the metallogenic aspects of Tuscany can be found in Tanelli (1983) and Lattanzi et al. (1994), according to which three main metallogenic epochs seem to be relatively well established in Tuscany (Figs. 10 and 11): *(i)* a Middle-Late Palaeozoic, *(ii)* a Palaeozoic-Triassic(?), *(iii)* an Apenninic stage.

To the second one would pertain the Fe (and Ba) metallogeny of Elba Island.

For the Fe oxide and/or pyrite deposits of Elba Island two basic genetic models have been so far proposed (Tanelli and Lattanzi, 1986): a) “plutonistic epigenetic” (cf. Marinelli, 1983; Dechomets, 1985); b) “syngenetic/hydrothermal-metamorphic” (cf. Deschamps et al., 1983; Lattanzi and Tanelli, 1985). The first line of thought makes reference to the intrusion of the late-Apenninic granitic stocks as the key event for the ore genesis, whereas the authors favouring the second hypothesis acknowledge the importance of the Apenninic tectonomagmatic event in metamorphosing and partly remobilising the pyrite Fe oxide barite ores, which, at least as pre-concentrations, would have formed in a sedimentary and/or hydrothermal sedimentary environments of Triassic and/or Palaeozoic age (stage *ii,* see above).

Fig. 9 - Geological sketch map of Elba Island (modified from Maineri et al., 2003), with location of iron ores, industrial deposits and other mineral occurrences. Iron deposits: 1) Rio Albano; 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) = S.Piero – S. Ilario; (m) = S.Piero – S. Florio; (n) = Monte Fico; (o) = S. Ilario - S. Piero, Seccheto, Cavoli. Tectonic lineaments: CEF = Central Elba fault; ZF = Zuccale fault; EBF= Eastern Border fault.

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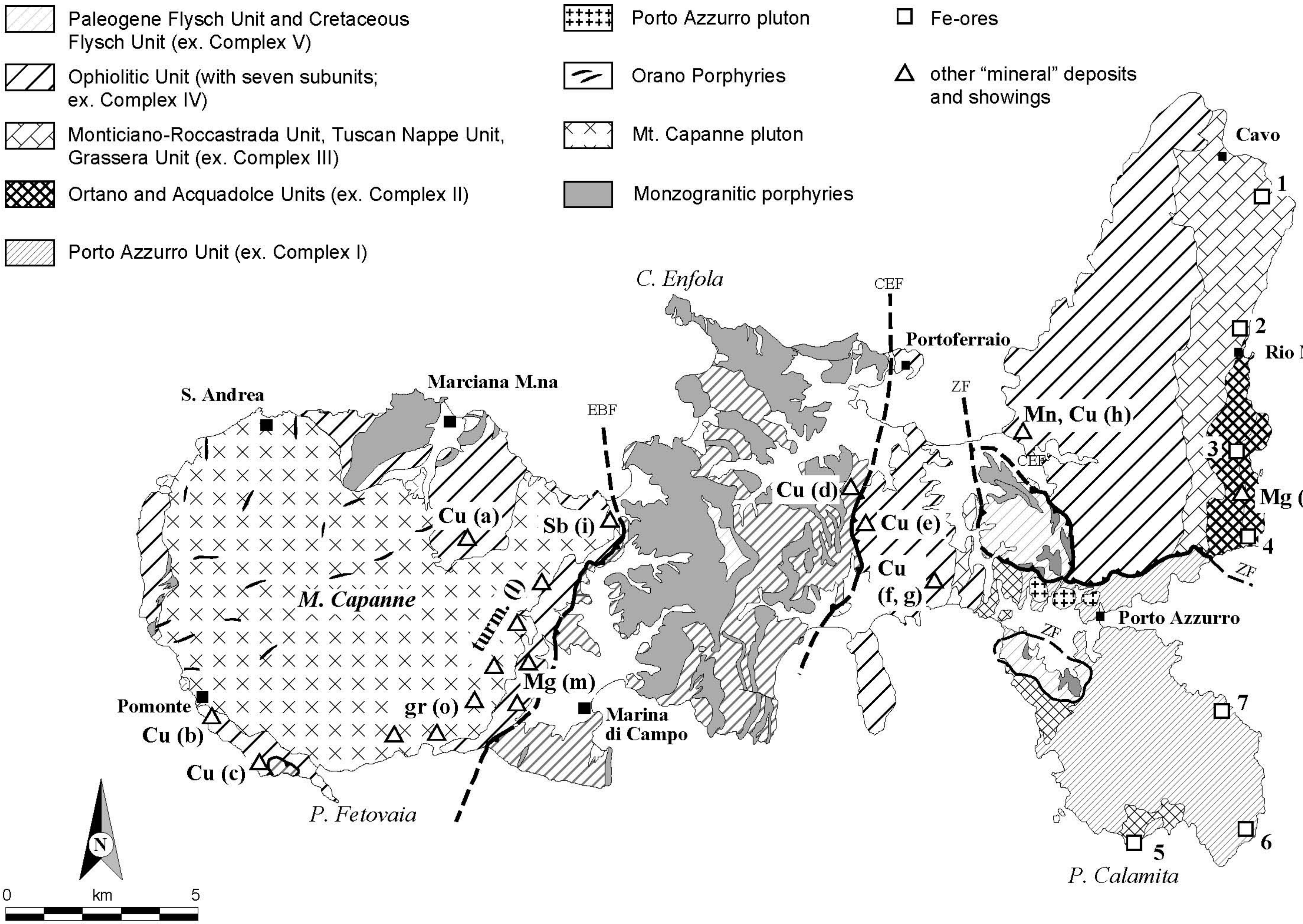
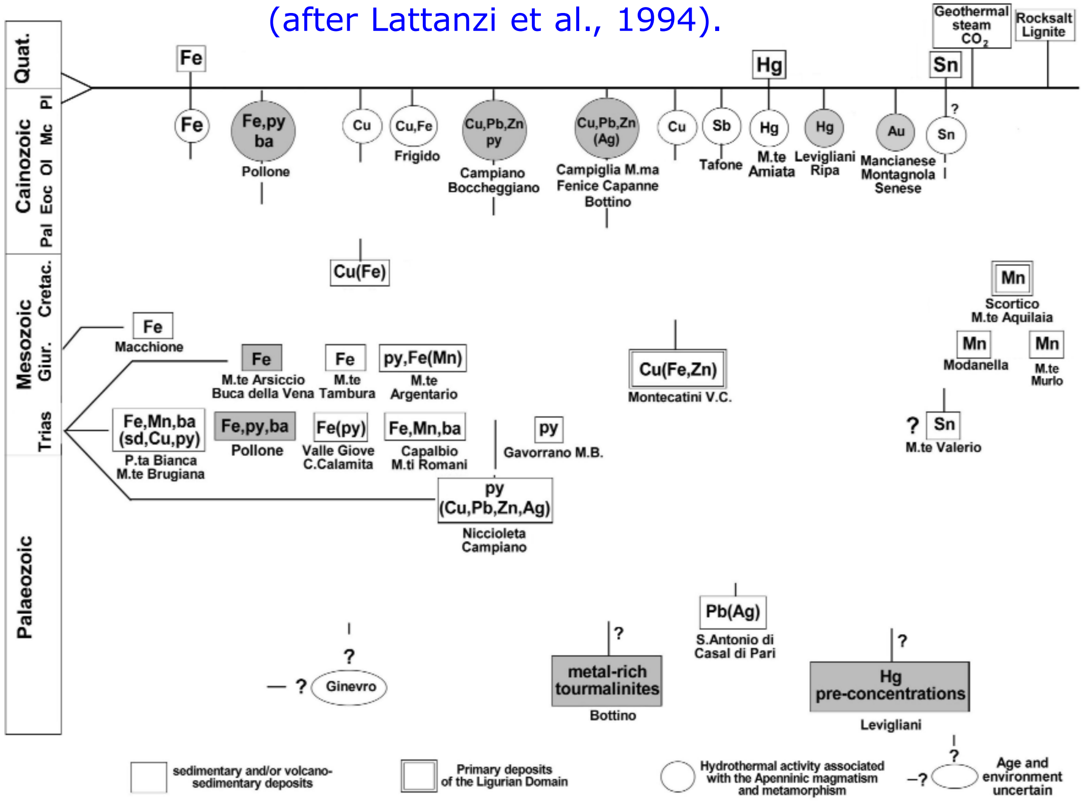

Paleogene Flysch Unit and Cretaceous Flysch Unit (ex. Complex V)
Ophiolitic Unit (with seven subunits; ex. Complex IV)
Monticiano-Roccastrada Unit, Tuscan Nappe Unit, Grassera Unit (ex. Complex III)
Ortano and Acquadolce Units (ex. Complex II)
Porto Azzurro Unit (ex. Complex I)
Porto Azzurro pluton
Orano Porphyries
Mt. Capanne pluton
Monzogranitic porphyries
Fe-ores
other “mineral” deposits and showings
C. Enfola
CEF
Portoferraio
ZF
EBF
Cavo
1
2
Rio Marina
3
Mg (n)
4
ZF
Mn, Cu (h)
CEF
S. Andrea
Marciana M.na
Cu (a)
Sb (i)
Cu (d)
Cu (e)
Cu (f, g)
M. Capanne
turm. (l)
Mg (m)
gr (o)
Pomonte
Cu (b)
Cu (c)
Marina di Campo
Porto Azzurro
ZF
7
6
5
P. Fetovaia
P. Calamita
N
0
km
5

The Fe deposits of Elba Island

The iron deposits hosted in the eastern part of Elba Island feeded a longstanding mining and metallurgical activity, dating back to the "first Mediterranean Iron" (beginning of the I millennium B.C.) and protracted almost uninterruptedly since the Etruscans up to fifteen years ago. In order to preserve and turn to better account such a long mining tradition and invaluable mineralogical heritage, a "Mining and Mineralogical Park" in eastern Elba has been recently established (cf. Tanelli and Benvenuti, 1997).

Fig. 11 – Metallogenic evolution of Tuscany (after Lattanzi et al., 1994).



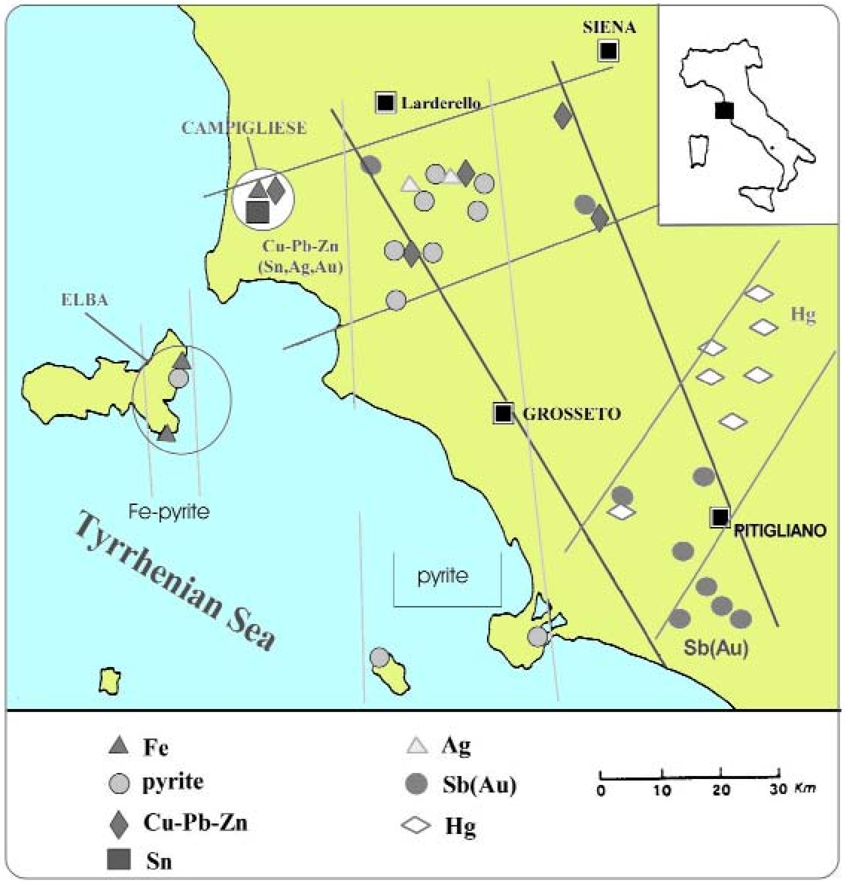


Fig. 10 - Location of the most important ore deposits of southern Tuscany and of Tuscan Archipelago (modified after Tanelli & Lattanzi, 1983).

The location of the main iron deposits of eastern Elba are reported in Fig. 10. A broad and rough distinction can be made between iron ore deposits located to the north or to the south of Rio Marina. The iron deposits in the northern portion (Rio Marina, Valle Giove, Rio Albano) and east of Porto Azzurro (Capo Bianco-Terranera) are constituted by stratiform, dyke-like or irregular bodies, hosted by Trevisan (1950)'s Complex III rocks, preferentially at the contact between Permo-Carboniferous phyllites ("Formazione di Rio Marina") or quartzitic/phyllitic rocks ("Verrucano", Middle Triassic) and the overlying calcareous levels ("Calcare Cavernoso" Auctt.). The main ore mineral is hematite, frequently associated with pyrite and/or its weathering products ("limonites").

Moving southward from Rio Marina along the coast, a quite distinctive geological and mineralogical picture appears: in fact, rock outcrops up to Capo d'Arco predominantly belong to Trevisan (1950)'s Complex II, whereas the main iron oxide is magnetite rather than hematite. Pyroxene-epidote-ilvaite skarn bodies, carrying usually minor amounts of iron minerals (magnetite, pyrite and pyrrhotite) - which justified limited exploitation activity in the past - extensively replace marbles and calcareous phyllites at several places (Torre di Rio, Porticciolo, Ortano and Capo d'Arco).

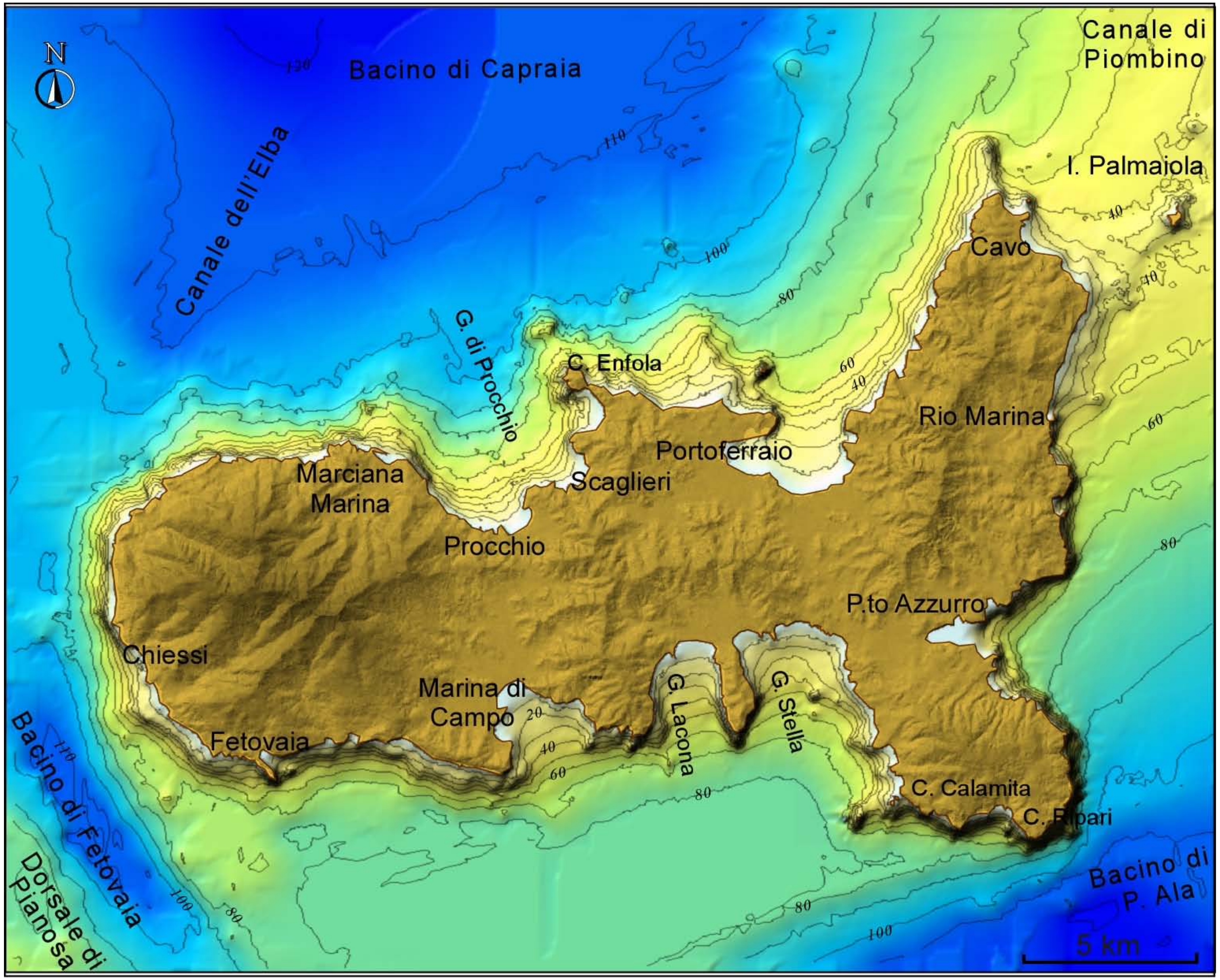


Fig. 12 – Morpho-bathimetry of the shelf around the Elba Island.

The famous iron deposits of Punta Calamita, Ginevro, and Sassi Neri are located at the southern margin of the M.te Calamita peninsula (Fig. 10). At Punta Calamita huge skarn bodies occur at the contact “Gneiss di Calamita”/marbles: their mineralogy mainly includes ilvaite, hedenbergite, amorphous silica, goethite, epidote and andraditic garnet. Ore minerals are mainly constituted by magnetite (and kenomagnetite) pseudomorphs after earlier hematite, a very peculiar feature with respect to common iron skarns, where magnetite is the primary iron oxide. The Ginevro and Sassi Neri deposits show very peculiar mineral associations. At Ginevro, for instance, skarn mineralisation is dominated by the presence of a rare amphibole, ferropargasite, associated with grossularite-almandine garnet and only minor amounts of hedenbergite, ilvaite and epidote. The main ore mineral is magnetite.

As more extensively discussed elsewhere (cf. Tanelli and Lattanzi, 1986; Lattanzi et al., 1994; Benvenuti, 1996; Tanelli et al., 2001), no completely satisfactory genetic model has been so far developed for iron deposits of eastern Elba Island. The general lack of detailed and updated studies on the various iron ores, as well as the complex and still partially obscure tectono-stratigraphic relationships of their host-rock do not allow to draw definite conclusions, even if the “syngenetic/hydrothermal-metamorphic” model (b) above seems to better explain the geological setting and the mineralogical, textural and compositional features of some deposits, like Rio Marina - Valle Giove (Deschamps et al., 1983), P.ta Calamita - Poggio Polveraio (cf. Torrini, 1990) and Sassi Neri (Del Tredici, 1990).

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THE GEOLOGICAL FEATURES OF THE MARINE AREA AROUND THE ELBA ISLAND

The continental margin of the Tuscan Archipelago is a relatively stable tectonic area, surrounded by important subsiding basins. To the N it is separated by the Viareggio Basin through the Livorno Line, while to the south a gradual transition to the most depressed areas exists. To the west this margin is bounded by the deep Corsican Basin which separates it from the Corsica Isle. To the E the Piombino Channel is the way between the Elba Island and the continent, working as a real connection bridge during the Pleistocene low-standing phases of the sea level.
The main morpho-geological features of the area are represented by small islands, by the Elba Island (fig. 12) and by the Pianosa Ridge, an antiformal structure, with N-S axis, bordering the Corsican Basin. Minor but considerable basins characterize the inner margin. Most considerable for the extension and thick of sediments are Punta Ala Basin, Pianosa and Giglio Basin and, on the N side, The Capraia Basin.
The tectonics responsible for the origin and the present setting of Tyrrhenian Sea was extensional. Minor compressive or transpressive deformations are signaled by some Authors in the Plio-Pleistocene levels,, The recent geodynamic evolution (Upper Pleistocene-Holocene) has been characterized by limited subsidence of basin and by relative stability of islands. The Pianosa Ridge shows evidences of rising; it is the most active tectonic feature in the whole area.

Around the Elba Island the bathymetric area over -50 m is most characterized by outcrops of a pre-Tortonian substratum; limited sedimentary accumulations of the Stella, Lacona, Campo and Procchio Gulfs, represent the submarine extension of pocket beachs or, as in Portoferraio Bay, the result of deposition of silty-clayey sediments carried by coastal currents.
The outer shelf shows three different situations:
- the Plio-Quaternary levels in the Capraia Basin, organized as several eustatic sequences, reaches the thickness of about 500 m. The Basin is a tectonic depression surimposed on Apennines structures, subsiding and actually limited by a canyon called “Canale dell’Elba” which separates it from the northern part of Pianosa Ridge;
- the Punta Ala Basin is an important half graben, NS trending, up to 2 seconds deep. In the northern part of this Basin six sedimentary sequence are recognized, five of these are related to the sea level lowstandings of the Upper Pleistocene, while the six one includes Holocene sediments;
- to the south of Elba an erosion surface is covered by an Holocene sequence characterized by some sedimentary bodies defining a paleo-lagoon, formed during the post-glacial sea level rise.

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The “Canale dell’Elba” is a main morphological feature of the shelf. It coincides with tectonic limit between Caparia Basin and northern part of Pianosa Ridge and is partially interested by submarine erosion.

The tectonic setting of whole area (Fig. 13) is mainly determined by normal fault which cuts the Miocene and a lower part of Plio-Pleistocene sequences. Only near the Pianosa Ridge some compressive structures (faults and folds) deforms also the Upper Pleistocene showing that this Ridge is a very active compressive or transpressive structure.

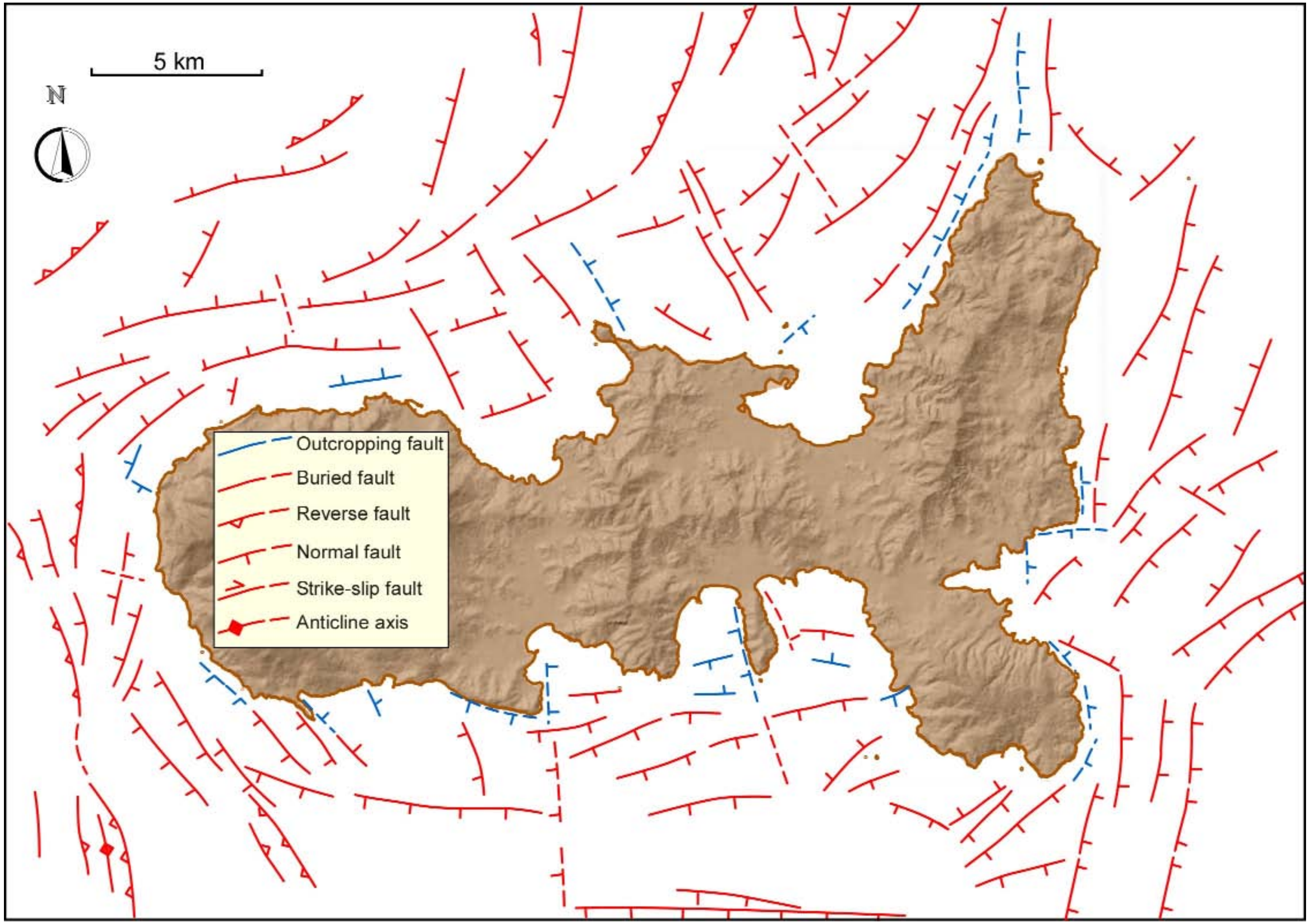

Fig. 13 - Structural sketch of the marine area around the Elba Island.

TECTONIC EVOLUTION OF ELBA ISLAND

The complex tectonic frame of the Island, which includes units of the Tuscan, Ligurian and Ligurian-Piedmont Domains, makes it difficult to reconstruct its geodynamic evolution. In any case three main Alpine stages can be pointed out.

Accretionary stage

This stage includes all the events that piled up the Ligurian and Ligurian-Piedmont units on the Tuscan units and culminated with the deformation of the paleomargin of the Adria block. These events of deformation and horizontal displacements began in the oceanic domain the Late Cretaceous-Eocene (Figs. 14 and 15) and went on during the Late Eocene, Oligocene and Early-?Middle Miocene with the collisional and ensialic phases (Fig. 16) (Boccaletti et al., 1980; Principi and Treves, 1984; Carmignani and Kligfield, 1990). During these last events the Porto Azzurro, Capo d'Arco, Monticiano-Roccastrada, Tuscan Nappe units -but also the Acquadolce unit, which has a Ligurian-Piedmont affinity (its metamorphism was dated to 19-20 Ma, Deino et al., 1992)- acquired their main tectonic regional imprint. The Early-?Middle Miocene was also the time in which the sequences with *"Schistes Lustrés"* affinity thrust on Tuscan units, till east of Elba, in the southern Tuscany (Roselle, Monte Argentario areas).

Pre-intrusion extensional stage

The extensional phenomena are linked to the uplift and emersion of the Apenninic orogen, caused by both an isostatic re-equilibration at the end of the piling up of the nappes, and an uplift of the asthenosphere in the area where the Tyrrhenian sea will come into being (Boccaletti e Guazzone, 1972; Boccaletti et al., 1985, 1990; Malinverno e Ryan, 1986; Channel e Mareshal, 1989; Jolivet et al., 1991; Kastens e Mascle, 1990; Serri et al., 1991; Carmignani et al., 1995; Bortolotti et al., 2001a). The beginning of these processes in the Tyrrhenian area corresponds to the opening of the Corsica Basin during the late Burdigalian-Langhian (Bartole et al., 1991; Bartole, 1995) (Fig. 17). Likely, in the latest Middle Miocene-earliest Late Miocene also the

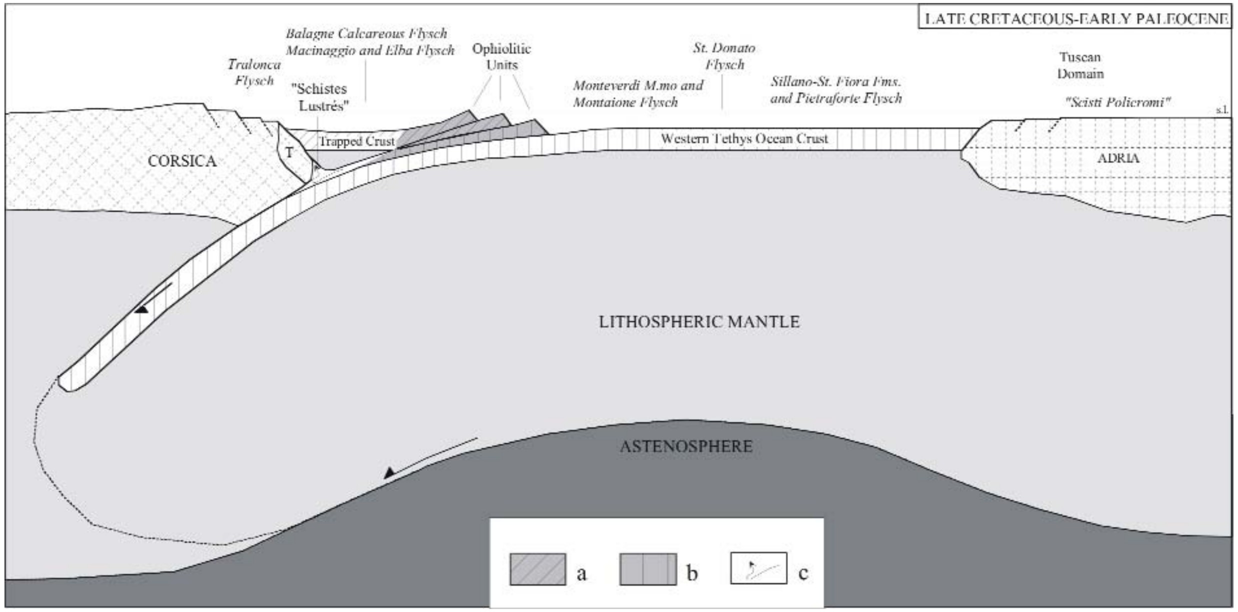

Fig. 14 - Schematic cross-section of the orogenic system Corsica-Northern Apennines during Late Cretaceous-Early Paleocene times. **T-** Tenda Massif; **a-** Upper portion of the accretionary wedge (AW) formed by trapper crust material; **b-** Lower portion of AW formed by ocean crust; **c-** Upwards flow of the deepest portions of AW. For explanation, see text. The legend for the geological units is shown in Fig. 17. Note that in this and in the following figures, Italic types are used for the formations during their deposition, normal types for the accreted units; the thickness of sediments and tectonic units is exaggerated.

beginning of exhumation of the Elba tectonic building took place, through low angle faults, which dismembered and juxtaposed units coming from different structural levels (e.g. the tectonic intercalation of the Acquadolce unit between two Tuscan units.

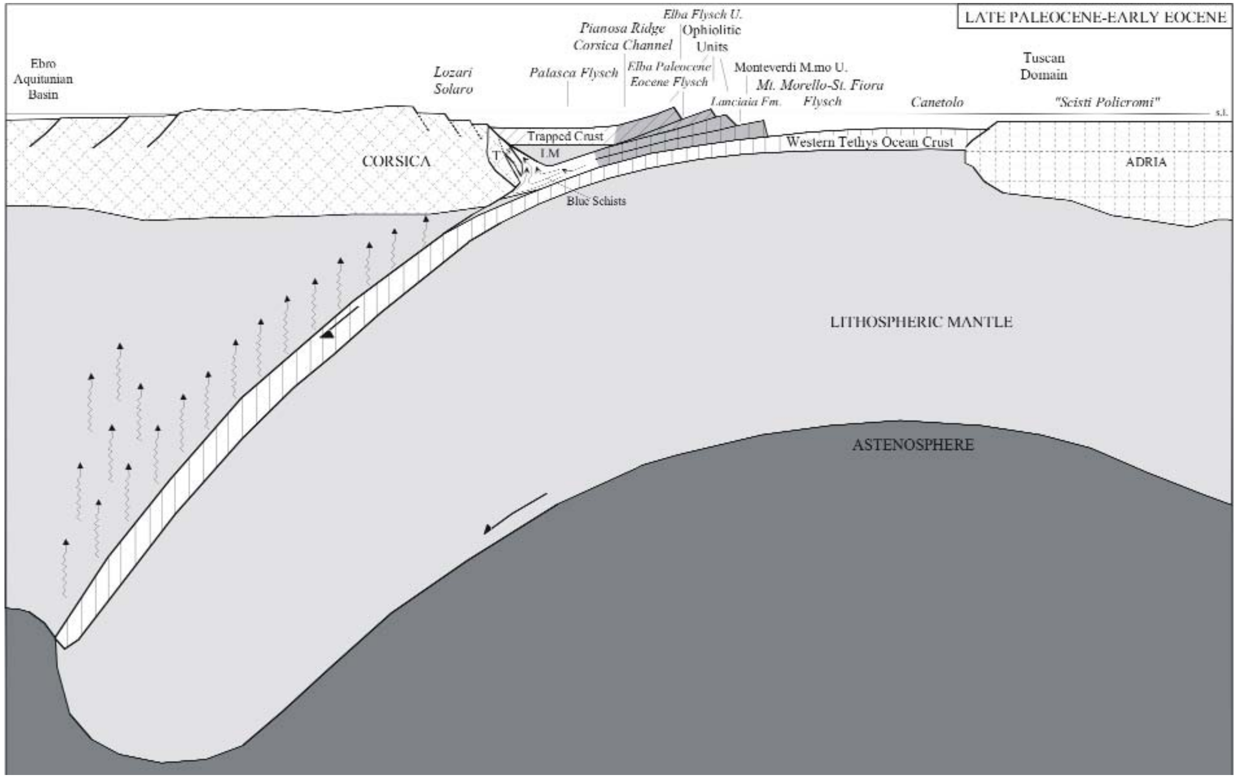

Fig. 15 - Schematic cross-section of the orogenic system Corsica-Northern Apennines during Late Paleocene-Early Eocene times.
T- Tenda Massif; **S-** Serra di Pigno slice; **zigzag arrows-** Path of the hydrating fluids rising from the subducting slab. For the other symbols see Figs. 14 and 17. For explanation, see text.

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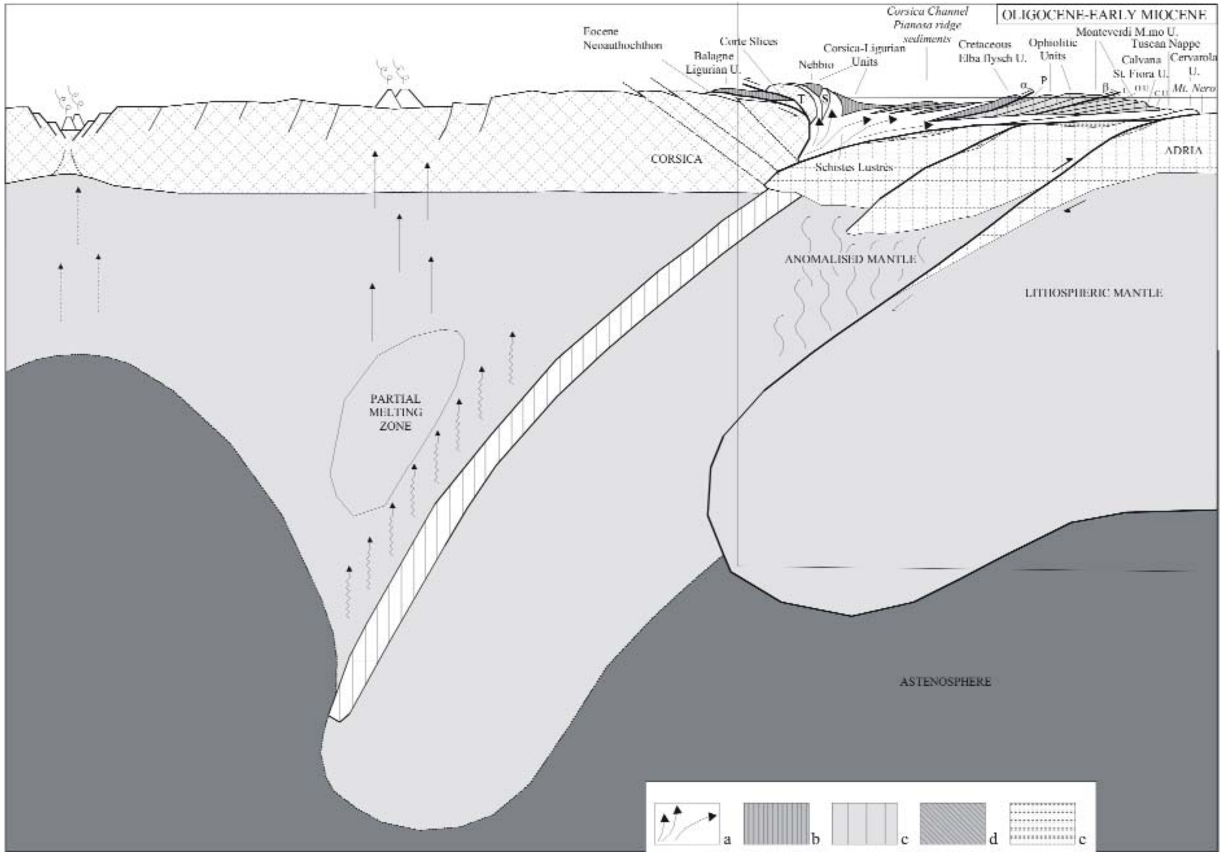

Fig. 16 - Schematic section of the orogenic system Corsica-Northern Apennines during Oligocene-Early Miocene times. **a-** "Schistes Lustrés" and calcschists with ophiolites (ductile metamorphic rocks of the deep portion of AW: AU and GU in Central and Eastern Elba) and their exhumation (upwards and eastwards) trajectories; **b-** Corsica Ligurides and Internal Ligurides; **c-** External Ligurides and epi-Ligurides; **d-** metamorphic Tuscan unit. **Vertical arrows-** feeders of the calc-alkaline offshore magmatism of Sardinia and Western Corsica. Vertical hatched arrows- feeders of the tholeiitic magmatism linked to the opening of the Ligurian-Balearic basin. Probable out-of-sequence thrusts: α**-** Cretaceous Elba flysch onto Paleogene Elba flysch; β**-** Monteverdi Marittimo unit (internal portion) onto the Lanciaia fm. The area outlined is shown in Fig. 17. For explanation, see text.

Syn- and post-intrusion stage (Figs. 18 a, b, c)

The emplacement and uplift of the Messinian main intrusive bodies (i.e. the Monte Capanne and La Serra-Porto Azzurro monzogranites) caused the thermometamorphism and the last horizontal movements of the Elba units through the low-angle Central Elba fault (CEF; Maineri et al., 2003; Westerman et al., 2004) and the younger Zuccale fault and Colle Reciso fault (Bouillin et al., 1993; Pertusati et al., 1993; Daniel & Jolivet, 1995; Bortolotti et al., 2001a; Maineri et al., 2003; Collettini et al., 2006a, 2006b). For example, the main thrust surface which separates the Porto Azzurro unit from the overlying tectonic pile (Zuccale fault), is clearly post-intrusion: all the dykes, belonging to the La Serra-Porto Azzurro pluton and crossing the Porto Azzurro unit host rocks, end at the fault surface. These last horizontal movements are related, according many authors, to

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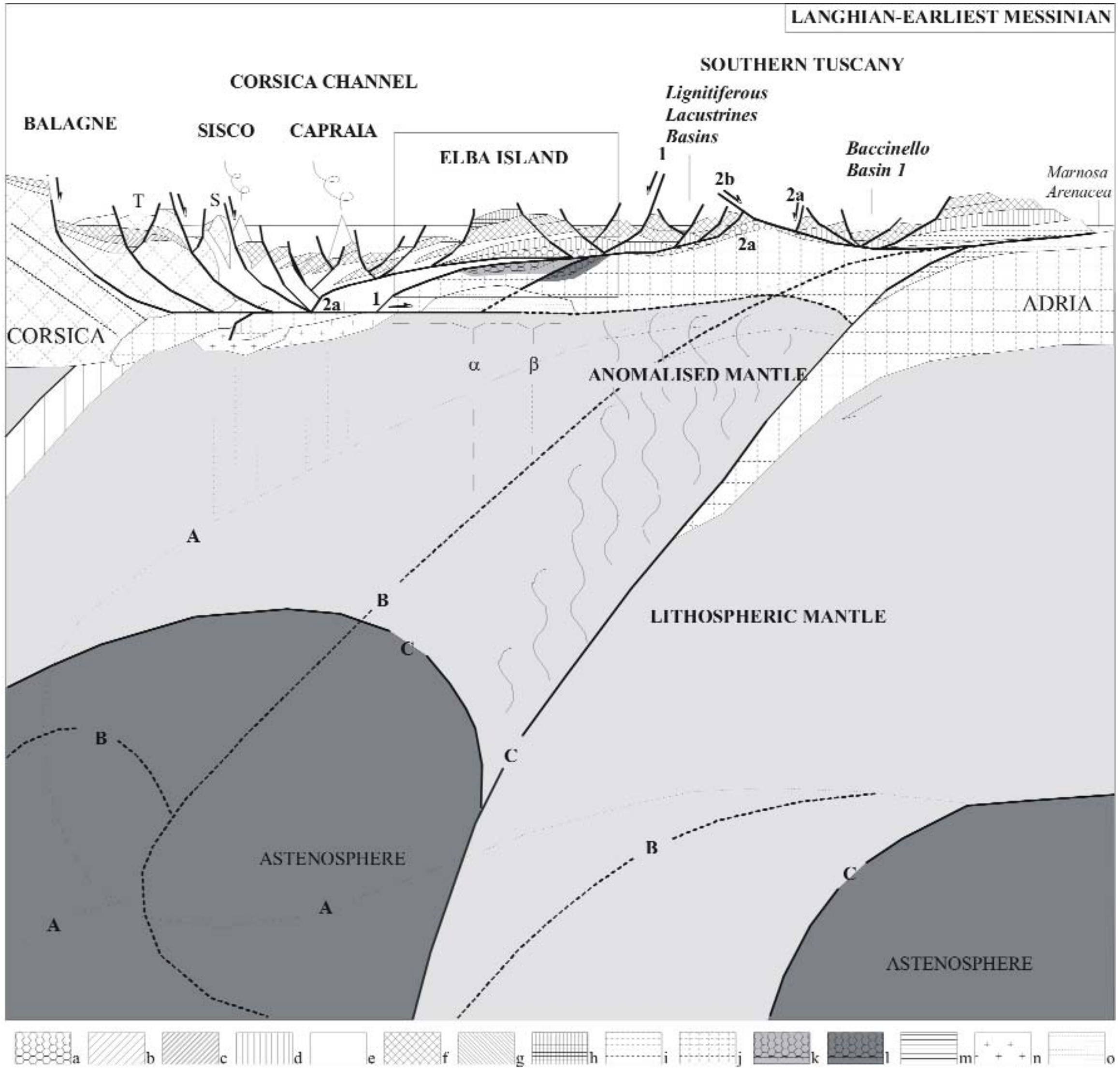

Fig 17 - Schematic section of the orogenic system Corsica-Elba-Northern Apennines during Langhian-earliest Messinian times. **a-** Tuscan metamorphic units; **b-** Corsica Middle Eocene neoautochthon; **c-** Corte slices; **d-** Tuscan Nappe; **e-** “Schistes Lustrés” and calcschists with ophiolites; **f-** Ligurids; **g-** Elba Paleogene flysch unit; **h-** Elba Cretaceous flysch unit; **i-** non metamorphic Cervarola and Umbria units; **j-** Adriatic metamorphic basement s.l.; **k-** internal Tuscan metamorphic basement (Ortano unit –UO- in the Elba Island); **l-** external Tuscan metamorphic basement (Porto Azzurro unit –PU- in the Elba Island); **m-** Neogene lacustrine deposits; **n-** underplating magmatic bodies; **o-** anatectic zone beneath Elba Island. **1** and **2a**- progressive west-vergent master detachment faults; **2b**- east-vergent master detachment fault. **A**, **B**, **C**- successive boundaries between the subducting slab and the lithospheric and asthenospheric mantle, due to the eastwards shifting of the subduction zone. Hatched lines- feeders of the supra-subduction magmatism (α**-** of the Monte Capanne and β**-** of the La Serra-Porto Azzurro plutons). **T-** Tenda Massif. **S-** Serra di Pigno slice. For explanation, see text. The area outlined is shown in Fig 18.

the gravity sliding (detachments) of the tectonic units, due to the uplifting of the magmatic domes (Pertusati et al., 1993; Boullin et al., 1994; Daniel and Jolivet, 1995; Bortolotti et al., 2001a) since 6.7 Ma (Maineri et al., 2003). The final stages of the uplift of the partially cooled La Serra-Porto Azzurro monzogranitic body caused also the deformation of the Zuccale fault. In the Early Pliocene, the main part of high angle, generally

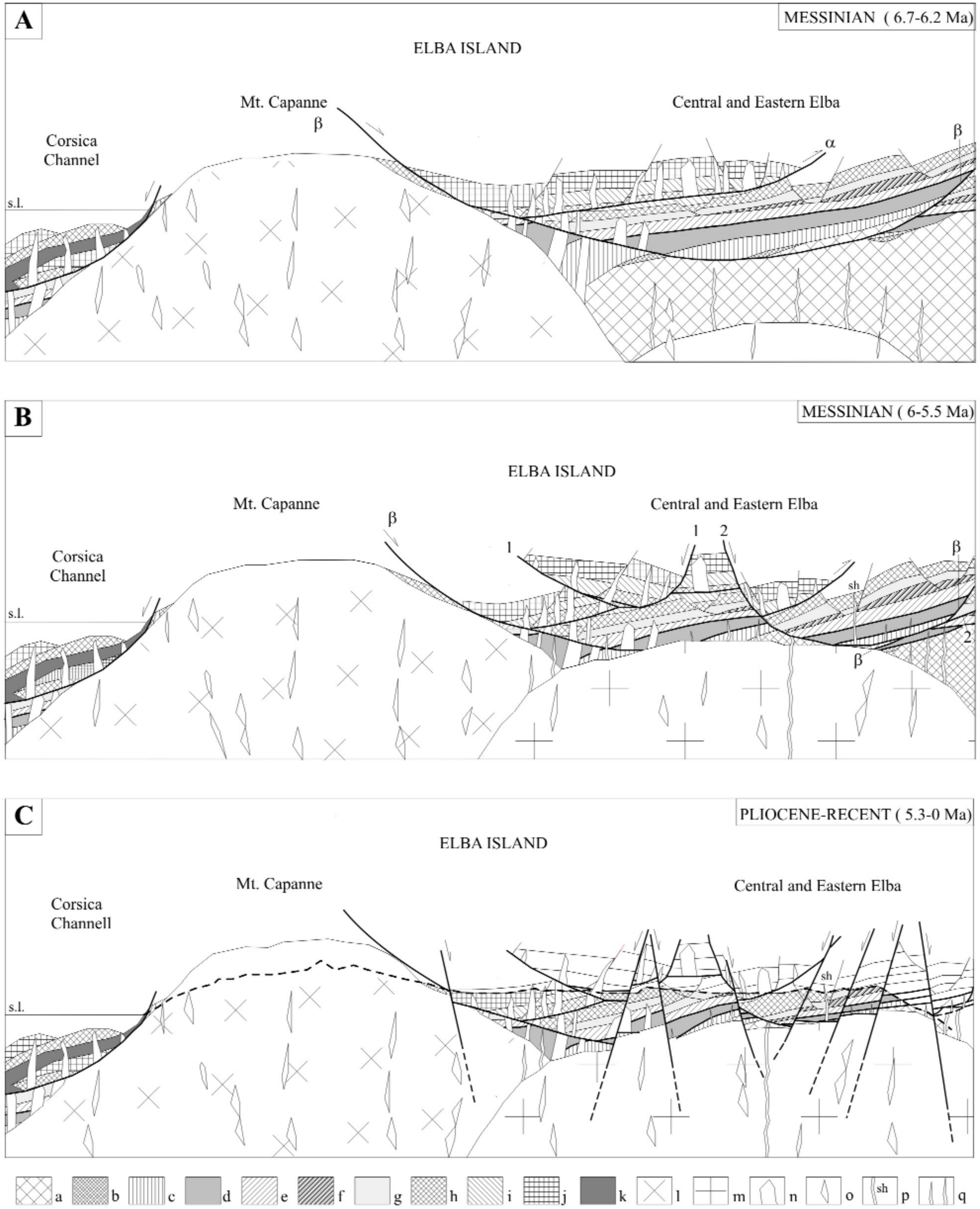

Fig. 18 - Schematic sections of the Elba Island from 6.7 to 0 Ma (uppermost Messinian to Present). **A-** Early Messinian (6.7-6.2 Ma). Early Messinian final uplift of the Monte Capanne pluton and the quasi-contemporaneous development of detachment faults (α-CEF 1 and β-CEF 2), producing westwards and eastwards delamination of the tectonic pile; **B-** Messinian (6-5.5 Ma). Final uplift of the La Serra - Porto Azzurro pluton and development of ZDF-Zuccale (2) and RDF- Colle Reciso (1) divergent delaminations; **C-** Late Messinian high angle normal faulting and the contemporaneous formation of the ore mineralisations. The sketched line represents the present W-E Monte Capanne-Monte Arco topographic section. **a-** Paleozoic successions of the Porto Azzurro unit; **b-** Mesozoic cover of the Porto Azzurro unit; **c-** Ortano unit; **d-** Acquadolce unit; **e-** Monticiano Roccastrada unit; **f-** Tuscan Nappe; **g-** Grassera unit; **h-** Ophiolitic unit; **i-** Paleogene flysch unit; **j-** Cretaceous flysch unit; **k-** "Schistes Lustrés" and calcschists with ophiolites; **l-** Monte Capanne pluton; **m-** La Serra-Porto Azzurro pluton; **n-** aplitic and porphyritic dykes within the Ligurids; **o-** acidic and basic dykes and enclaves in the plutonic bodies; **p-** shoshonitic dykes; q-aplitic and microgranitic dykes in the Porto Azzurro unit.

N-S-trending normal faults of eastern Elba were originated and were sealed by the hematite-rich ores (5.3 Ma in Lippolt et al., 1995; Bortolotti et al., 2001a).

Field Trip Itinerary and Stops

The general map of the itineraries and Stops is shown in Fig. 19. The itineraries are three: Eastern Elba, Western and Central Elba and Calamita promontory.

EASTERN ELBA ISLAND

The metamorphic tectonic units and the Fe-ores between Porto Azzurro and Rio Marina (Eastern Elba).

Fig. 19 - General map of the itineraries and Stops in the Elba Island.

In the Eastern Elba Island the tectonic pile is well exposed (Barberi et al., 1967a; 1969; Bortolotti et al., 2001a; Babbini et al., 2001). In this part of the field trip (Fig. 16) we will visit the best outcrops of the lowermost tectonic units (from the bottom: Porto Azzurro, Ortano, Acquadolce and Monticiano-Roccastrada units), to recognise their tectonic relationships (Fig. 2) and the setting of the hosted Fe-ore bodies. From Portoferraio to Porto Azzurro. A few kilometres beyond Porto Azzurro, along the road to Rio Marina, we turn right to the Spiaggia di Reale (Fig. 20).

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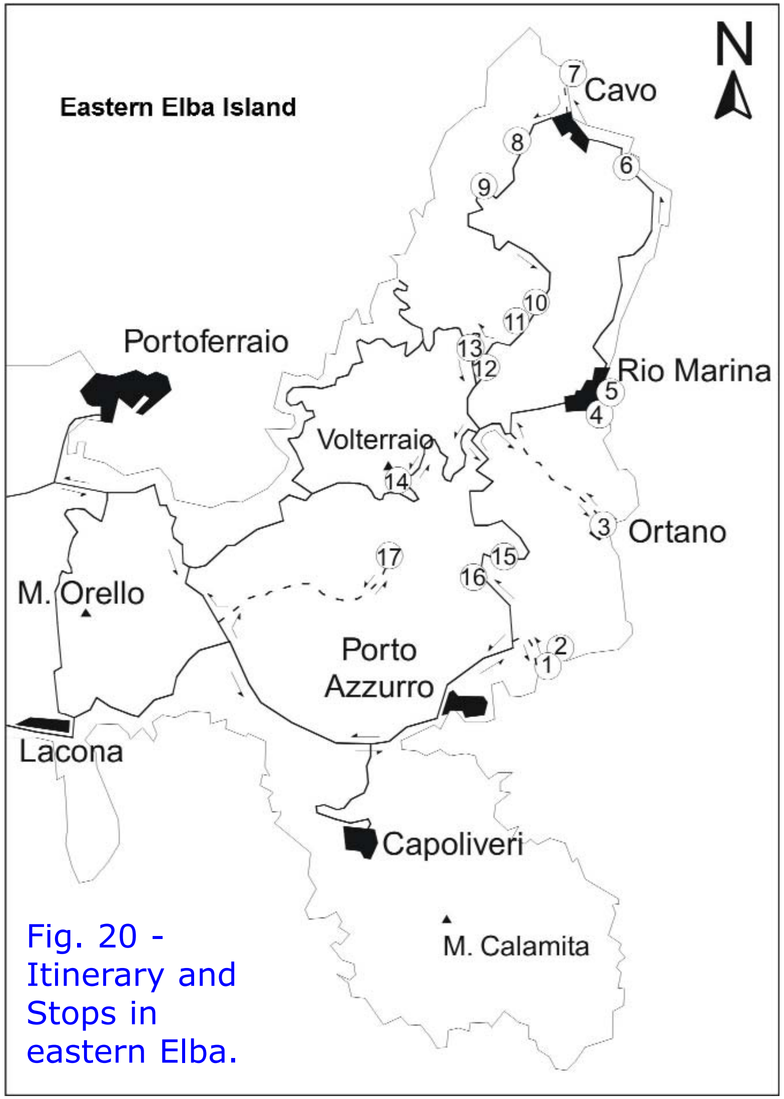

Fig. 20 - Itinerary and Stops in eastern Elba.

Stop 1. The tectonic units of the *Spiagge Nere* area

In this area (Fig. 21), the contact (Zuccale fault) of the Porto Azzurro unit with the overlying imbricated units (Acquadolce unit and Monticiano-Roccastrada unit) crops out.

a- Monte Calamita formation (Calamita gneiss Auctt. *pro parte),* is made up of grey to grey-greenish polydeformed

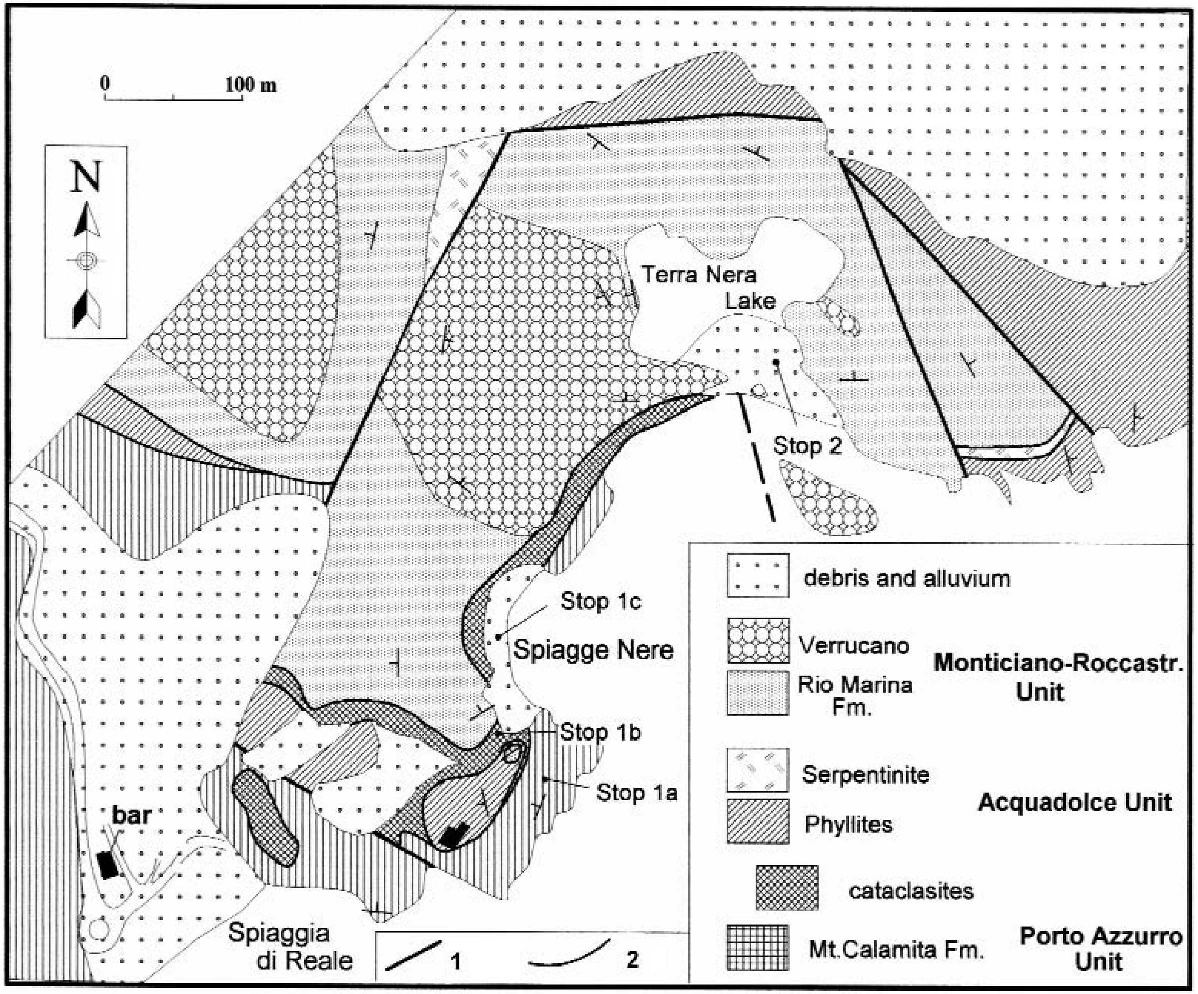

Fig. 21 - Geological sketch map of the Spiaggia di Reale-Spiagge Nere-Terranera mining area. 1) High-angle normal fault, 2) Low-angle fault.

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quartzitic phyllites and micaschists whose protolith is probably Paleozoic in age (Puxeddu et al., 1984; Pandeli et al., 1994). The Alpine main schistosity has an attitude of N120/45 or N310/25 and is strongly overprinted by static thermometamorphic minerals (e.g. static biotite and andalusite) due to the La Serra-Porto Azzurro monzogranitic intrusion (5.9 Ma radiometric age: Borsi & Ferrara, 1971; Saupé et al., 1982; Ferrara & Tonarini, 1985; 1993; Maineri et al., 2003), which crops out west of this area (Barbarossa beach). The metasedimentary rocks do not show Fe-mineralisations and are cross-cut by centimetric/decimetric white tourmaline-bearing aplites, which belong to the dyke network of the Messinian granitoid. The structural framework of the Monte Calamita fm. at the mesoscale is characterized by centimetric/decimetric, tight to isoclinal folding (F2) of the main continuous schistosity (related to the first Alpine tectono-metamorphic event S1) which were deformed by younger open to close folds, metric to decametric in size and following faults. In particular, the D_2 folds show a N-S to NE-SW orientation of the axis and a west-low dipping axial surface; the D_3 folds are characterised by a wide spread of the axial strike (mainly in the SW and NW quadrants) and a sub-vertical axial surface. Moreover, a pervasive zonal to discrete crenulation cleavage is associated to F_2, while fracture cleavage is connected to D_3 folding. Relic centimetric D_1 isoclinal folds are rarely preserved because of the D_2 transposition. Moreover, The D_1 and D_2 Alpine structures completely transpose the Hercynian structures eventually present in these rocks (e.g. the pre-Alpine intrafolial schistosity relics in some of the typical outcrops of the Monte Calamita fm. in the Monte Calamita promontory). F3 deformed the aplitic dykes which clearly cut through the ductile D_1 and D_2 structures. A centimetric to decimetric-spaced, high angle fracture cleavage (generally with a N20° to N50° dip direction in the Terranera area), which displaces the Monte Calamita fm. and the included aplite dykes, and is consistent with the axial direction of the latest folds (A_3). These dykes are also locally dissected by N250-trending low-angle shear bands. The top contact with the overlying mineralised cataclastic horizon is sharp and the dykes end abruptly against this surface (Fig. 22). The contact is gently dipping to the W/WNW. Looking to the North, we can see a fine view of the Terranera Lake and of the mining area. We go 5-6 m up the cliff to the beginning of a canyon which is cut in the cataclastic rocks.

b- Zuccale cataclasite (Zuccale fault). It is an about 10 m-thick horizon consisting of an ochre-yellowish, often foliated polymictic breccia. Its clasts (millimetric up to 10-15 cm) derive mostly from the underlying Monte Calamita fm. (micaschists and phyllites cut by aplitic dykes more or less kaolitised) and from the overlying Monticiano-Roccastrada unit (e.g.: the black graphite phyllites of the Rio Marina fm.). The angular/subangular

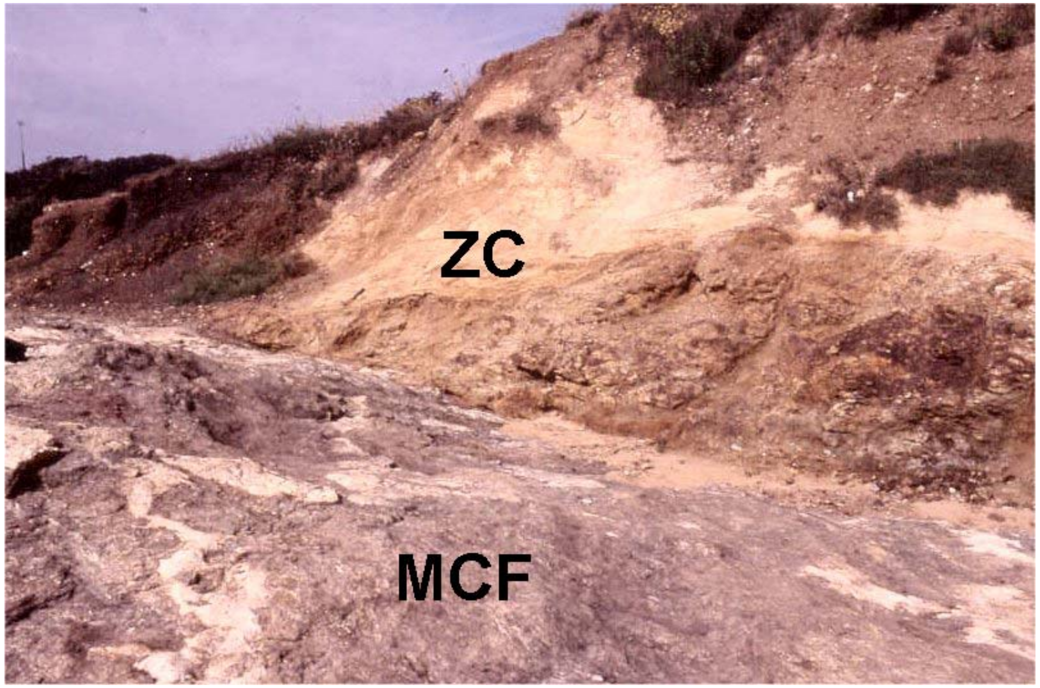

Fig. 22 - Contact of the Monte Calamita fm. (MCF) with the overlying Zuccale cataclasite (ZC) at Terranera. The aplitic dykes, intruded in the Monte Calamita fm., abruptly end against the cataclasite.

clasts are generally aligned along the foliation and the whole rock is affected by pervasive Fe-oxides /hydroxides mineralisations and by decimetric/metric asymmetric to overturned W-facing folds. Moreover, clasts and metric, more or less mineralised, tectonic slices of the Acquadolce unit (green quartzitic phyllites) are included in the breccia; one of these slices, tectonically capped by the graphitic Rio Marina fm., crops out along the road to the cottage.

The Carboniferous-Permian Rio Marina fm. (Monticiano-Roccastrada unit) tectonically rests on the cataclastic horizon. This formation includes black graphitic phyllites with grey quartzitic metasiltstones and metasandstones locally imprinted by thermometamorphic biotite or andalusite spots. We continue down to Spiagge Nere where the tectonic breccia is well exposed.

c- Zuccale cataclasite. Here the foliated breccia (plunging to the N or W) includes also many carbonatic and rare foliated, more or less chloritised serpentinite clasts in a dominant phyllitic-carbonate matrix. Metric tectonic slices of whitish to yellowish bedded marbles and grey-whitish calcschists are locally present within the cataclastic horizon. These carbonate rocks probably belong to the Acquadolce unit (Ortano Marbles, calcschists) or correspond to the Mesozoic cover of the Porto Azzurro unit. The marbles show pervasive cataclastic textures, while the calcschist and phyllite levels are also boudinaged even at a sub-centimetric scale. Microscopic observations reveal the absence of blastesis along the pervasive foliation of the cataclastic horizon, indicating that the thermometamorphism predate the cataclastic event. These data point to a “cold” nature of this cataclastic horizon, which was formed after the intrusion of the La Serra-Porto Azzurro

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monzogranite. Therefore, the foliation of the breccia seems to be due to mechanical iso-orientation of its clastic elements, possibly in a fluid-rich environment (see also Collettini et al., 2006a, 2006b). Several kinematic indicators (asymmetry of folds, intrafolial "mantled" or faulted clasts, etc.) reveal a "top to NE" or a "top to SW" sense of shear. The opposite sense of shear could suggest a repeated utilisation of this cataclastic horizon during the last emplacements of the eastern Elba units. Finally, in this outcrop the foliation appears gently folded, possibly by a later deformation event.

The promontory, which closes to the north Spiagge Nere, is made up of the Monte Calamita fm. (see before. a-). The contact with the overlying cataclasite horizon has an antiformal shape. The cataclastic horizon disappears northwards, below the quartzite and the green to whitish-pearly phyllites of the triassic "Verrucano". This latter represents the core of a NW-SE trending syncline of the Monticiano-Roccastrada unit. We reach the eastern part of the beach in front of the acidic Terranera Lake.

Stop 2. Fe-ores of the Terranera area

Here (Fig. 21) the graphitic phyllites and quartzites of the Rio Marina fm. crop out, cross-cut by N320-360 trending fractures and faults filled by hematite±quartz±adularia mineralisations. Easthwards, beyond a main high-angle mineralised fault, the uppermost levels of the Acquadolce unit (serpentinite altered in talcschist tectonically covering chloritic phyllites and metasandstones) underlie the Rio Marina fm.

The Fe-ores of the Terranera mine. Mining works at Terranera started in the 18th century and ended about 30 years ago. They were partially carried out by open pit excavations, now occupied by the Terranera Lake, fed by both fresh and marine waters. The exploited ores consisted of lenses of Fe oxides (hematite with minor magnetite) and pyrite at the tectonic contact between the Paleozoic basement (Rio Marina fm., Trevisan's Complex III) and the overlying "Verrucano" succession. The upper portion of the deposit was predominantly constituted by limonitic masses, derived from the exogenous alteration of pyrite. According to Lotti (1886), the iron orebody extended even below the low-angle normal fault (Zuccale fault) which separates the Rio Marina fm. from the underlying Calamita fm. (Trevisan's Complex I). The genetic processes leading to the development of this deposit still await to be better defined. Ongoing research should try to solve several problems, among which the predominance of hematite over magnetite (which is otherwise the dominant Fe oxide south of Rio Marina) and the relationships with the skarn bodies (extensively cropping out at the nearby Punta delle Cannelle).

We come back to Spiaggia di Reale and continue the road to Rio Marina. Along the road we cross many outcrops of ophiolites and of their cover (Ophiolitic unit; see Stop 15). After the San Felo Pass, the serpentinite sheet at the top of the Acquadolce unit is visible on the right, at the Monte Fico quarry (see Stop. 3-i). At the round-about of Rio Elba, we turn to the right and reach the Ortano residence.

Stop 3. The tectonic stack of the Ortano Valley (Ortano, Acquadolce, Monticiano-Roccastrada, Tuscan Nappe, Gràssera units)

We walk along the southern part of the residence (Fig. 23) as far as the wharf ruins; then we continue southwards along the quartzitic cliff (path) until a landslide. Near the sea, phyllitic-quartzitic rocks crop out which represent the geometrical base of the non-fossiliferous, W-plunging **Ortano unit** (Fig. 24). The Ortano succession recalls the Ordovician lower-middle part of the well-known Tuscan Paleozoic basement of the Apuan Alps (Pandeli et al., 1994) (Fig. 25), and of the central Sardinia (Nappe Zone Auctt., Pandeli & Puxeddu, 1990; Duranti et al., 1992). In particular, this unit corresponds to the "Acidic metavolcanites and metasediments" (porphyroids and porphyritic schists) and "Transgressive metasiliciclastic cover" (Silver-grey phyllites and quartzites, Capo d'Arco schists). The lithological-petrographical similarities of the

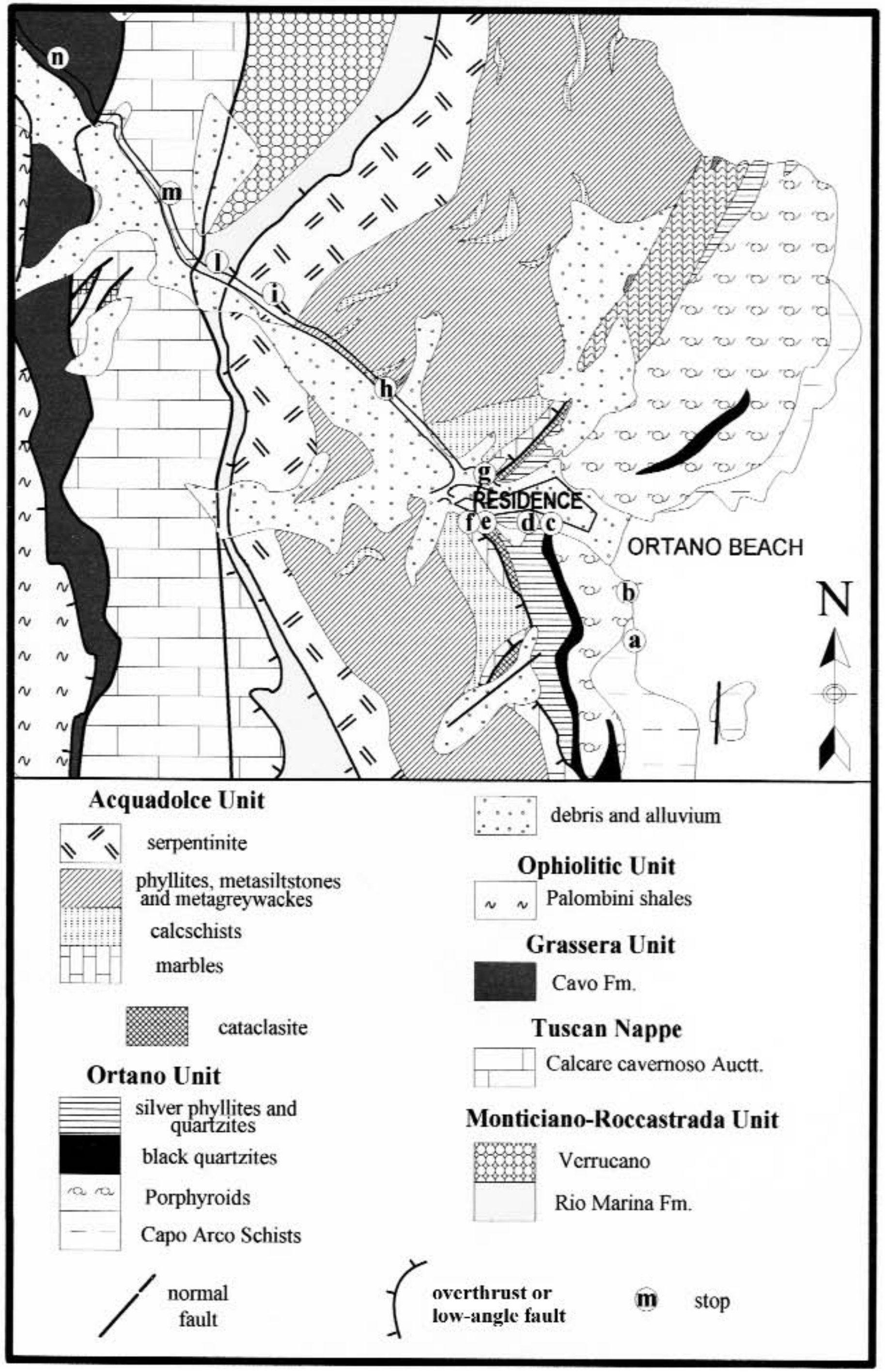

Fig. 23 - Geological sketch map of the Ortano Valley.

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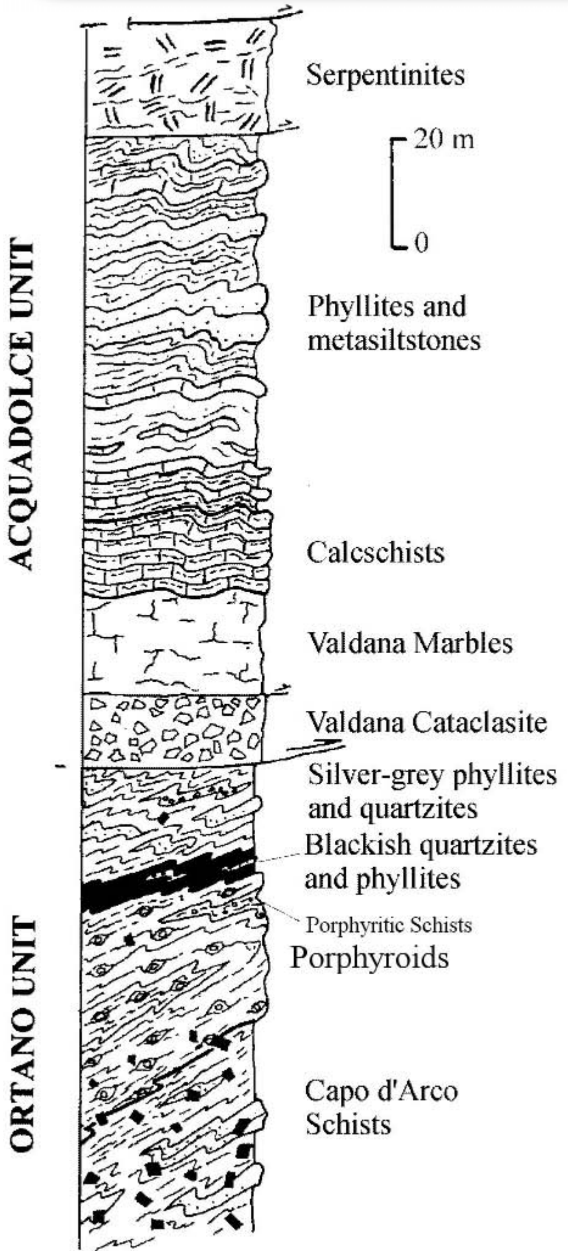
Fig. 24 - Tectonic-stratigraphic sketch of the Ortano and Acquadolce units (thicknesses of the formations, approximate).



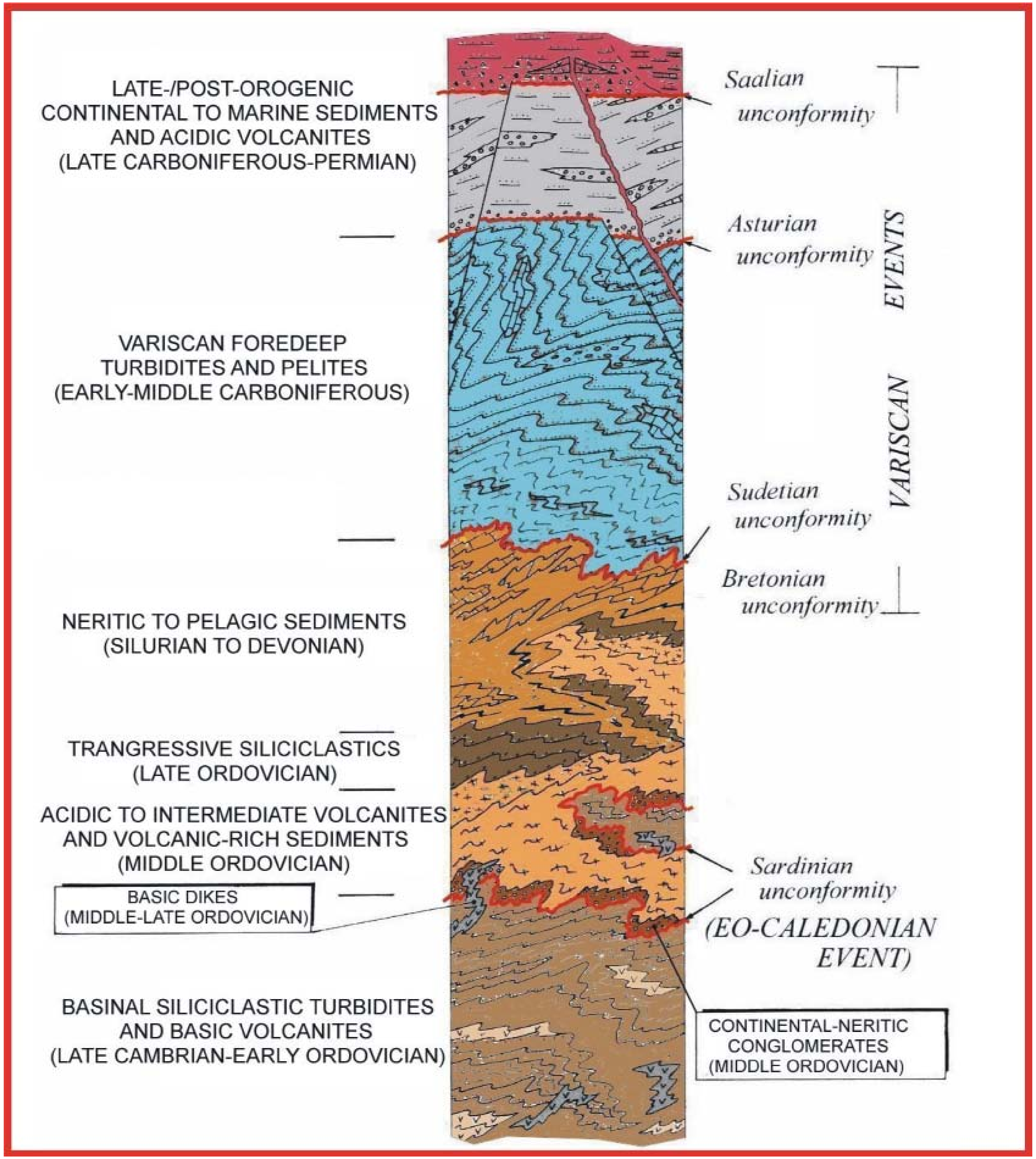


Fig. 25 - Restored "type"-succession of the Northern Apennines Paleozoic basement (after Elter & Pandeli, 1996).

Capo d'Arco schists and the Silver-grey phyllites and quartzites (below and above the porphyroids, respectively) could suggest that they represent the same stratigraphical unit at the top of the porphyroids. Therefore, the Ortano unit as a whole may represent an east-vergent megafold with the porphyroids at the core.

a- Capo d'Arco schists. (Ortano schists Auctt.) (Ordovician?). They consist of grey-greenish to brown phyllites, quartzitic phyllites, micaschists and minor quartzites which include typical syn- and post-tectonic quartz veins and local thermometamorphic "spots" (andalusite, cordierite) . Locally, graphitic phyllite levels are present. In the surrounding areas, the Capo d'Arco schists include lenticular, metric to decametric horizons of coarse pale-grey/whitish quartzites and quartzitic metarudites. Looking to the SE, the morphological discontinuity in the Isolotto d'Ortano corresponds to the contact between a quartzitic body and the metapelites of the Capo d'Arco schists. Coming back along the path up to the wharf, we can see well exposed outcrops of the overlying porphyroids.

b- Porphyroids (Middle Ordovician?). They are massive to poorly stratified, grey to brownish acidic metavolcanites which are characterised by a millimetric (3-4 mm) augen texture due to quartz and feldspar (sanidine) porphyroclasts. In the middle and upper parts of this unit, the levels of augen quartzites and quartzitic phyllites ("Porphyritic schists") probably correspond to volcanic-rich metasediments. Post-tectonic veins of chlorite+quartz+epidote±tremolite/actinolite locally occur. We continue along the white road until a little square in front of the theatre of the residence. At the top of the porphyroids, black rocks are exposed.

c- Blackish quartzites and phyllites (Middle Ordovician?). This is a metric horizon of alternating dark-grey/black quartzitic phyllites and 10-20 cm-thick fine-grained quartzitic levels. These rocks pass upwards to:
d- Silver-grey phyllites and metasandstones (Late Ordovician?). They are shining silver-grey phyllites with pale grey/whitish, decimetric to metric, locally coarse-grained quartzitic metasandstones and metaconglomerates. These lithotypes are locally crosscut by quartz±chlorite veins.
Walking along the road of the residence, we reach the southern quarry, where we can observe the lower formations of the metamorphic **Acquadolce unit,** plunging westwards. The Acquadolce unit (Fig. 4) was traditionally interpreted as a Mesozoic-Cainozoic Tuscan-type metamorphic sequence (Trevisan, 1951; Barberi et al., 1969; Perrin, 1975; Boccaletti et al., 1977; Keller & Pialli, 1990) which represented the "cover" of the underlying Paleozoic rocks (Ortano unit). On the contrary, Duranti et al. (1992) and Pertusati et al. (1993) considered it as a part of the Ophiolitic unit (Trevisan's Complex IV*)* which was deformed and metamorphosed

by the intrusions of the Messinian-Pliocene granitoids. On the other hand, Corti et al. (1996), Bortolotti et al. (2001a) and Pandeli et al. (2001a) correlate this succession to the “Schistes Lustrés” of the Gorgona Island; the analogies of this sequence with the “Schistes Lustrés” were also pointed out by Termier (1910).

e- Valdana cataclasite**.** (“Calcare Cavernoso” or “Vacuolar dolomitic limestone” Auctt.). It is a 10-15 m thick, pale grey to yellowish carbonate rock, roughly stratified and affected by variable recrystallisation which often obliterates the previous textures. Locally it is a vacuolar, well-cemented calcareous breccia with marble and subordinate phyllite clasts (more frequent in the lower part). Dolomitic horizons are locally present. In spite of the recrystallisation, cataclastic textures are frequent at the microscopic scale as scattered Fe-oxides and pyrite, especially in the carbonate-micaceous-quartzitic matrix. This unit is considered a tectonic breccia formed during the emplacement of the Acquadolce onto the Ortano unit.
Locally, a thermometamorphic imprint is present (clinopyroxene±garnet±amphibole). Thick skarn (hedenbergite±ilvaite) horizons are associated to the cataclasite north of the Ortano Valley (Ortano pyrite±pyrrhotite mine). Therefore, this horizon represented an important pathway for the metasomatic fluids and Fe-ores (e.g. the Tignatoio and Porticciolo skarns and ores, north of the Ortano area, along the same structural alignment).

f- Valdana Marble (“Ortano Marble” Auctt., Cretaceous?). This unit is about 15 m thick and includes massive grey-whitish, medium to coarse grained, saccharoidal marbles with local yellowish bands and horizons of dolomitic marble. Rare and discontinuous millimetric phyllitic levels also occur. The transition with the overlying calcschists is marked by an about 1 m thick alternating marble-calcschist horizon. Along this contact decimetric folds are locally present. We cross the valley and reach the same contact behind the souvenir shop.

g- calcschists. This more than 50 m thick unit is made up of 10-40 cm thick, grey and grey-greenish calcschists beds with millimetric grey green to black phyllite layers. Siliceous white quartzitic bands and nodules (metacherts) are present, particularly in the middle-upper part of the succession along the road (about 100 m after the souvenir shop). Veins of calcite±pyrite±quartz and adularia are ubiquitous. The contact with the overlying phyllites with calcschists intercalations is gradual. We continue along the road for about 200 m.

***h- Grey and greenish phyllites and metasiltstones**,* with calcschist intercalations (Early Cretaceous). They are represented by a more than 250 m-thick succession of grey, grey-greenish and black quartzitic phyllites and metasiltstones with local decimetric/metric levels of calcschists and rare grey-greenish metagraywackes. Post tectonic veins of adularia±tremolite/actinolite±albite are locally present. North of Ortano (Porticciolo area), Duranti et al. (1992) found radiolarians, calpionellids and globigerinids of Early Cretaceous in the carbonate intercalations. 200 m ahead along the road, to the right (near a house) the serpentinite sheet at the top of the Acquadolce unit crops out.

i- Serpentinite. It is massive dark green serpentinite (lherzolite) about 100 m thick. Local shear bands and foliation are present. We reach the curve of the road close to a small house (to the left), where the Monticiano Roccastrada unit is thrust onto the serpentinite of the Acquadolce unit. The **Monticiano Roccastrada unit** includes here only the Rio Marina fm.

l- Rio Marina formation (Late Carboniferous-Early Permian). In this section the maximum thickness of this formation is about 50 m. Its lithologies are black graphitic phyllites and metasiltstones with grey quartzitic metasandstone intercalations. Post tectonic veins of quartz±pyrite are locally observed. After the curve of the road, a high-angle, west-plunging normal fault (Terranera fault) puts in contact the Rio Marina fm. with the basal carbonate breccia (“Calcare Cavernoso”) of the **Tuscan Nappe**.

m- “Calcare Cavernoso”. Its thickness is about 150 m. A massive grey, cataclastic, calcareous-dolomitic breccia, locally characterised by vacuolar structures, is the dominant lithotype. At times, grey-pearly and greenish phyllitic clast and quartz grains are present. Calcite±Fe-oxides/hydroxides also occur. Horizons or metric boulders of poorly stratified triassic dolostones and dolomitic limestones are sometimes recognisable as well as karst alterations and sedimentary fillings (yellowish carbonate sand).
About 300 m ahead, we find the tectonic contact (by a system of high angle normal faults) (St. Caterina fault) between the “Calcare Cavernoso” and the **Gràssera unit** (Cavo fm., see Stops 8 and 10).

n- Cavo formation. It consists of grey-greenish and vine-reddish slates and siltstones with syn-/post-tectonic quartz veins. Local blackish manganiferous levels and rare siliceous limestone beds are present. The Gràssera unit tectonically underlies the Palombini shales of the Ophiolitic unit.
The trip continues coming to the round-about of Rio Elba and reaches the central square of Rio Marina (in front of the panoramic dock). We walk along the dock as far as the old tower with the clock (Torre di Rio o Torre degli Appiani) and then we took the road on the right, along the cliff.

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Stop 4. The calcschist bodies and the skarn of Torre di Rio

The calcschist bodies. Here the upper portion of lower subunit (Porticciolo subunit) of the Acquadolce unit crops out. It is represented by a NW-plunging succession of centimetric to decametric marbles and calcschists (a metric grey/whitish calcschist bed is well exposed along the road) with minor grey/greenish quartzitic phyllite intercalations. Going on the road, all the rocks show more and more evidence of hydrothermalism (yellow-green epidote) which obliterates the tectono-metamorphic texture. The appearance of fan-shaped hedenbergite crystals marks the contact with the Torre di Rio skarn.

The skarn of Torre di Rio. This skarn is exceptionally well developed (Fig. 26). It preferentially replaces the calcareous interbeds in the phyllites of the Acquadolce unit, forming large, almost monomineralic masses of epidote, hedenbergitic pyroxene (locally in centimetric to decimetric mega-rossette and fan-shaped aggregates) and ilvaite (after hedembergite), with associated quartz, chlorite and minor amounts of iron minerals (magnetite, pyrite and pyrrhotite), which justified a limited exploitation activity in the past. Mesoscale textures clearly indicate that the calcschist are replaced by skarn minerals occurring preferentially along the schistosity planes of the rock, as already pointed out by Lotti (1886, pp. 205-206). Black, vertically striated prismatic crystals with submetallic luster were here described for the first time in 1802. They were subsequently attributed to a new mineral species, called “ilvaite” after the Latin name “*Ilva*” of Elba Island. We come back to the Torre degli Appiani clock tower and continue along the dock to the small tower.

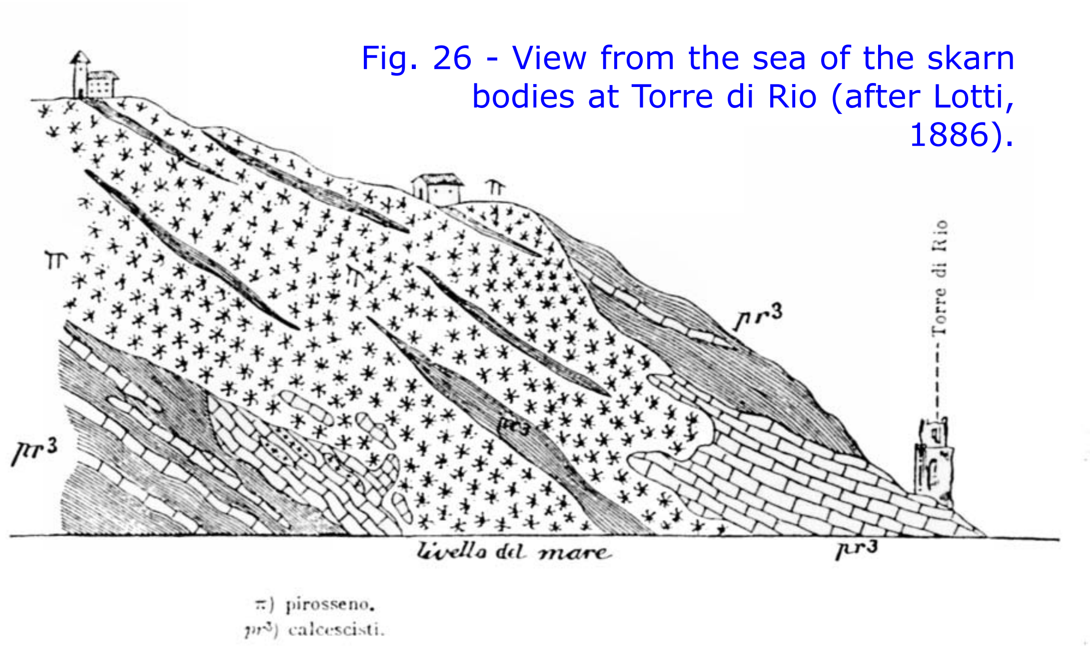

Fig. 26 - View from the sea of the skarn bodies at Torre di Rio (after Lotti, 1886).

This tower is built on a decametric metacarbonate horizon (grey-whitish to grey-greenish marble and calcschist) within the phyllites of the Acquadolce unit. Syn-metamorphic tight to isoclinal folds with a pervasive axial plane schistosity are well exposed. Deino et al. (1992) obtained a $^{40}Ar/^{39}Ar$ radiometric age of 19-20 Ma for the main schistosity.

Stop 5. The Rio Marina mining area

Looking to NW (Fig. 27), the landscape is dominated by the Rio Marina mines (from the left: Bacino, Zuccoletto, Valle Giove and Vigneria mines) and by the Monte Torre del Giove, with the ruins of a castle of the 16th century). The Rio Marina ores are hosted in the Permo-Carboniferous (Rio Marina fm.) and in the triassic "Verrucano" group metasiliciclastics of the Monticiano-Roccastrada unit (Fig. 28). To the north of the last house of Rio Marina (Fig. 27), the tectonised serpentinite lying at the top of the Acquadolce unit crops out and is tectonically covered by the Permo-Carboniferous metasediments of the Rio Marina fm. (graphitic

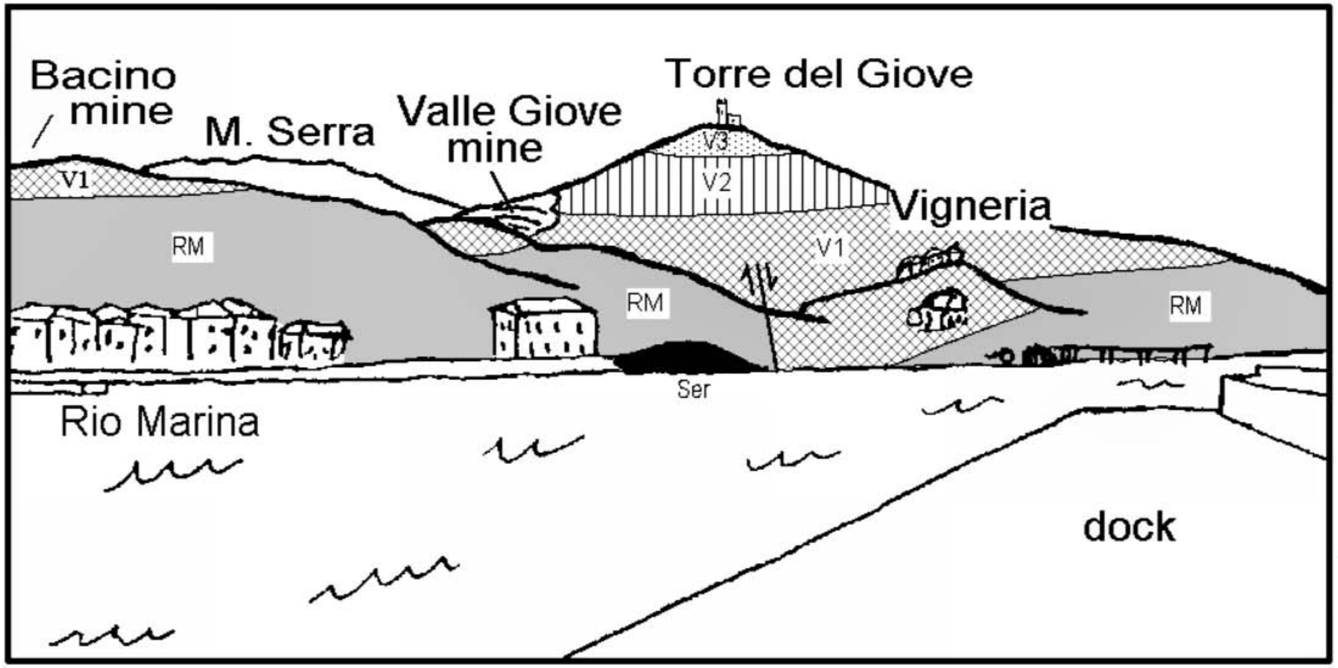

Fig. 27 - Panoramic view of the Rio Marina mines. Ser- serpentinites; RM- Rio Marina fm. V- "Verrucano" group (V1- Verruca fm.; V- Monte Serra quartzites (V2- green quartzites member; V3- white-pink quartzites member).

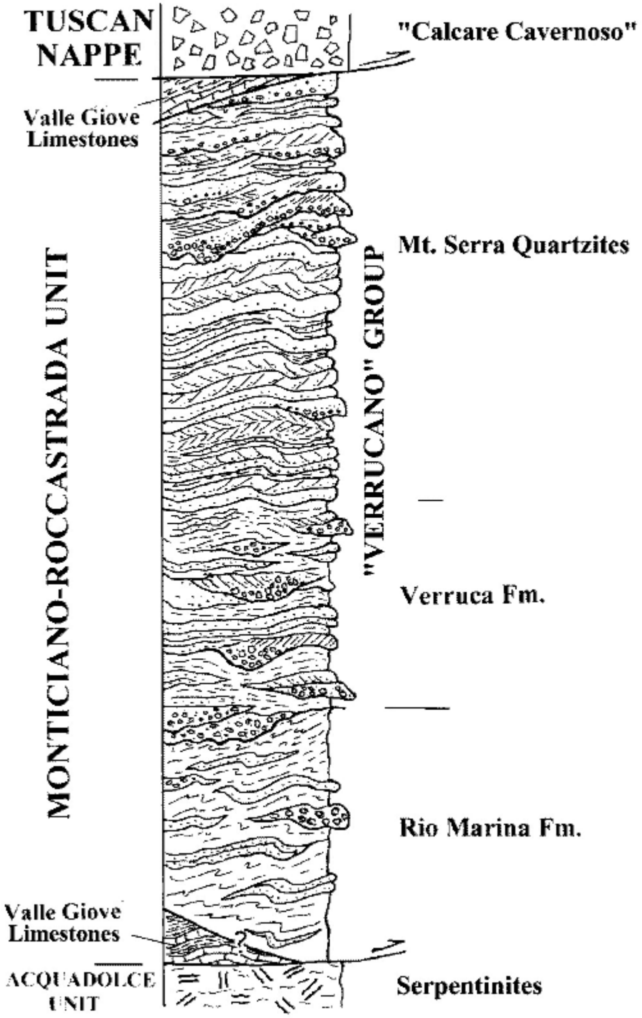

Fig. 28 - Tectonic and stratigraphic sketch of the Monticiano-Roccastrada unit in the Rio Marina area

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phyllites and metasiltstones with quartzitic metasandstones and minor metaconglomerates. Paleoenvironment: deltaic-coastal). Behind Rio Marina and Vigneria (i.e. Valle Giove-Torre del Giove area) (Fig. 27), the whole "Verrucano" group succession crops out at the top of the Rio Marina fm. (Fig. 28).

Geology of the Rio Marina mines. The "Verrucano" group metasediments represent the basal transgression of the Alpine sedimentary cycle. The "Verrucano" succession of Elba Island (Deschamps, 1980; Deschamps et al. 1983; Pandeli, 2002), probably late Ladinian-Carnian in age and more than 350 m thick, is made up of three lithological units correlatable with the "Verrucano" group succession of the Pisani Mts. (Rau & Tongiorgi, 1974). From the base to the top they are:

Verruca formation. It widely crops out in the mining areas behind and to the north of Rio Marina (e.g. Bacino, Valle Giove and Vigneria). This formation is made up of violet and minor greenish phyllites and metasiltstones, laminated quartzites and lenticular (up to 4-5 m thick) quartzitic metaconglomerates. Paleoenvironment: continental with medium to high sinuosity rivers.

Monte Serra quartzites. They are exposed in the upper part of the Valle Giove mine and on the eastern flank of the Monte Torre del Giove. Two members were distinguished; from the base they are: 1- *Green quartzites member (= "Quarziti verdi")* Parallel- to cross-stratified (e.g. herring-bone cross-bedding) and rippled, pale grey-greenish quartzites with phyllitic interbeds and rare metaconglomerates. Paleoenvironment: littoral. 2- *White-pink quartzites member (= "Quarziti bianco-rosa")*. Prevailing quartzose pale grey/pink metaconglomerates and quartzites with minor phyllitic levels. Paleoenvironment: deltaic?

In the westernmost part of the Valle Giove mine, slices of non-fossiliferous, varicoloured marbles, calcschist and calcareous phyllites (Valle Giove limestones) are tectonically intercalated in "Verrucano" succession or underlie the "Calcare Cavernoso"(see Fig. 28). Similar lithotypes are also present in the Vigneria sub-surface (Vigneria limestones) tectonically interposed between the serpentinite and the Rio Marina fm. These varicoloured lithotypes probably represent tectonic slices of an epimetamorphic Tuscan succession of Mesozoic-Cainozoic age (e.g. the Capo Castello succession of the Stop 7).

The Fe-ores of the Rio Marina mines. The iron deposits occurring at Rio Marina and northwards of it, almost up to Cavo (Valle Giove, Rialbano, etc.) are constituted by stratiform, massive or vein bodies, hosted by Trevisan's (1950) Complex III rocks, preferentially at the contact between Permo-Carboniferous phyllites (Rio Marina fm.) or quartzitic/phyllitic rocks ("Verrucano", Middle Triassic) and the overlying calcareous levels ("Calcare Cavernoso"). According to some authors (cf. Gillieron, 1959) in the northern sector (Cala Seregola, Rialbano) the setting of orebodies is markedly controlled by tectonic lineaments, produced during the Apenninic event. Nevertheless, at least at Rio Marina (Valle Giove area), Deschamps et al. (1983) recognised the occurrence of stratiform pyrite mineralisation within a particular horizon of the "Verrucano", which could represent the relic of a syngenetic iron protore. All these deposits include hematite as the main ore mineral (variety "oligisto"), which may show either a typical lamellar-micaceous habitus or flattened, rhombohedral crystals, often covered by iridescent films of iron hydroxides. Pyrite is also common, predominantly as pyritohedra, although octahedra or cubes have been observed as well. Exogenous limonites, massive or concretionary (sometimes stalactitic) may locally constitute the main ore minerals, especially at Rialbano and other northern mineral showings. To be noticed that in the 50's-60's underground mine workings partly exploited a hematite pyrite orebody associated with skarn silicates, known in the literature as "Rio Marina profondo". The scarcity of geologic documentation and the unaccessibility to underground workings do not allow to study in more detail the otherwise peculiar setting and mineralogic features of the deposit.

The trip continues along the road to Cavo. After the Vigneria mine the graphitic Rio Marina fm. crops out as far as to the Ripabianca area where the contact with the basal phyllites and quartzites of the "Verrucano" group succession is exposed (beyond a wire-net protection). We cross the Rialbano Creek (view on the Monte Sassera cliff, made up of Monte Serra quartzites) and go up the winding road (outcrops of Triassic violet phyllites and pink quartzites of the Verruca fm.) and reach the Rialbano mining area (hematite+limonite±pyrite). Here the mineralised high-angle contact between the basal "Verrucano" and the slates of the Gràssera unit is due to an east-plunging normal fault (Punta del Fiammingo fault). At the top of the Monte Calendozio, Triassic dolomite limestones tectonically rest onto the Monte Serra quartzites ("Verrucano" group). About 1 km ahead, along the road, the Gràssera unit is in tectonic contact (Punta del Fiammingo fault) with the Rio Marina fm. We continue as far as Fornacelle Creek (close to the Cala del Telegrafo).

THE TUSCAN NAPPE SOUTH OF CAVO

In the Eastern Elba Island, South of Cavo, a sedimentary succession,pertaining to the Tuscan Nappe, crops out. This link has been recognised by many Authors for a long time (e.g. Cocchi,1871; Lotti,1886; Trevisan, 1950; Barberi *et al*., 1969; Perrin, 1975; Boccaletti et al., 1977) and therefore the formational names are the same than those of the Tuscan Nappe in central and southern Tuscany (Ciarapica *et al*., 1982; Ciarapica *et al*., 1987; Fazzuoli & Maestrelli-Manetti, 1973; Fazzuoli *et al*., 1985; Fazzuoli *et al*., 1988) (fig. 22).

From the bottom upwards, the sedimentary succession consists of the following formations (Fig. 29): “Calcare Cavernoso”, Pania di Corfino fm., Monte Cetona fm., Calcare Massiccio, Grotta Giusti cherty limestones, “Rosso Ammonitico”, Limano cherty limestones, *Posidonia* Marlstones (Bortolotti et al., 2001). From le Fornacelle Creek northwards, along the Road Rio Marina - Cavo, most of these formations crop out.

Stop 6. The Tuscan Nappe succession

Owing the severe block faulting of the area, it is not possible to observe a continuous stratigraphic succession, but four partial, stratigraphic intervals, all along the main road (see Fig. 30).

Monte Cetona formation. From Fornacelle Creek up to the fault in correspondence of the road bend overlooking Cala del Telegrafo.
The main lithotypes are dark grey calcilutites, up to 1 m thick, abundant marlstones cm- to dm- thick, and dolomitised calcilutites or coarsely crystalline dolomites, 1 to 2.5 m thick. In the upper portion of the formation, dark grey, 20-50 cm thick, bioclastic and oolitic grainstone and packstone beds crop out. Dm-thick coquina beds, corresponding to storm-layers, also occur.

Grotta Giusti cherty limestones (upper portion). The formation consists of grey calcilutites and subordinately fine calcarenites, 5-100 cm thick (mainly 10-20 cm) with abundant horizontal laminations and rare chert nodules and silicified areas. Cm-thick shaly beds are frequent, as well as dm-thick beds of more or less shaly marlstones. The beds plunge 30-50° northwards. The transition with the overlying formation is stratigraphic.

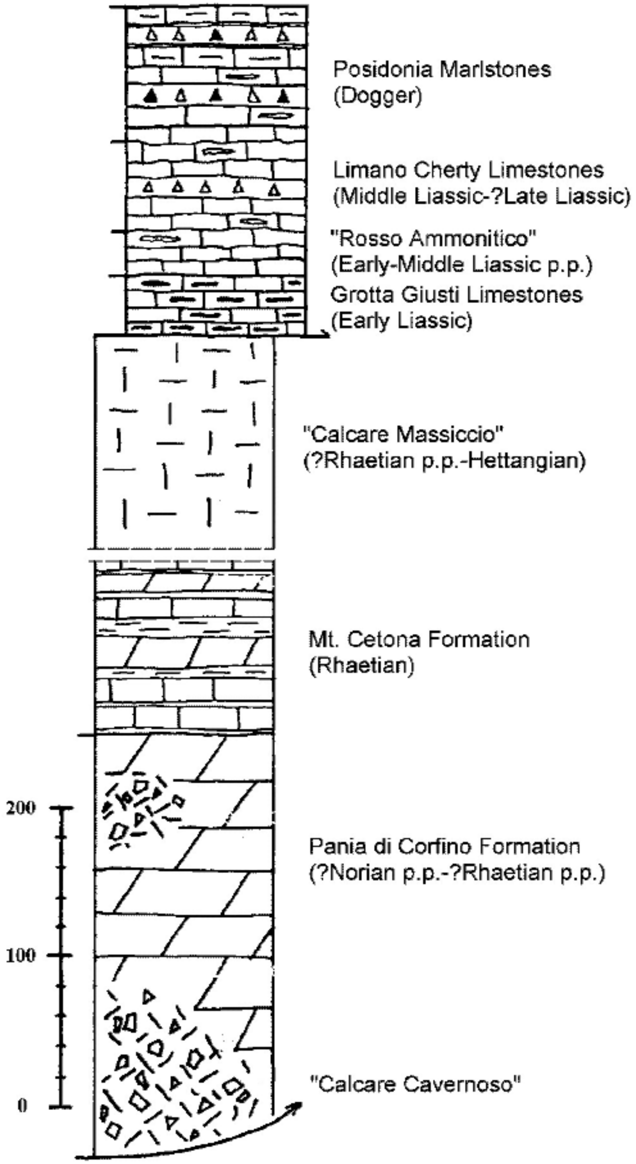

Fig. 29 - Tectonic-stratigraphic sketch of the Tuscan Nappe succession.

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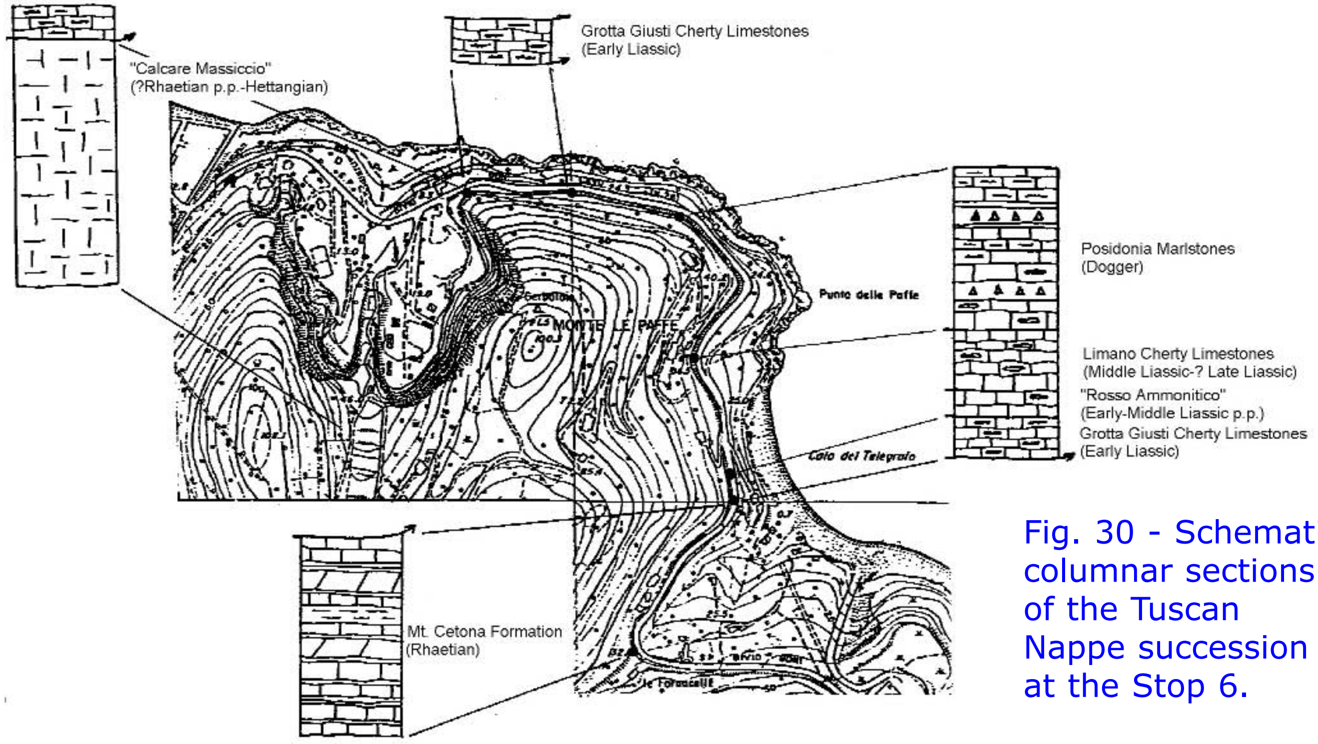

Fig. 30 - Schematic columnar sections of the Tuscan Nappe succession at the Stop 6.

Rosso Ammonitico. The section consists mainly of pink or pale grey calcilutite beds, up to 70 cm thick (prevailing thickness is 20 cm), with cm-thick, grey or pink shaly beds. Grey chert nodules are present. Calcilutite beds, sometimes nodular, are intersected by abundant stylolites parallel to bedding or wavy. In the upper half of the section, 45 cm thick calcirudite bed occurs. Beds plunge 30-40° to the north.

Limano cherty limestones. Grey or pale brown or pinkish calcilutite beds with rare grey chert nodules constitute the main lithotype. In the lower portion of the section the beds, up to 140 cm thick, are intersected by abundant stylolites, parallel to the bedding. In the upper portion, 5-30 cm thick beds prevail. The bedding joints consist of stylolites and of mm-thick shaly and marly beds. Grey calcarenite beds up to 180 cm thick are present, as well as two 50 cm thick calcirudite beds with cm- to dm-sized calcareous and cherty clasts, and slump and debris flow structures. Most beds plunge 30-40° northeastwards.

Posidonia marlstones. The lower half of the section mostly consists of grey or pinkish, slightly marly, calcilutite beds, up to 360 cm-thick, characterised by abundant stylolites parallel to the bedding and inclined cleavage joints. Grey calcarenite and calcirudite beds up to 25 cm thick are also present. The calcarenites show horizontal laminations; calcirudites slump structures, graded bedding and laminations, indicating turbiditic and mass-flow processes.

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The upper half of the section mostly consists of pale grey, more or less marly and silty calcilutite beds, up to 160 cm-thick, sometimes with parallel laminations. Grey shales and marlstones, cm- to dm-thick, often with slaty cleavage, are abundant. Dm-thick beds of dark grey calcarenites with filaments are present and, in the uppermost portion of the section, also five beds of calcirudites, 50 to 160 cm thick, with cm- to dm-sized calcareous and subordinate cherty clasts. Beds plunge 30°- 50° northwards (that is seawards). The outcrop of *Posidonia* Marlstones continues along the E-W oriented stretch of the road.

Going on towards Cavo, two normal fault, oriented SE-NW and N-S, individuate minor horst of “Calcare Massiccio”, with the *Posidonia* marlstones to the East and Grotta Giusti cherty limestones (lower portion) to the West.

Grotta Giusti cherty limestones (lower portion). The outcrop consists of 5-15 cm-thick beds of dark grey fine calcarenites and calcilutites, horizontally laminated, with abundant beds and nodules of grey cherts. The beds plunge 30° to 50° northwards: here an east-west trending fold system deforms the earlier north-south system.

Calcare Massiccio. The Calcare Massiccio crops out in a big quarry on the left side of the road (western slope of Monte le Paffe). The formation consists of massive, pale grey or whitish calcarenites and calcilutites, sometimes intensely recrystallised and dolomitised. The quarry is intersected by pervasive fracture systems, the main of which trends east-west and plunges 70° northwards. On both sides of the quarry, the Calcare Massiccio is tectonically overlain by the Grotta Giusti limestone.

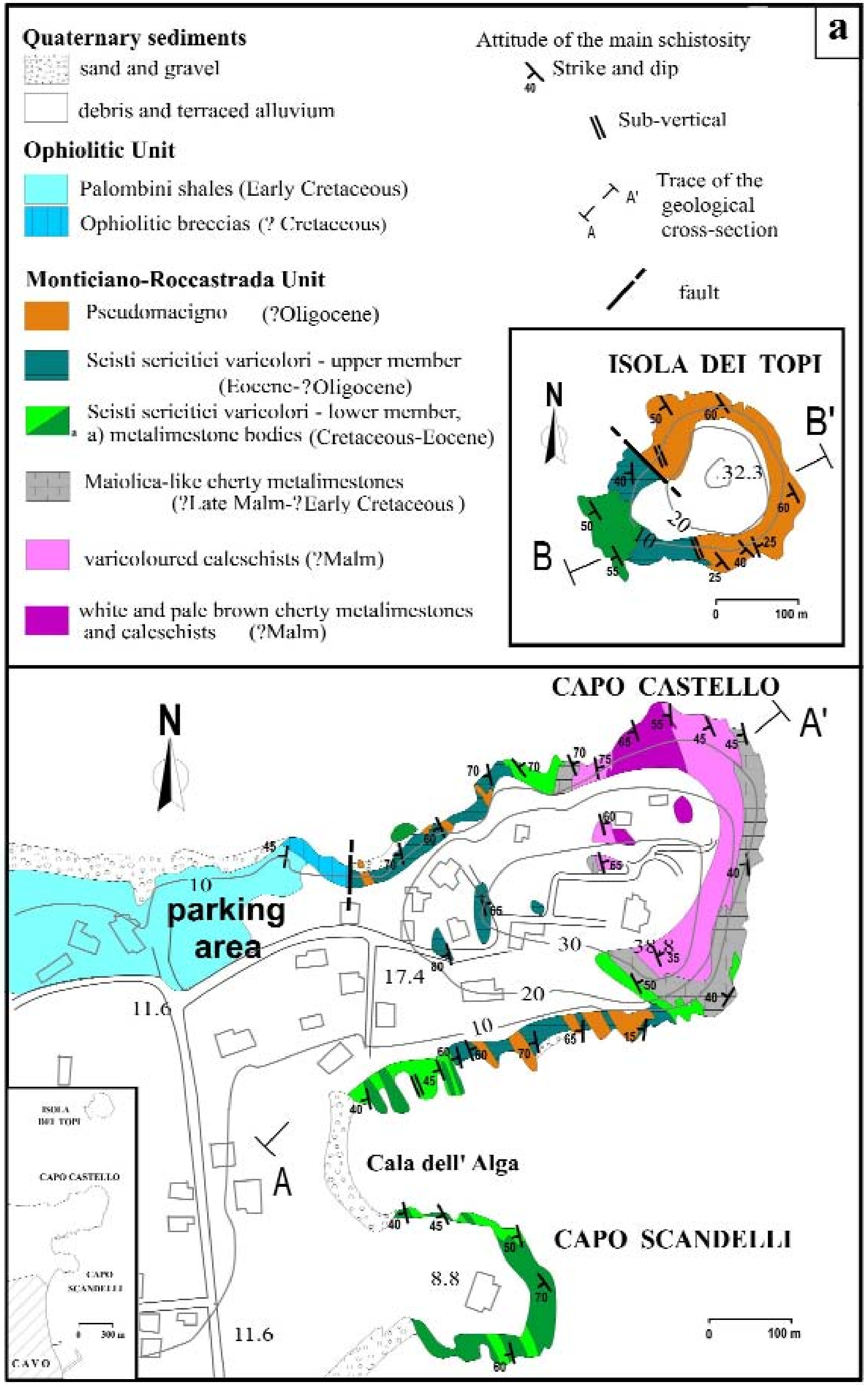
We cross Cavo and continue northward as far as reaching the parking area of the Capo Castello (Fig. 31).

THE TUSCAN EPIMETAMORPHIC SUCCESSION OF CAPO CASTELLO

Stop 7. The Tuscan epimetamorphic succession, Cala dell'Alga

In the parking area and along the beach to the north, the Palombini shales of the Ophiolitic unit crop out, which overlie a thick ophiolitic breccia (on the beach). Eastwards, a high-angle normal Cala dell'Alga fault separates the Ligurid formations from the Capo Castello epimetamorphic rocks.
The Capo Castello fossiliferous metamorphic succession (cropping out also at the Capo Scandelli and the Isola dei Topi, to the north and to the south of the Capo Castello, respectively, see Fig. 31a) belongs to the Tuscan low-grade metamorphic succession of the Monticiano-Roccastrada unit (Pandeli et al., 1995) and includes (from the bottom): **a**- Varicoloured cherty calcschists and crystalline limestones (Capo Castello calcschists, Late Dogger?-Malm?); **b**- "Maiolica"-type, grey cherty limestones (?Early Cretaceous); **c**- varicoloured phyllites and calcschists with metalimestones and metacalcarenites (varicoloured sericitic schists, Late Cretaceous/Eocene) and, **d**- metagraywackes (Pseudomacigno, Oligocene). From the structural point of view, at least three ductile deformation events (D_1, D_2 and D_3), the first two syn-metamorphic in the greenschist facies, are distinguished.

From the parking area, we take the road to Capo Castello. After about 100 m, we turn to the right and go down a little road with stairs till the Cala dell'Alga. We turn left and reach the first two little rocky promontories along the northern side of the gulf. Here the varicoloured sericitic schists are well exposed and clearly show their tectono-metamorphic imprint.
The "varicoloured sericitic schists" are made up of varicoloured phyllites and calcschists with levels and metric bodies of recrystallised, at times cherty, grey limestones. These rocks show a main continuous penetrative schistosity (S_1 = calcite + sericite ± quartz ± hematite ± chlorite), which is parallel to the lithological subdivisions (S_0) and is associated to a main D_1 hectometric isoclinal, recumbent fold defined along the Cala dell'Alga-Capo Castello-Isola dei Topi alignment (see Fig. 31a and b).
The D_1 structures were deformed and transposed by the D_2 event into centimetric to decametric close to isoclinal synforms and antiforms (e.g. the NE-vergent synformal anticline of the eastern part of Capo Castello) with sub-vertical, NNW/SSE-trending axial planes and spaced, zonal to discrete crenulations (C_2/S_2 = hematite±sericite) (Fig. 32). Gentle to open folding, generally with sub-horizontal axial plane



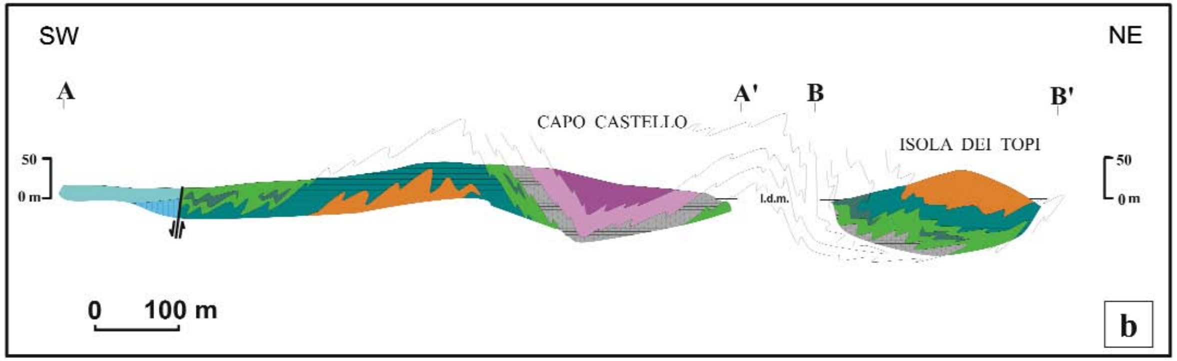


Fig. 31 - Geological sketch map **(a)** and cross-sections **(b)** of the Capo Castello area (after Pandeli et al., 1995).

crenulations/kinking (C_3, Fig. 32) and fracture cleavage, represent the coaxial D_3 event and a possible anti-apenninic-trending D_4 event.

The low-grade metamorphic succession of Capo Castello probably represents part of the pristine cover formations of the triassic “Verrucano” metasediments belonging to the Monticiano-Roccastrada unit and reconstructs in the Elba Island the stratigraphical typical succession of the Tuscan metamorphic ridge (from the Apuan Alps-Mts. Pisani to the Monticiano-Roccastrada area). Coming back to the parking area, the trip continues along the la Parata (from Cavo to Rio Elba) panoramic road.

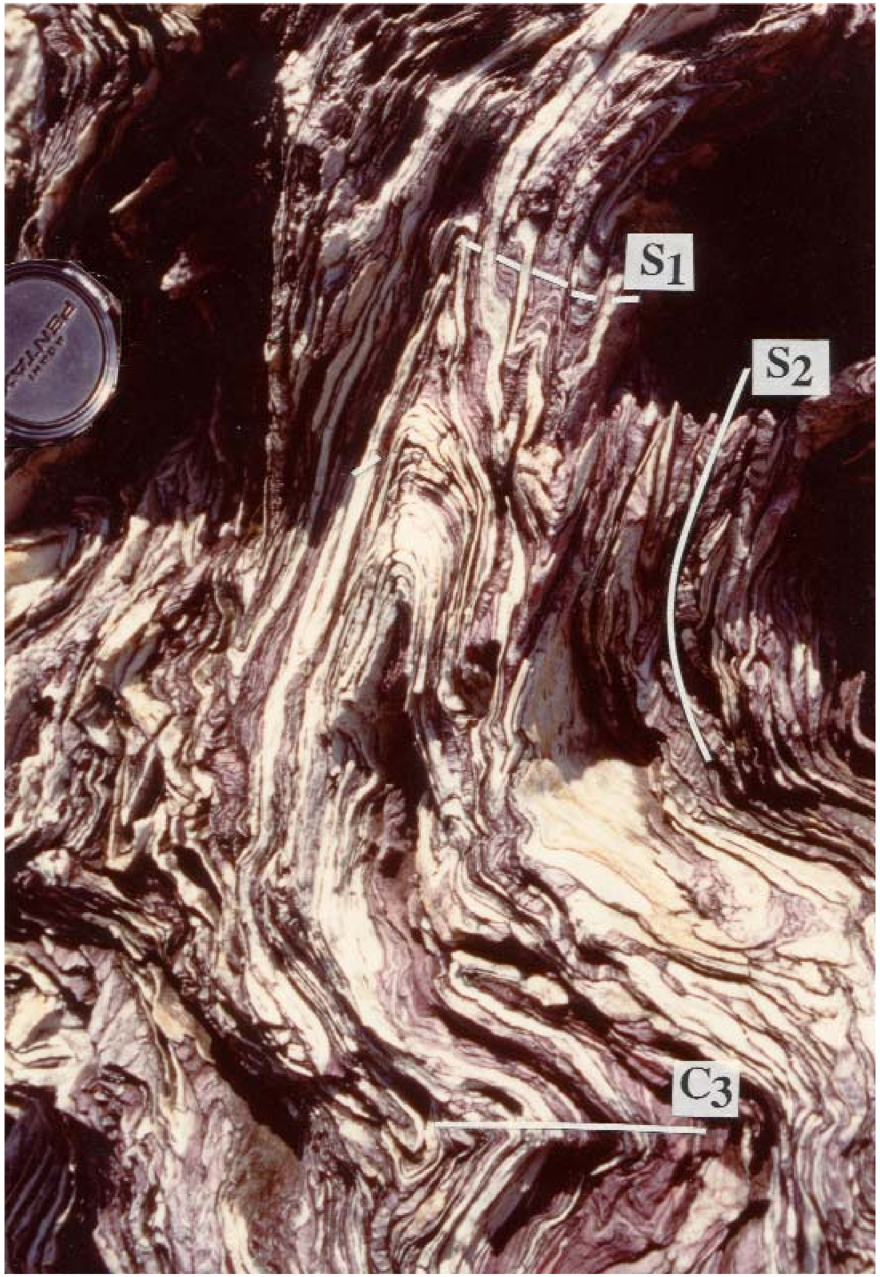


Fig. 32 - The Varicoloured Sericitic schists in the Cala dell'Alga area. For details see text, Stop 7.

THE GRÀSSERA AND OPHIOLITIC UNITS

The la Parata road exposes the two lowest subunits of the Ophiolitic unit (Monte Serra and Acquaviva subunits) and the underlying Gràssera unit. From Cavo to Case Braschi we cross only the Gràssera unit.

Stop 8. The Gràssera unit

We stop at a big curve of the road to the left, some hundred metres from Cavo. Here the upper portion of the Gràssera unit (Cavo formation, see Bortolotti et al, 2000) crops out. It consists of greenish and wine-red slates and siltstones with rare manganiferous siliceous limestones and cherts. These rocks show a pervasive slaty cleavage, deformed by open to close folds with a spaced fracture cleavage. Typical syn-tectonic quartz veins are also present.

Near Case Braschi we enter the **Ophiolitic unit** (see Bortolotti et al., 2000; Fig. 33), but the contact is covered by a slide. The first outcrops pertain to the Acquaviva subunit. Here ophicalcites and Palombini shales are tectonically repeated as lenses. At the watershed before the Gorgoli Creek we cross the thrust contact between the Acquaviva and the overlying Monte Serra subunit, represented here by Calpionella limestones. This formation crops out for some hundred metres and no evident structures are visible along the road.

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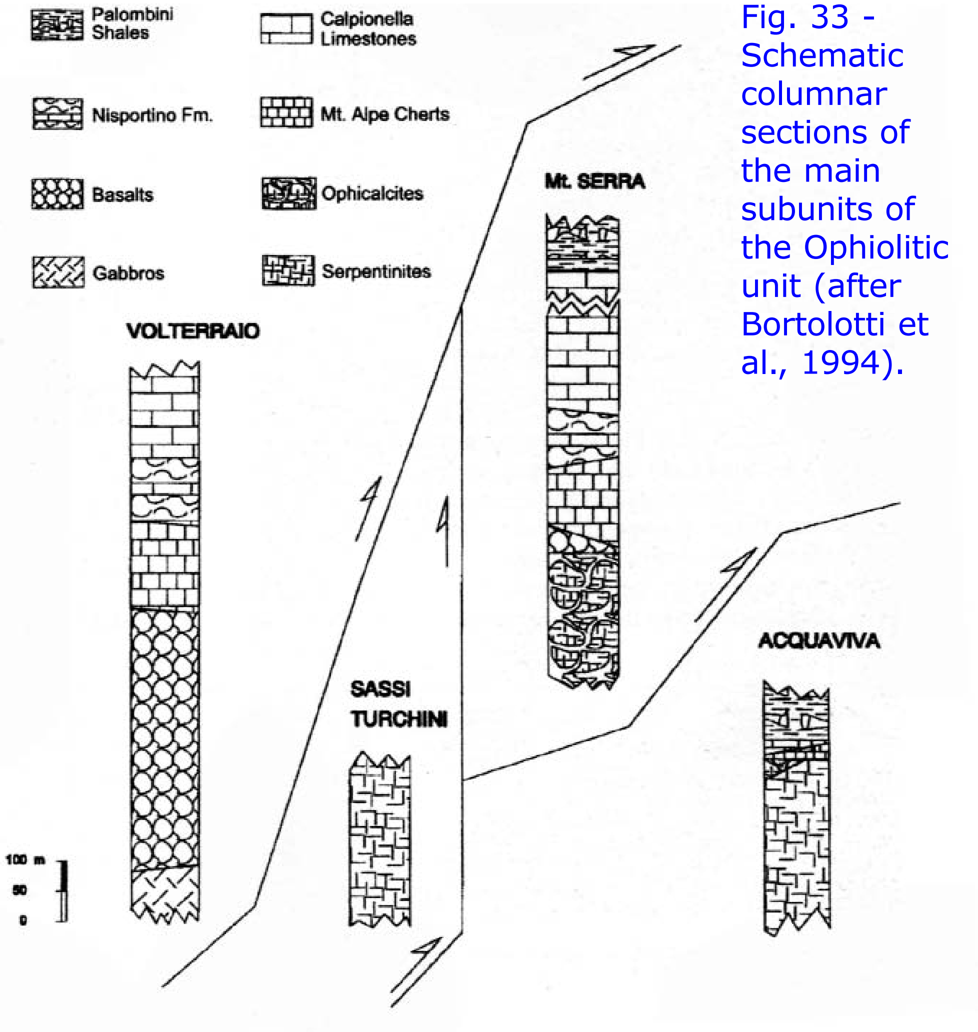

Fig. 33 - Schematic columnar sections of the main subunits of the Ophiolitic unit (after Bortolotti et al., 1994).

Stop 9. The Gorgoli anticline

We stop at the bridge along the Gorgoli Creek ad go upstream some tens metres crossing the whitish and thick beds of the Calpionella limestones; beyond a fault cutting the creek, we can observe the core of a big anticline trending NNW-SSE, with a NE vergence. On the right side a succession dipping to the NE crops out, here made up of: i- a few metres of pillow lavas, ii- a cliff some metres high of thin-bedded red cherts and siliceous shales (Monte Alpe cherts) and, iii- the Nisportino fm., here formed, just from the base, by the pale grey marly calcilutites of the Rivercina member. On the left side of the structure the same succession dips to the NW.

Coming back to the road, we cross twice the same anticline, faulted on its eastern side. After 1 km of very folded Calpionella limestones we cross again the Acquaviva subunit. The contact along the road is faulted. In this area we can reconstruct the disrupted and condensed succession of this subunit: at the top of the ophicalcites of the little quarry on the right, some chert beds (Monte Alpe cherts) crop out in the Mediterranean scrub; along the road the cherts grade upwards to Palombini shales.

From here, to near the La Parata Pass, for about 2 km, the road cuts the Acquaviva subunit terrains with minor internal thrusts: on the road two contacts between Palombini shales and the overlying ophicalcites are well exposed. 250 m before the La Parata Pass we cut the hidden thrust contact between the Ophiolitic and the underlying Gràssera unit.

In the La Parata zone four units of the eastern Elba tectonic pile crop out very closely spaced. The road runs on the Gràssera unit. Immediately above the road lies the thrust contact with the overlying Ophiolitic unit. On the other side of the road, the Mediterranean scrub covers the faulted contact with the Tuscan Nappe and, a little to the east, the faulted contact between this latter and the Monticiano-Roccastrada unit.

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Stop 10. The thrust contact Tuscan Nappe-Gràssera unit

Along the road, 200 m south of the Pass, a little outcrop of Triassic limestones ("Calcare Cavernoso") of the Tuscan Nappe shows the thrust contact with the overlying Gràssera unit (Fig. 34). The latter is here represented by its basal portion: brown-grey polydeformed calcschists (calcschist member of the Cavo fm.). In the calcschists the last folding event is very pervasive on a previous tectono-metamorphic layering (see the intrafolial schistosity relics).

Nearby, until the 16th century flourished the charming Gràssera village, destroyed by the terrible pirate Khair Eddin (Red Beard).The only remains are the ruins of the San Martino church, immediately on the left of the road, the underground aqueduct and the name of the creek. We gave this name to the unit in its memory.

From here we can enjoy a spectacular panorama on the Fe-mines of Rio Marina (foreground, the Valle Giove Mine) and on the Monte Torre del Giove where the upper formation (Monte Serra quartzites) of the triassic Verrucano group of the Monticiano-Roccastrada unit (see Stop 5) crop out. Westward (the western side of Monte del Giove), the "Verrucano" is in contact, through a high-angle normal fault (Terranera fault), with the "Calcare Cavernoso" of the Tuscan Nappe.

We continue southwards 200-300 m along the Parata road up to the crossroad with the little road (to the left) for the cemetery of Rio Marina. Here the road intersects the St. Caterina Normal fault high angle normal fault, just observed in the Ortano Valley (Stop 3 m, n). This structure is part of the system of westward-high-angle normal faults which dissects the tectonic pile of eastern Elba. To the North, it lowers the Monte Serra subunit, with respect to Acquaviva subunit and the underlying Gràssera unit; to the South, the same structure lowers the Gràssera unit with respect to the Tuscan Nappe. Afterwards, the road turns south-west and crosses some tens of metres of ophicalcites.

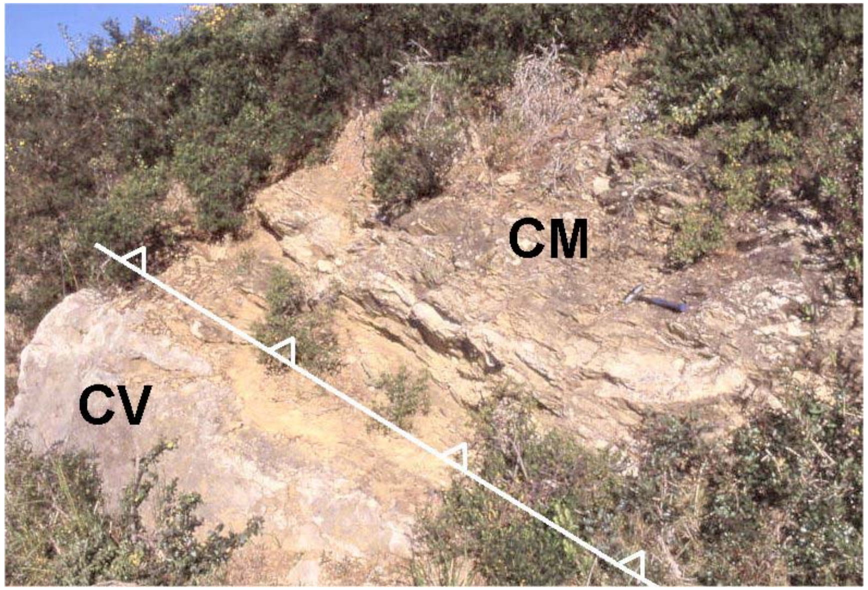

Fig. 34 - The thrust contact (La Parata thrust fault, Bortolotti et al., 2001a) between the triassic calcare cavernoso (CV) of the Tuscan Nappe and the overlying calcschist member (CM) of the Cavo fm. belonging to the Gràssera unit), 200 m south of Parata Pass, Stop 10.

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Stop 11. The ophicalcites

These ophicalcites probably constitute the base of the Monte Serra subunit, although in many cases their upper contact with the basalts is more or less tectonised. We prefer to call these rocks ophicalcitised serpentinites because they do not show all the structures of the typical ophicalcites of eastern Liguria. They are pervasively fractured serpentinites with scattered calcite veins without any preferential trend. The veins become more and more frequent near the upper contact. A little more than 100 metres passed the ophicalcites we enter a strongly folded zone, made up of the sedimentary cover of the Monte Serra subunit (from Monte Alpe cherts to Calpionella limestones).

Stop 12. The base of the Nisportino formation

Near the first creek (Fig. 35) we can observe the contact between Monte Alpe cherts and Nisportino fm.
Nisportino formation. This formation is composed of three distinct members, from the bottom: **a**. A basal level (15-30 m thick), made up of siliceous calcilutites, red siliceous siltstones and, locally, marlstones and/or shales; **b**. A level, formally distinguished as Rivercina member (11-30 m), consisting of marly calcilutites; **c**. An upper section (50-70 m) characterised by red siltstones and/or shales with rare beds of siliceous calcilutites, followed upwards by calcilutites prevailing on the siltstones. The upper section ends with a few meters of siltstones and marly shales. According to calcareous nannofossils the age is Berriasian.
Along the road the upper levels of the Monte Alpe cherts crop out. Here red siliceous claystone and siltstone beds prevail on radiolarites and laminated clay-rich cherts. All the sequence is thin-bedded. Five metres above the road, on the right side of the creek, we find a very little quarry. On the right, to its base and at the top, we can observe two cherty calcilutite beds, and in between a thin-bedded sequence of siliceous siltstones and claystones with rare cherts. The contact between Monte Alpe cherts and Nisportino fm. has been placed at the base of the first calcareous bed. Going upwards we find five more metres of the same type of succession and then 15-20 metres of light grey marly calcilutites, a key level of the formation that we called Rivercina member. It ends upwards with a thick bed of siliceous calcilutite. The upper levels of the formation will be seen in the next Stop.

We come back to the road (Fig. 35), to San Pietro and turn right towards Nisporto. Along this road we see cherts and serpentinites in tectonic contact. At a curve to the left with a big oak we cut again the contact between Monte Alpe cherts and Nisportino fm. Here the limestones are completely decalcified. At the first bend of the road we cross the core of a reverse anticline trending N-S and with clear NE vergence, exposing the top of the Monte Alpe cherts and the basal portion of the Nisportino fm.

Stop 13. The Nisportino formation

We stop at the last bend of the road (Fig. 35). The Rivercina marly calcilutites are tectonically cut away, but we can see the siliceous limestone beds at their top. The upper portion of the formation consists of alternating marly and siliceous siltstones, cherty and siliceous calcilutites and rare clay-rich cherts. Upwards, the calcilutites, scarce at the base, become more and more abundant. The top of the formation is marked by a thick level of light grey marly siltstones. Above, the well-bedded, whitish calcilutites, without any silty or shaly

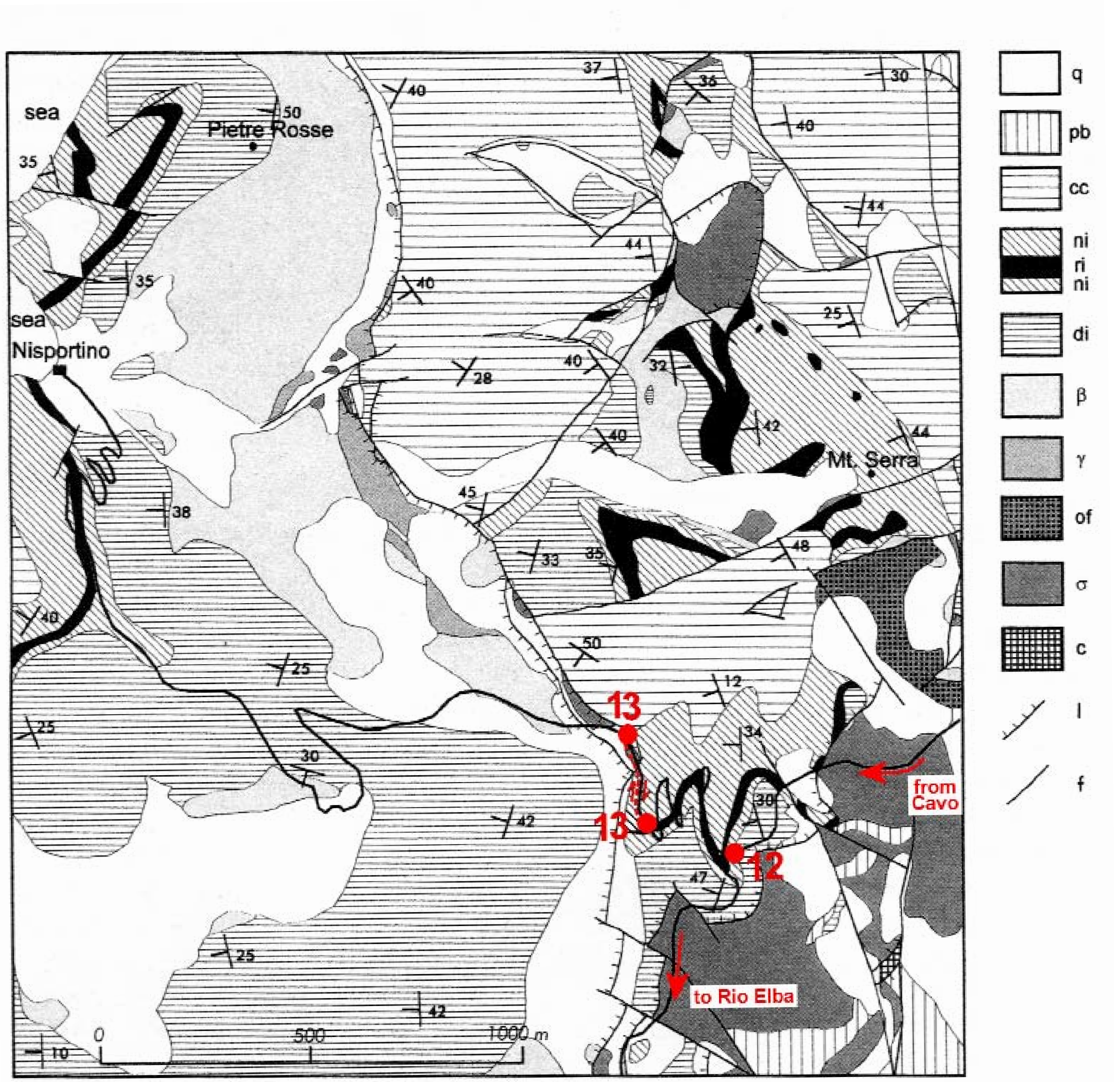

Fig. 35 - Geological map of the area south-east of Nisportino, with the location of Stops 12 and 13. **q-** Quaternary deposits. Ophiolitic unit: **pb-** Palombini shales; **cc-** Calpionella limestones; **ni-** Nisportino fm., with **ri-** Rivercina member; **di-** Monte Alpe cherts; β**-** Basalts; γ**-** Gabbros; **of-** Ophicalcites; σ**-** Serpentinites. Gràssera unit: **c-** Cavo fm. **l-** low angle tectonic surfaces: thrusts and detachments; **f-** normal faults.

intercalations, constitute the Calpionella limestones fm. The transition can be observed in the quarry near the pass, on the right of the road, where it is dissected by some minor faults.

The road exposes some fragments of the serpentinite slices which run along the thrust contact between the Monte Serra and the overlying Volterraio subunit (Fig. 2), which constitutes the hills to the South. In front of us, looking westwards (Fig. 36), we can observe the succession of the Monte Serra subunit, overthrust by the Volterraio subunit, to the left (Pietre Rosse Hill). The well exposed succession of the latter subunit includes basalts at the base, overlain by Monte Alpe cherts and, then by the Nisportino fm. (type-section).

We go back to San Pietro, then to Rio nell'Elba, where we cross a complicate, thin "Schuppenzone", in which the Monte Serra, Sassi Turchini and Volterraio subunits are implicated. An outcrop of serpentinite of the Sassi Turchini

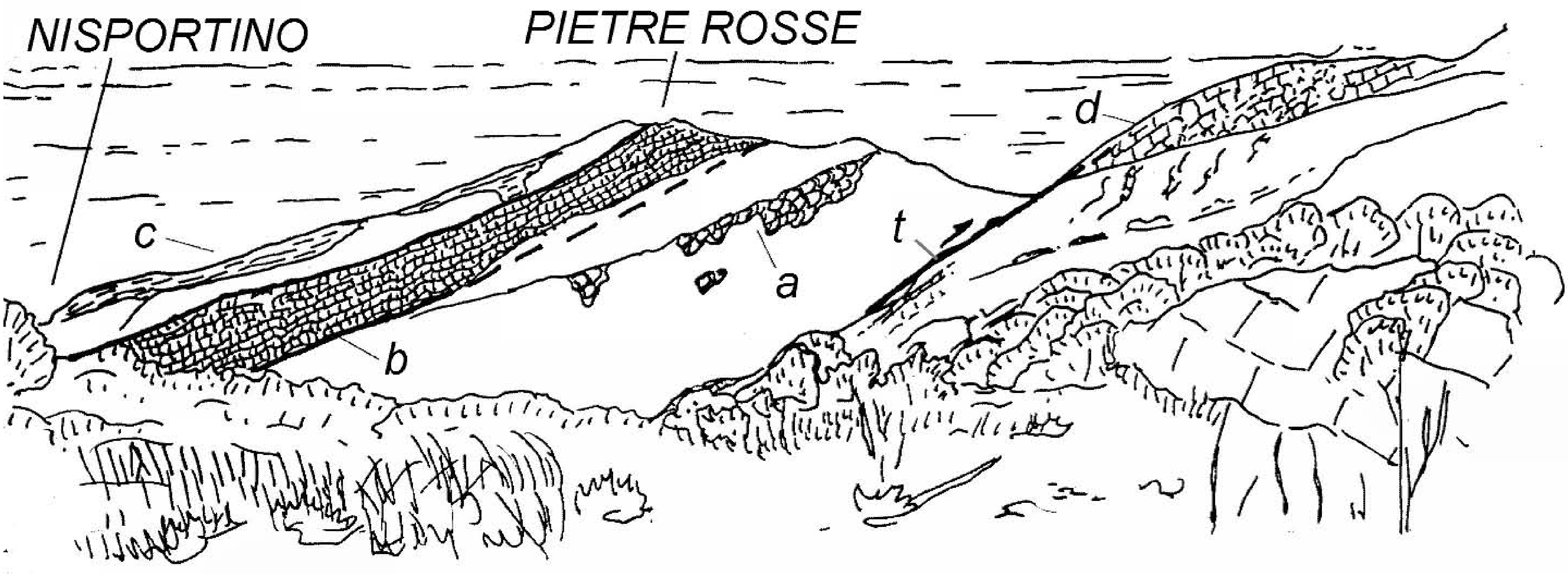

Fig. 36 - Panorama from Mt Strega-Monte Serra pass towards Nisportino-Pietre Rosse. The succession of the Monte Serra subunit (to the right) is overlain by the Volterraio subunit (central-left part of the figure). The Nisportino-Pietre Rosse zone is the type locality of Nisportino fm. a- Basalts; b- Monte Alpe cherts; c- Nisportino fm.; d- Calpionella limestones; t- Thrust surface between Monte Serra and Volterraio subunits.

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subunit is immediately below the village. We continue up to the Volterraio Pass, crossing a thick basalt succession. From the pass we enjoy a wonderful view to the east, toward the zone visited in the morning, and to the west, toward the Portoferraio Bay, the Medieval Volterraio Castle (Fig. 37) and, on the horizon, to the Monte Capanne Massif, which we will tour the next day. We proceed, and stop some hundred metres further on, where the road skirts long high walls of pillow basalts.

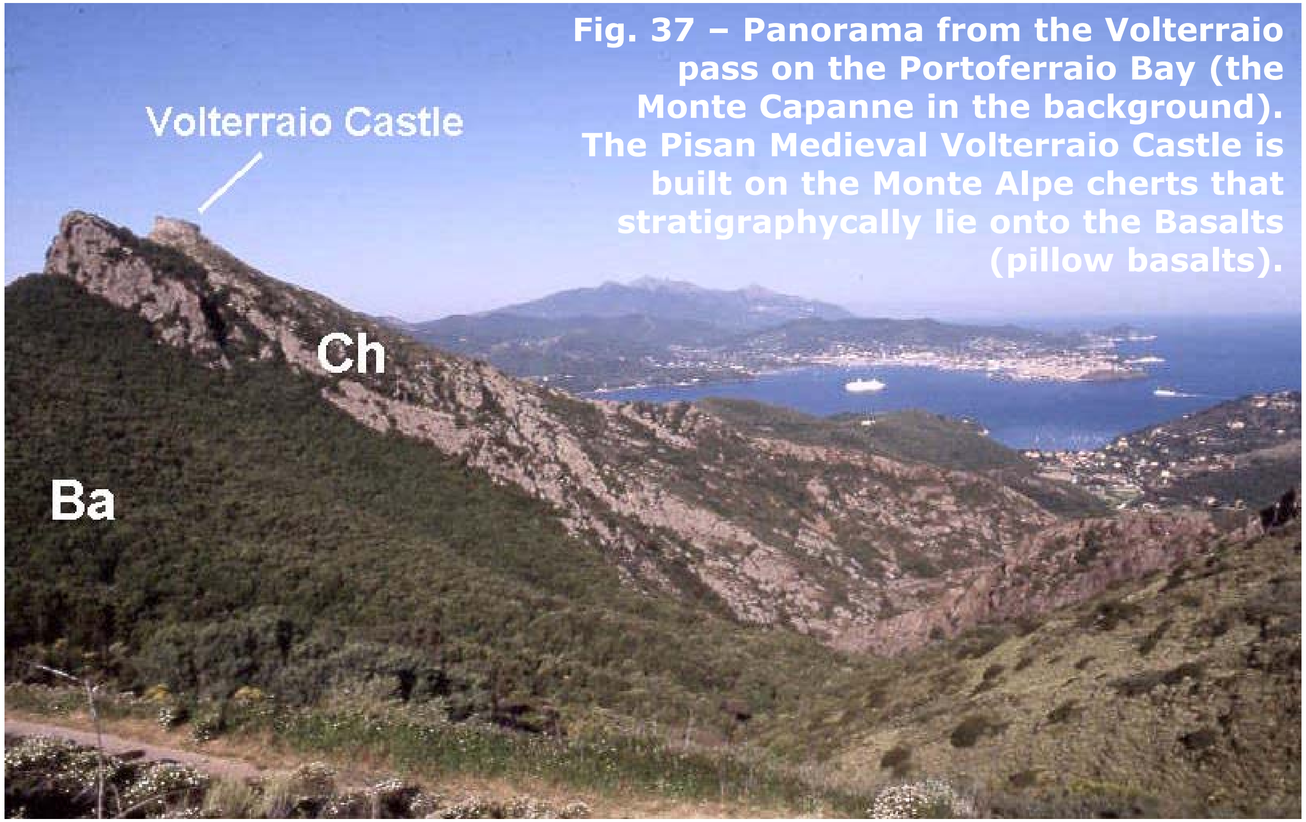


Fig. 37 – Panorama from the Volterraio pass on the Portoferraio Bay (the Monte Capanne in the background). The Pisan Medieval Volterraio Castle is built on the Monte Alpe cherts that stratigraphycally lie onto the Basalts (pillow basalts).

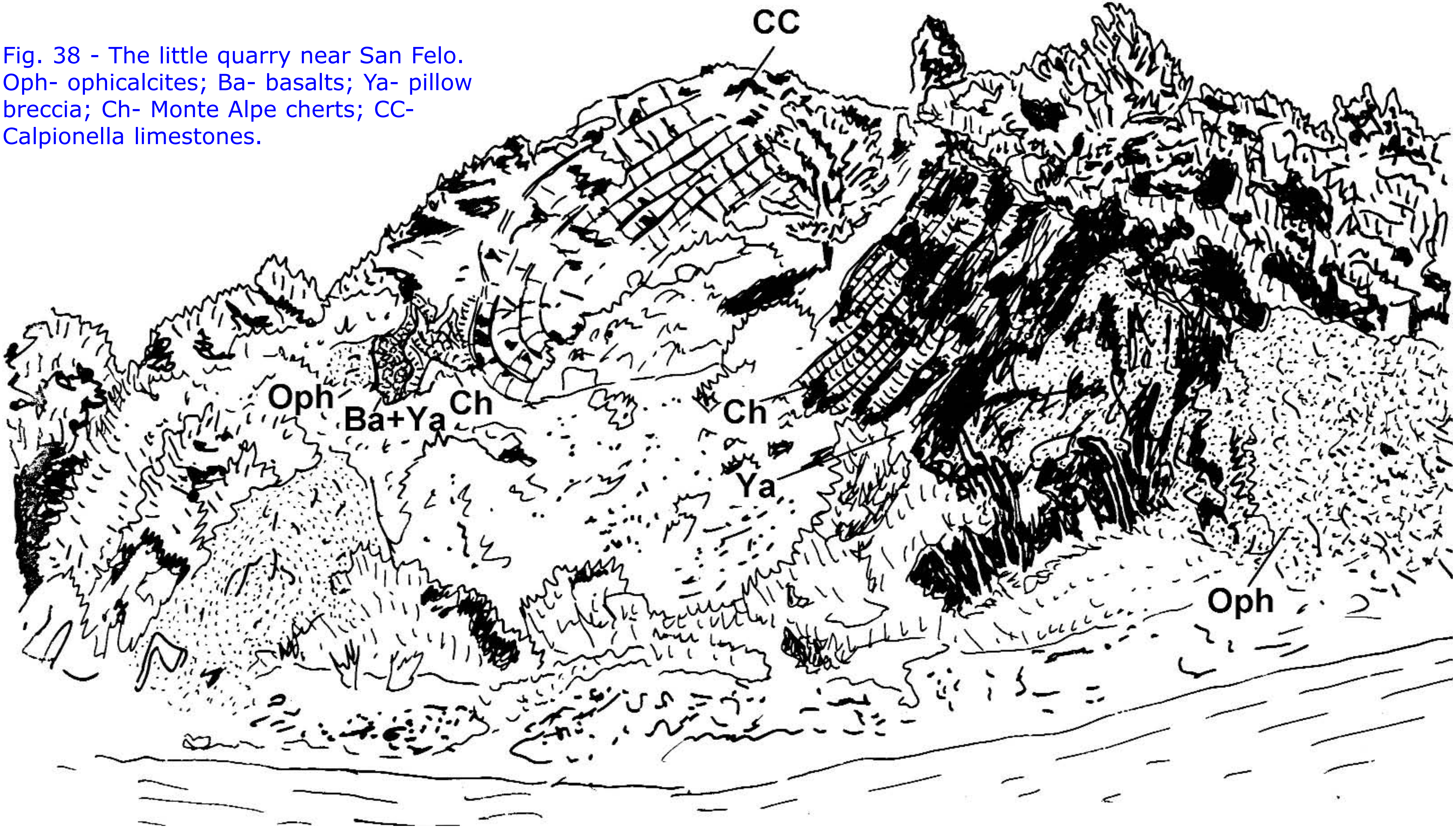
Stop 14. Pillow lavas

Here, along the walls, the basalts are represented by large sized pillow-lavas, characterised by a strong oceanic alteration and by the crystallisation of chlorite, albite, actinolite and pumpellyite. In some of these pillows we can see variolitic structures and some pillow-shelves. We come back to Rio nell'Elba and go toward Porto Azzurro. The road, beyond la Ginestra, runs near and crosses, before, the thrust contact between the Sassi Turchini serpentinite and the Monte Serra basalts and, further on, the thrust contact between the Sassi Turchini serpentinite and the Volterraio gabbro. Shortly after the Fosso delle Maceratoie we enter the Acquaviva subunit

Stop 15. San Felo ophiolitic succession

Shortly past San Felo, we can observe an ophiolitic klippe, pertaining to the Monte Serra subunit, which shows a very reduced succession, well exposed in a little quarry on the right of the road. This klippe constitutes an east-vergent, reverse, almost isoclinal syncline (Fig. 38). The succession comprehends, from the bottom: **a**. ophicalcites, cropping out on the road, which show two different facies. Far from the quarry they are fragmented serpentinites with calcite veins very close one another ("Breccia di Levanto" type, see Cortesogno et al., 1987). Close to the quarry, and on its left side, they show a detrital facies, with small fragments of

Fig. 38 - The little quarry near San Felo. Oph- ophicalcites; Ba- basalts; Ya- pillow breccia; Ch- Monte Alpe cherts; CC- Calpionella limestones.



serpentinite dispersed in a calcitic cement (“Framura Breccia” type see Cortesogno et al., 1987); **b**. A few meters of a basalt breccia on the right side of the quarry while, on its left side few pillow lavas; **c**. The Monte Alpe cherts, in their typical facies. At the base some dm of red shales including a big pillow lava; upwards about ten metres of thin bedded radiolarites alternating with siliceous siltstones and shales, more and more abundant going upward; **d**. Calpionella limestones, with the typical well-bedded, whitish calcilutites. The contact is sharp and probably tectonised: no traces of the Nisportino fm. Some hundred metres further on, we reach the Acquaviva Creek.

Stop 16. Fosso Acquaviva, serpentinites

Just crossed the bridge, we turn right along the river and stop at the end of the small road. We go up a big boulder, made up of serpentinised tectonites. They have a composition ranging from spinel-bearing lherzolites to spinel-bearing harzburgites. The rock of the boulder contains interstitial clinopyroxene and plagioclase. The plagioclase occurrence is usually concurrent with stable spinel. We can see also some dykelets crosscutting the peridotite with different trends. They are made up of altered plagioclase and clinopyroxene. At some distance from the dykelets (2 cm) clinopyroxene forms mm-sized poichiloblasts enclosing serpentinised olivine grains These data can suggest that the Sassi Turchini peridotites have been extensively impregnated by mafic melts producing plagioclase and clinopyroxene patches and veins. The presence of impregnated mantle peridotites is reminiscent of the upper-mantle-lower oceanic crust transition zone (Bortolotti et al., 1994; Tartarotti & Vaggelli, 1994a; 1994b).

We come back to the road and, turning right, we go through Porto Azzurro (Fig. 20) and, just before the cross-road to Spiaggia del Lido, we turn right towards il Buraccio-La Crocetta mining area (in the Fosso Mar di Carpisi Valley). A few tens of meters ahead, we take a country road on the right which climb up the La Serra high. Along the road, we cross the intrusive contact between the Monte Calamita fm. and the underlying La Serra-Porto Azzurro monzogranite and arrive to a little plateau with threes. Here the tectonic superposition of the Cretaceous flysch unit above the Porto Azzurro unit crop out. Looking towards NW, the landscape is characterized by the Buraccio-La Crocetta mining area. This mine is still an important producer of raw materials for the ceramic industry. Exploitation focoused on pervasively metasomatized Capo Bianco porphyritic aplite (the so-called “eurite”), located in the basal part of the Cretaceous flysch unit, which underwent significant potassium enrichment during the sericitic alteration at 6.7 Ma (Maineri et al., 2003). This process has been referred to the infiltration of metasomatic fluids along the Central Elba detachment fault

(CEF) during the uplift of the Monte Capanne plutonic body which altered the magmatic bodies present at the base of the Cretaceous flysch unit. We take a track to the north and cross the Cretaceous flysch unit, the higher unit of the Ligurian Domain in the Elba Island, which include the body of the Capo Bianco aplite. We reach a country road (see below) at the divide.
A more practicable road by cars (jeep) is that runs from the Valdana area (Fig. 20 and 39). In particular, from Porto Azzurro we continue to Portoferraio as far as C. Marchetti Locality (Valdana, just after 700 m after the cross road to Lacona). Here we take the road on the right to Buraccio-C.Traditi and La Crocetta (panorama on the La Crocetta Mine) and reach the divide. Near the the divide we cross repeatedly the contact with a very large porphyritic dyke (Portoferraio porphyry) locally associated with aplites. Just before the pass, we turn left, on a very very bad and narrow road (only for little cars). Here we cross a thin outcrop (10-20 m) of Paleogene flysch unit and we enter immediately the Ophiolitic unit (all these tectonic contact are not observable). Going up, we can see on the left a very complicated folded structure in the Calpionella limestones and the underlying Nisportino fm.

Stop 17. Monte Castello-Cima del Monte Pass. The folded structure of the Volterraio subunit and the shoshonitic dyke

We stop on the Pass (Fig. 39) and go down by foot some tens metres. We stop on a small rock spike. We just crossed an important normal fault, dipping NW, which uplifts the Monte Alpe cherts, on which we are, respect to the Nisportino fm. We can note the difference of the tectonic style on the two sides: the cherts are strongly deformed, with tight, vertical isoclinal folds, the Nisportino fm. shows a large anticline, with some minor folds at the core (Fig. 40), which is on our right (E) in the Monte Alpe cherts. We have to note that in spite of the very complicated folds present in the cherts, the contact line with the underlying basalts is very softly folded. We can see this contact immediately beyond the little church (Madonna di Monserrato), where the rugged landscape of the cherts is substituted by smooth and woody hills. In the hills close the sea the underlying units crop out, included the metamorphic Paleozoic basement (Ortano unit) that constitutes the coastal relieves of Porto Azzurro.

We go down some metres westward end we can observe, along the fault plane a cataclastic breccia, some metres thick, made up only of cherts; the marly limestones on the other side are undisturbed. Along the fault

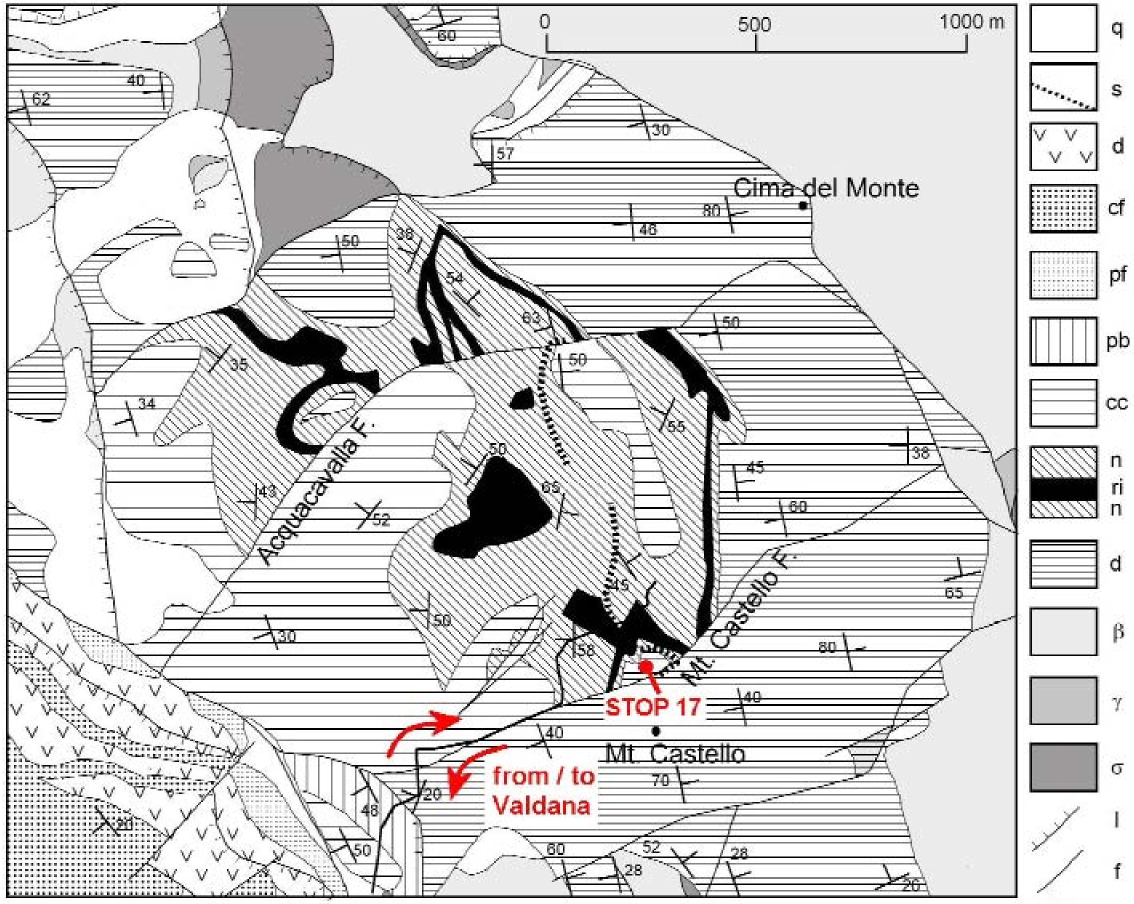


Fig. 39 - Geological map of the area. North of Monte Castello. **q-** Quaternary deposits; **s-** shoshonitic Monte Castello dyke; **d-** Neogene acidic dykes; **cf-** Marina di Campo fm.; **pf-** Colle Reciso fm.; **pb-** Palombini shales; **cc-** Calpionella limestones; **ni-** Nisportino fm., with **ri-** Rivercina member; **di-** Monte Alpe cherts; β**-** basalts; γ**-** gabbros; σ**-** serpentinites.

plane we can observe a some dm thick mafic dyke (Monte Castello dyke in Conticelli et al., 2001). This dyke more west turns right (N-S) and crosscuts the Monte Alpe cherts, the Nisportino fm. and the Calpionella limestones, finally it enters a successive E-W fault (Fig. 39). It has a porphyritic texture with phenocrysts of olivine, plagioclase and clinopyroxene, with seldom large K-feldspar xenocrysts. 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 also occur in the olivine ghosts. In the most fresh samples the groundmass is made by clinopyroxene, k-feldspar, plagioclase, magnetite and apatite. ^{39}Ar/^{40}Ar dating performed on the k-feldspar-rich groundmass give a cooling age of 5.83±0.14 Ma. The whole rock chemistry indicates that the parental magma has a shoshonitic composition, with a clear alkaline-potassic affinity. These data together with trace element data and mineral chemistry suggest that the magma belong to the italian Plio-Pleistocene potassic suite, and closely resemble the 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. The presence of xenocrysts from a monzogranite, and the lack of reaction paragenesis clearly indicates that the mafic magma intruded the monzogranite successively to its cooling.

This dyke is very important for dating the brittle tectonics of the eastern Elba. In fact the SW-NE fault system is older that 5.8 Ma, and is cut by the NW-SE system, which is younger (Fig. 39). This latter moves the thrust of the Volterraio subunit on the Acquaviva (transfer faults?) and does not interrupt the N-S fault system to the east. This latter fault system can be considered the last tectonic structure of the Elba Island. We come back to the main road, and then to Portoferraio.

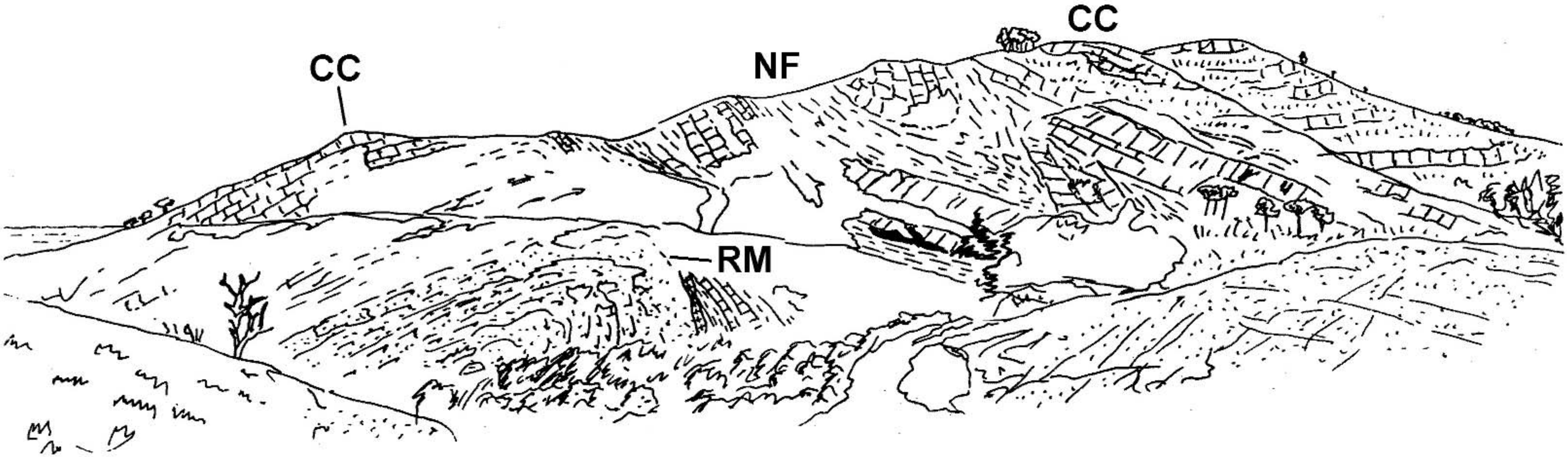


Fig. 40 - Panorama on the complex anticline north of Monte Castello. The core is made of Rivercina fm. (RM) overlain by the upper portion of the Nisportino fm. (NF) and, finally, in the external limbs, by the Calpionella limestones (CC).

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WESTERN AND CENTRAL ELBA

This part of the field trip (Fig. 41) is devoted to observe the main geological feature of the western Elba: i) the Monte Capanne pluton with associated dyke swarm and ii). its thermometamorphic aureole consisting in different types of hornfels after a ophiolitic succession. During the trip we will also visit some outcrops of the flysch units in the Western (Fetovaia) and Central (Lacona-Colle Reciso) Elba. Leaving Portoferraio, we take the road to Procchio. From the Campitelle locality (cross-road to the Napoleonic San Martino Villa), several outcrops of the Cretaceous flysch unit cut by locally decametric S.Martino dykes are present. After the pass (on the right, beautiful view on the Biodola Gulf to the Enfola Cape), we continue for some kilometers as far as the landscape opens on the Procchio Gulf and on the Monte Capanne massif in the background. We stop at a panoramic point.

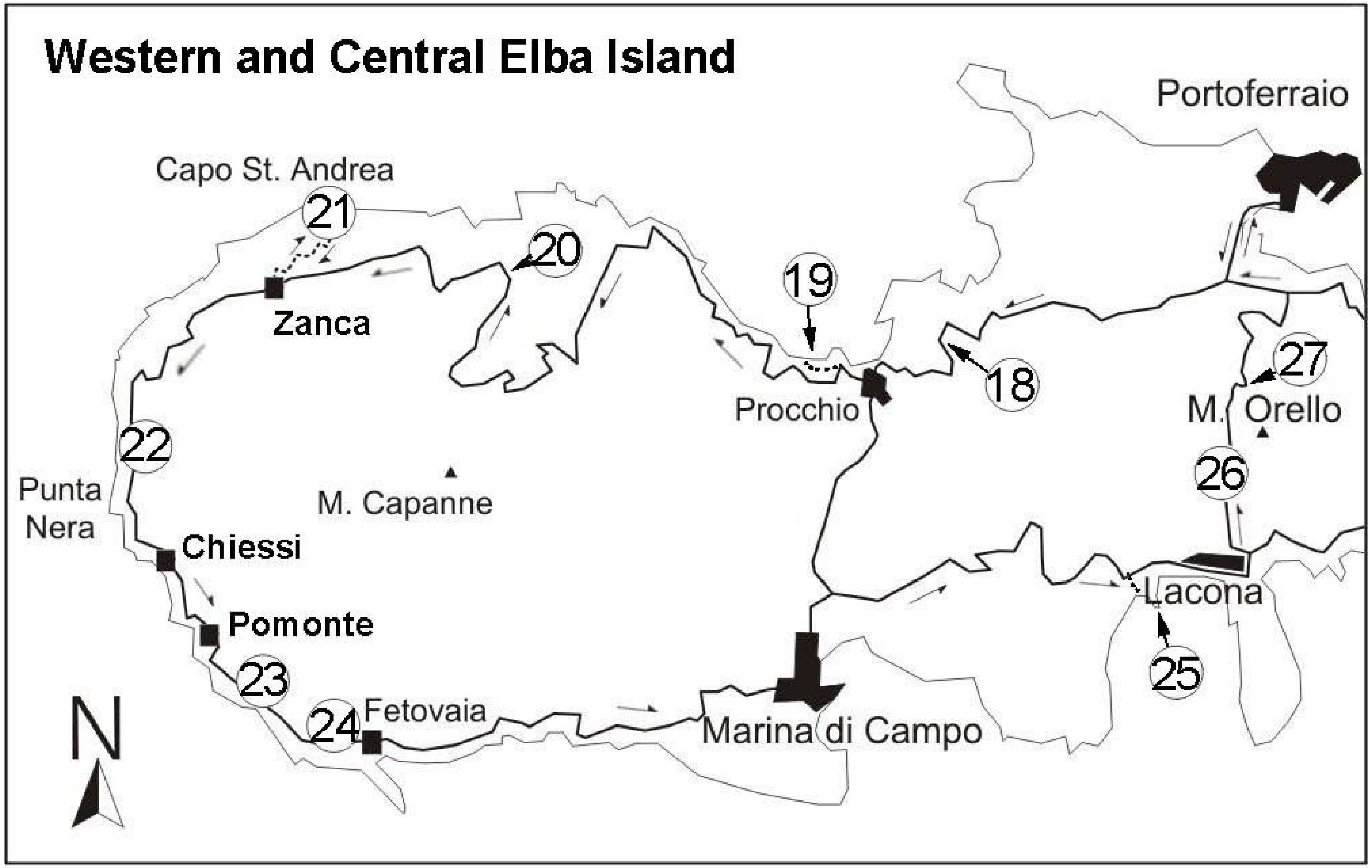

Fig. 41 – Itinerary and Stops in western and central Elba.

Stop 18. View on the Western Elba and the Cretaceous flysch unit of the Central Elba

The Stop allows us to introduce the geology of western Elba (Fig. 42), dominated by the Monte Capanne monzogranitic magmatic body (6.9 Ma) which is about 10 Km^2-wide and 1016 m (a.s.l.) high. Along its slopes, part of the contact metamorphic aureole, made up of a ophiolitic succession, is preserved (e.g. Procchio-

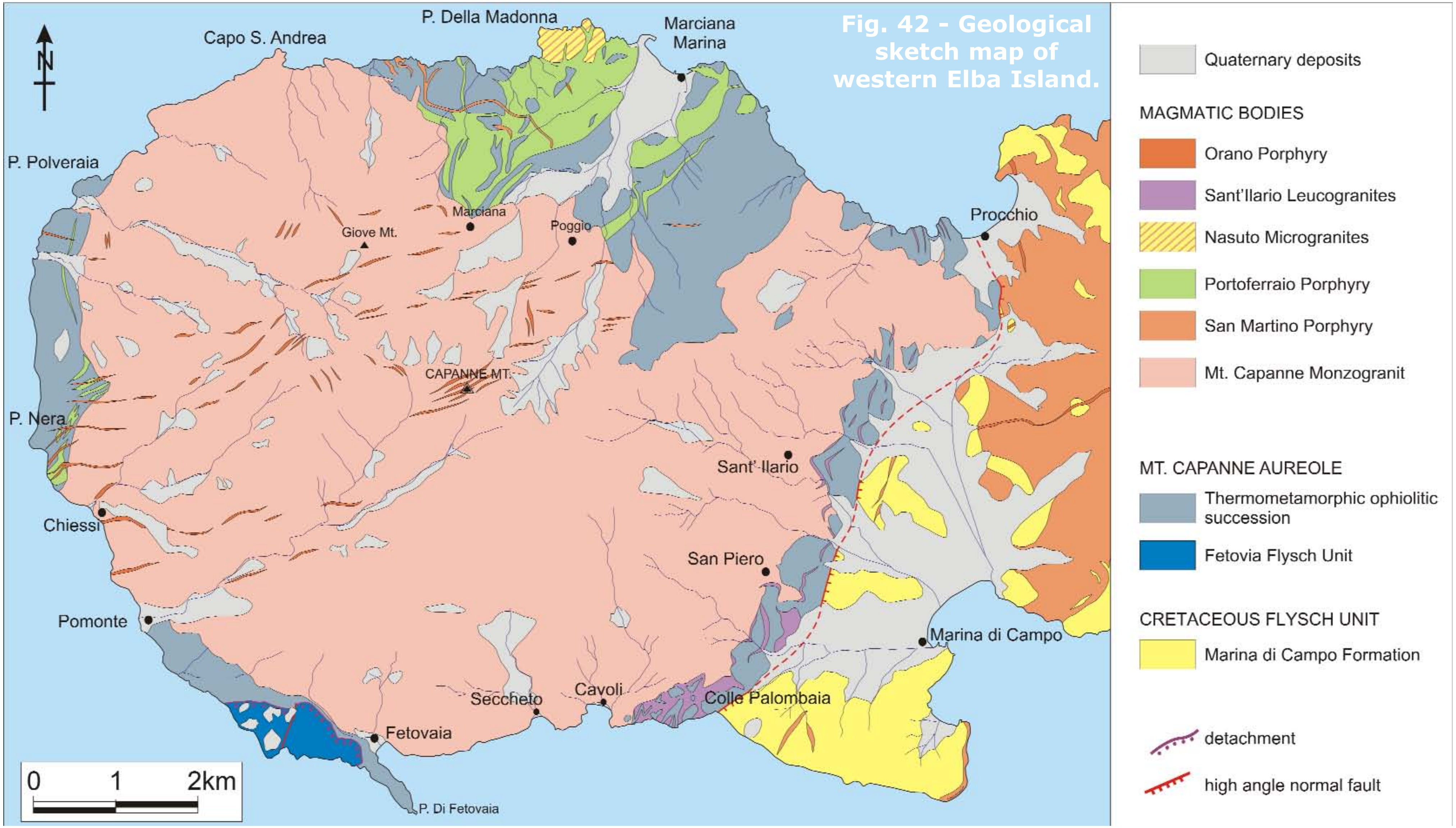

Fig. 42 - Geological sketch map of western Elba Island.

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Spartaia-Paolina Isle and Marciana Marina-Marciana areas). These contact metamorphic rocks are also intruded by the pre-Capanne laccolithic complex (e.g. Capo Bianco aplites, Portoferraio porphyries). At the back of Procchio, the about NS-trending Eastern border fault (Colle Palombaia-S.Piero-S.Ilario-Procchio fault) downthrown to the east the non-metamorphic Cretaceous flysch unit of Central Elba respect to the ophiolitic thermally metamorphosed succession.

Along the slope of the road, the marly limestones with marl, siltstone and shale interbeds of the Cretaceous flysch unit (Marina di Campo fm.) crop out. These rocks are intruded by dykes of the S.Martino porphyry (7.4 Ma). The Marina di Campo fm. is characterised by alternation of four main lithotypes: **a**- grey fine-grained quartz-feldspathic thin-bedded sandstones, **b**-thick-bedded (1-4 m), grey, medium/coarse-grained quartz-feldspathic sandstones with a carbonatic cement, **c**-calcarenitic to marly very thick beds (up to 6 m); frequently, their base is made of an arenaceous level, with carbonate cement, grading upward to the calcarenite which in its turn grades to marlstone, **d**-dark grey very fissile shales which occur in beds showing very variable thickness; their mineralogical association is similar to that of the arkosic turbidites of the Ghiaieto ss., but also includes vermiculite. The lithotypes a- and b- closely alternate at the base of the formation, b-, c- and d- upwards. We continue the trip crossing Procchio and continuing along the panoramic road to Marciana Marina. A few kilometrs ahead, we take the road to Spartaia on the right.

Stop 19. The rocks of the inner part of the M.Capanne contact metamorphic aureole

We reach the parking area of the Spartaia beach. Along the road, in front of the Désirée Hotel, the intrusive contact between the Monte Capanne monzogranite, intruded by leucogranitic dykes, and the thermally metamorphosed host rocks (Monte Alpe cherts of the recrystallized Ophiolitic succession) is exposed. We take a path along the cliff of the western part of the Spartaia bay where metacarbonates with metapelite intercalations crop out. Some undeformed leucogranitic dykes crosscut the foliated thermally metamorphosed rocks. We reach in a few minutes a quarry cut characterised by polydeformed calcschist and marble (Fig. 43) that we correlate to the Calpionella limestones. These rocks are crosscut by a foliated dyke of the Portoferraio porphyry.

Metric to decametric, tight to isoclinal folds represent the main structural feature of this outcrop (see also Spohn, 1981; Bouillin, 1983; Daniel & Jolivet, 1995). We interprete these folds as F2. At the mesoscale, a millimetric to centimetric-spaced axial plane foliation (zonal ti discrete crenulation cleavage, S2) is associated to F2, whose axes mainly strike NE-SW and NNW-SSE with a SW or a northward plunge. Thir axial planes have a NW dip. F2 deformed a previous metamorphic layering which correspond to the lithologic partitions (S1//?S0). S2 and S1, outlined by opaque minerals alignements, are generally replaced by the contact metamorphic minerals (e.g. biotite). Rare unrooted F1 isoclinal folds of decimetric size are locally present. A metric dyke of foliated Portoferraio porphyry, that cut the S1 foliation of the metacarbonates, is present at the top of the outcrop. The foliation of the porphyritic dyke is related to D2 deformation event. In fact, S2 continues from the metacarbonates to the dyke crossing the folded contact (Fig. 44).

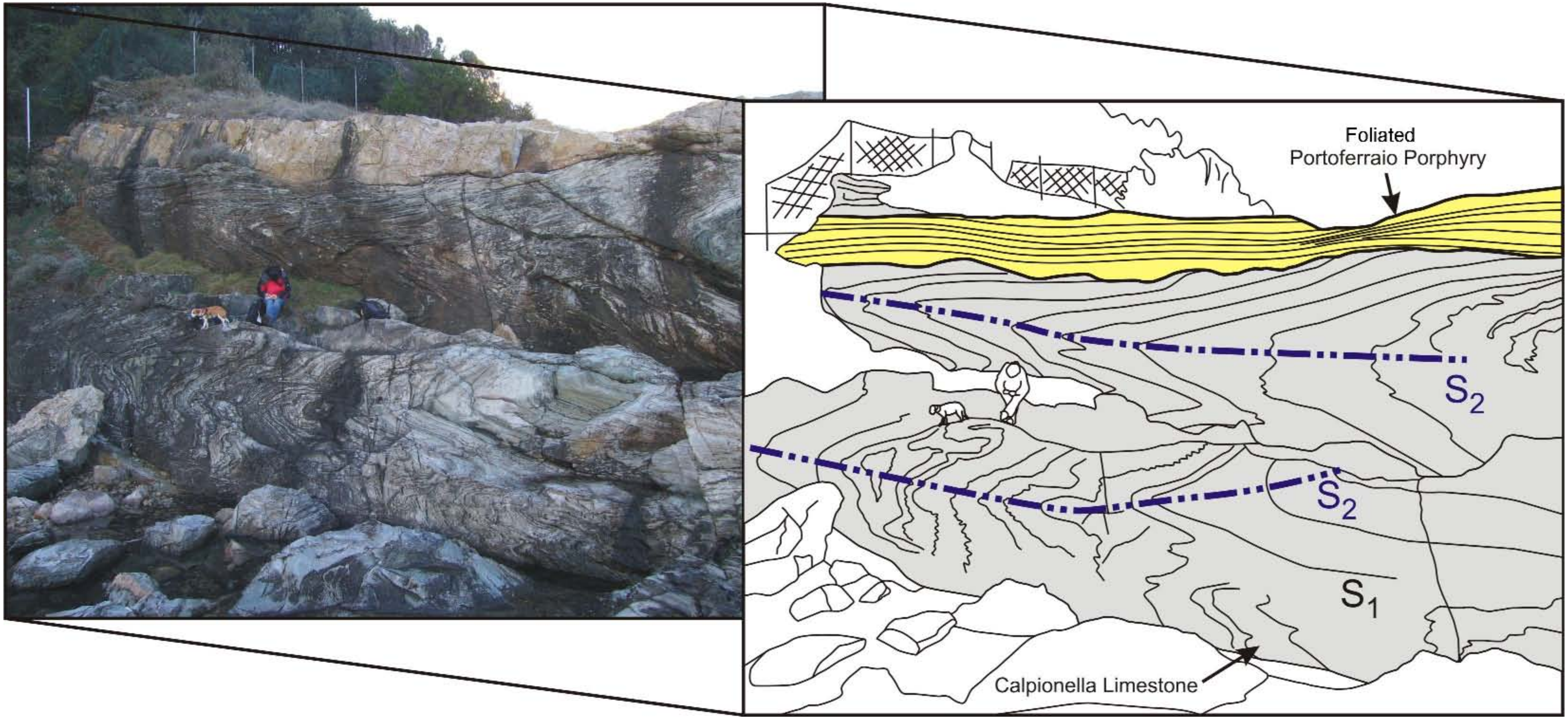

Fig. 43 – Outcrop of polydeformed calcschist and marble west of the Spartaia Bay. These rocks are crosscut by a foliated Portoferraio porphyry dyke.

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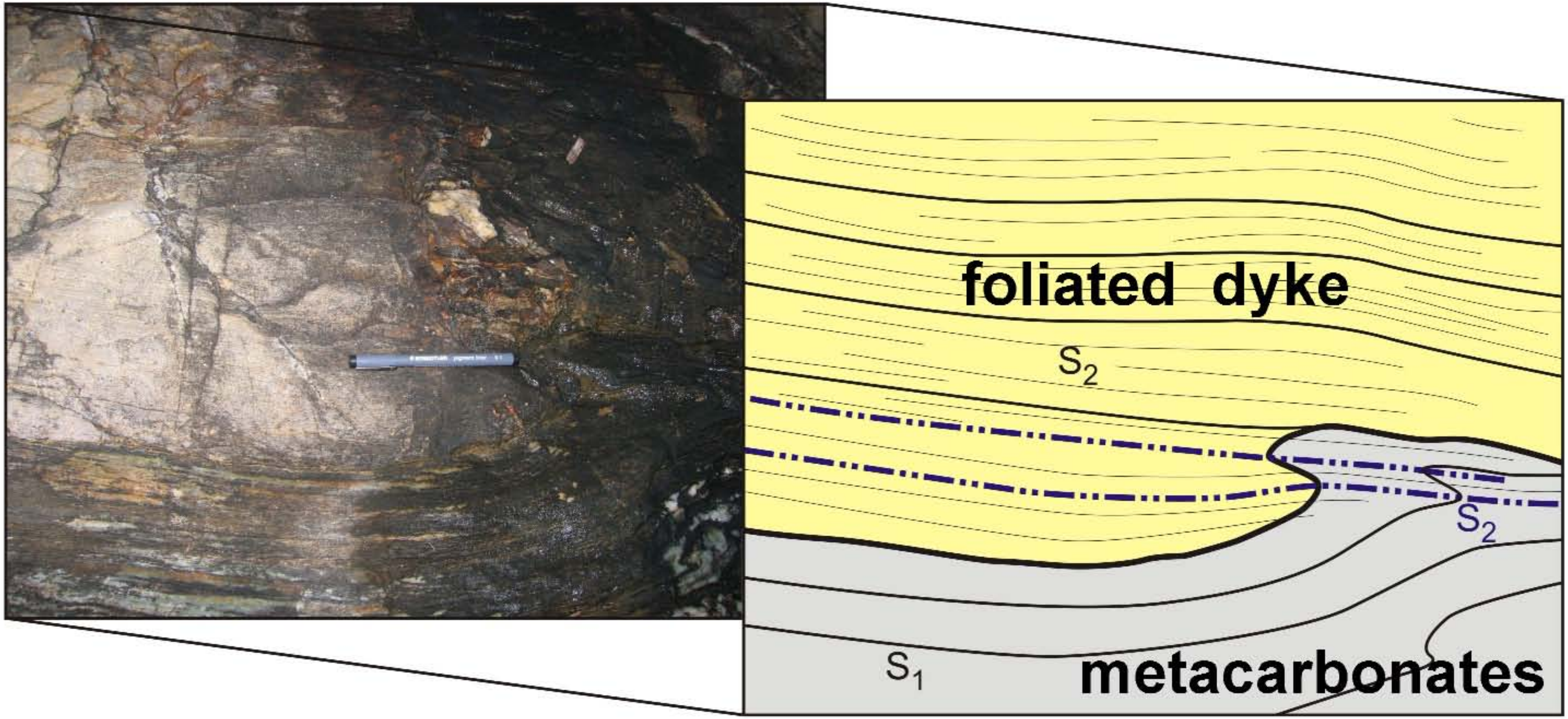

Fig. 44 - Folded contact between the foliated porphyritic dyke and the deformed metacarbonates.

The association contact metamorphic minerals (metacarbonates: wollastonite, calcic plagioclase, diopsidic clinopyroxene, grossularitic garnet, vesuvianite scapolite K-feldspar; metapelites: biotite, intermediate-calcic plagioclase, cordierite, andalusite and k-feldspar) is typical of the pyroxene facies that is consistent with the nearness of the Monte Capanne plutonic body with peak temperatures of 600°-700°C at P 2kbar (Barberi & Innocenti, 1965; Dini et al., 2002; Rossetti et al., 2007). The HT minerals grow statically and mimetically above the D2 structures in plague and foliation-parallel veins.

The folded metacarbonates and the foliated dyke are crosscut by a decimetric to centimetric spaced fracture cleavage filled by high temperature (vesuvianite, grossularite wollastonite) and hydrothermal (e.g. epidote, quartz) mineralizations.

The data suggest that the D2 ductile folding and shearing event occurred after the intrusion of the Portoferraio porphyry and it is likely connected to the hot emplacement of the Monte Capanne pluton which here produced a northward discarge of the cover rocks. During or immediately after these processes, HT fluid infiltration produced hydrofracturing and contact metamorphism of the deformed metasedimentary rocks.

We come back to the panoramic road and continue to Marciana Marina. Just before the village, at Punta della Crocetta, pillow-lavas metabasalts (transformed in amphibole hornfels facies) are well exposed and include an about 2 m-thick porphyritic dyke (Portoferraio porphyry, about 8 Ma). We cross Marina di Campo and continue to Marciana and then to Zanca along the panoramic road. After about a kilometer from Marciana, we stop in front of a quarry (Cava di Caolino locality in Fig. 5).

Stop 20. The “eurite” quarry (S. Rocco or Cava di Caolino)

The quarry exploited a metasomatized Capo Bianco aplite body (8.4Ma) as raw material for ceramic industry. The metasomatic fluid, linked to the final exhalative stages of the Monte Capanne pluton, produced a potassium enrichment (sericitization) of the aplitic body which is included in a laccolithic body of the Portoferraio porphyry. The latter is intruded in mainly metapelitic-metasiltitic rocks (thermally metamorphosed Palombini shales). A S.Martino dyke and a mafic Orano dyke finally cut the above said geological units. The S. Rocco quarry is now in environmental restoration.

We continue along the panoramic road and reach Zanca; we turn on the right, going down the slope as far as the parking area of Capo Sant’Andrea. We take a path along the western cliff and reach the Capo Sant’Andrea.

Stop 21. The Monte Capanne monzogranite

Capo Sant'Andrea - Punta del Cotoncello area.

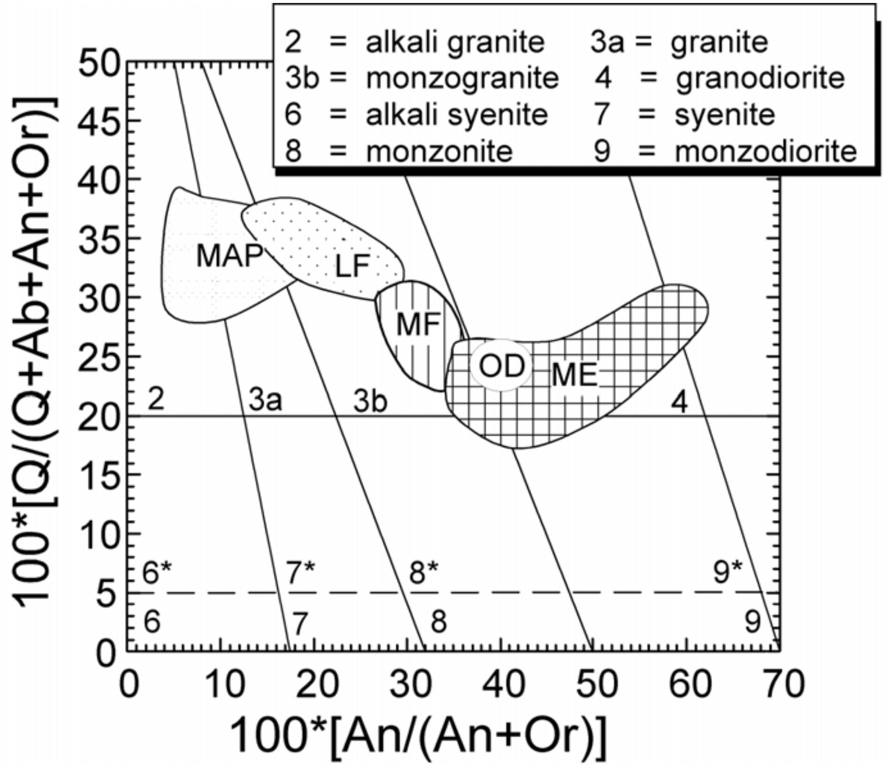

Fig. 45 - Classification normative diagram (after Streckeisen & Le Maitre, 1979) for the Monte Capanne and Porto Azzurro magmatic bodies. Data from Juteau, 1984; Juteau et al., 1984; Peccerillo et al., 1987; Poli et al., 1989b; Poli, 1992. Numbers with asterisks refer to rocks names with quartz- as prefix (after Coli e al., 2001).

The Monte Capanne pluton (about 6.8 Ma) and the related leucogranitic and aplitic dykes are among the oldest magmatic rocks outcropping in the Elba island (Eberhardt & Ferrara, 1962; Borsi & Ferrara, 1971; Saupe et al., 1982; Juteau et al., 1984; Coli et al., 2001; Dini et al., 2002; Gagnevin et al., 2004, 2005, 2008, 2010; Westerman et al., 2004; Farina et al., 2010). The main body intrudes a ophiolite succession including the Jurassic oceanic basement and volcanics, and their Upper Jurassic to Cretaceous pelagic sedimentary cover rocks which Barberi et al. (1969) attributed to their Complex IV widely outcropping in Eastern Elba. These rocks which form a well developed thermometamorphic aureole all around the Mt. Capanne pluton. The main magmatic body of the Mt Capanne intrusion (Poli, 1992; Dini et al., 2002; Westerman et al., 2004) is represented by a light-grey, medium-to coarse-grained hypidiomorphic monzogranite (MF in Fig. 45). The *MF*(=main facies) locally exhibits a marked inequigranular texture due to the occurrence of large Karlsbad-twinned K-feldspar megacrysts (up to 10 cm along the c axis; Fig. 46). In particular, the monzogranitic Monte Capanne pluton was fed by several magma pulses that coalesced into a single intrusion. Three main facies can be detected in the pluton but the first two are more important: 1) the monzogranitic Sant'Andrea facies, characterized by

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numerous large K-feldspar megacrysts and mafic enclaves; 2) the granodioritic-monzogranitic San Piero facies, typically quarried for its homogeneous texture almost devoid of large megacrysts and mafic enclaves; 3) S.Francesco facies show intermediate features between the 1) and 2) facies (Dini et al., 2002; Westerman et al., 2004; Farina et al., 2010). The megacrysts-rich facies (Sant'Andrea facies in Westerman et al., 2004) is well exposed in some outcrops along the outer portions of the pluton and especially at Capo Sant'Andrea, and is also typical of the external parts of other plutons of the Tuscan Archipelago (e.g., Giglio and Montecristo). Beside the megacrysts, the MF is composed of perthitic orthoclase, quartz, plagioclase, and biotite, whilst apatite, zircon, tourmaline, sphene, and monazite occur as accessory phases. Furthermore, in some place (expecially in the Sant'Andrea facies) the monzogranite is dotted by abundant mafic microgranular enclaves with ellipsoidal shapes, centimetric to decimetric in size. They commonly make up 1-2% of the

Fig. 46 - Mesoscopic textural feature of the external portions of the Monte Capanne pluton, where the MF is typically enriched in euhedral K-feldspar megacrysts. These megacrysts respond to a high-volatile conditions of the acid end member, in the early phases of crystallisation (Vernon, 1986). This is testified by their accidental inclusion in the large mafic enclaves that can be observed at Capo Sant'Andrea, which represent a remnant of a partially mingled and mixed sub-crustal end-member. Note the iso-orientation of the K-feldspar megacrysts (see text for explanation) (after Coli e al., 2001).

outcrop surface, and locally, like in the Capo Sant'Andrea, mafic microgranular enclaves tend to increase in abundance and size, reaching metric diameters. The leucocratic facies *(LF)* or San Piero facies consists of a fine-to medium-grained equigranular rock, ranging from monzogranite to syenogranite in composition (Fig. 45). The paragenesis is similar to the MF, although with less biotite and plagioclase. Small amounts (<2 vol.%) of primary muscovite can also occur, but mafic microgranular enclaves are absent. Leucocratic veins and dykes, from a few millimetres up to 2 m in width, commonly crosscut both the *MF* and *LF* of the Mt. Capanne and Porto Azzurro plutons as well as the subvolcanic bodies in the central part of the island. They consist of rnicrogranites, aplites and pegmatites *(M4P).* Microgranites and aplites have a fine-grained texture and are composed of quartz, K-feldspar, plagioclase and muscovite with minor tourmaline and biotite. Pegmatites, on the other hand, have a coarse-grained texture and are composed of quartz, K-feldspar and tourmaline associated to a large variety of accessory phases. The Elba pegmatite are world-famous for their superb, museum quality minerals of polychrome tourmaline and K-feldspar, which can reach dimensions

Fig. 47 - Orano mafic dyke at Capo Sant'Andrea. Note the sinuous trending, and the iso-orientation of c-axis of K-feldspar megacrysts in the host. These characteristics were generated by injection of mafic magma in a crystal-mush represented by the Monte Capanne monzogranite (after Coli e al., 2001).

Fig. 48 - Photograph of mesoscopic texture of the external portions of the Monte Capanne pluton at Capo Sant'Andrea. Large ellipsoidal to irregular shaped light gray mafic enclaves are shown. It is also evident the presence of large K-feldspar crystals in both MF and enclaves. In the latter case the K-feldspar crystals represent xenocrysts withnesses of the mixing process. Note also the irregular rounded to cuspate contact between the enclaves and the host rocks, which suggest that both enclaves and host were molten at the moment of inclusion (e.g., Vernon, 1984; Bacon, 1986; Poli & Tommasini, 1991) (after Coli e al., 2001).

up to several decimetres. Beside *MAP* some peculiar mafic dykes (Orano dyke = OD) also crosscut the Monte Capanne pluton near Orano, NW of Monte Capanne, and at Capo Sant'Andrea. These dykes are different from *MAP* because of: (i) the dark-grey to greenish colour; (ii) the sinuous trending indicating they were injected into the still molten monzogranite; (iii) the presence of mafic microgranular enclaves and K-feldspar macrocrysts like the *MF;* (iv) the less evolved composition than *AMP* and *MF* (Table 1; Fig. 45). In Fig. 47 is shown a 20 cm wide, WNW to ESE-trending *OD* dyke cropping out at Capo Sant'Andrea.

The Elba island intrusive rocks have high $^{87}Sr/^{86}Sr_i$ (from 0.71464 to 0.71528) and low $^{143}Nd/^{144}Nd$ (from 0.51209 to 0.51212) (Juteau, 1984). These values, coupled with high ^{18}O (i.e., 11.40-11.43; Turi & Taylor, 1976) and trace element data (Poli, 1992) are strongly suggestive for the crustal origin of the parental magmas. The *MF* and *LF* rocks from Elba island rocks, however, are the least peraluminous of the overall Tuscan Archipelago and mainland crust-derived rocks (ASI = 1.01-1.16), and together with petrological and geochemical data establish that the monzogranite magmas of the Elba Island are not pure crustal melts, but are somehow contaminated via mixing and/or mingling with sub-crustal magmas (e.g., Peccerillo et al., 1987; Poli et al., 1987; Innocenti et al., 1992; Poli, 1992).

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Mafic microgranular enclaves (ME) are commonly present in the *MF* of the Monte Capanne pluton and in the *OD,* forming 1-2 vol.% of the outcrop surface. They consist of dark-grey, fine-grained rocks ranging from tonalite to monzogranite in composition (Fig. 45). They have ellipsoidal shapes and range from centimetres to some meters in size (Fig. 48). The accidental embodiment of K-feldspar megacrysts and plagioclase crystals from the host-granitoid gives the *ME* a pseudoporphyritic texture, and is suggestive of a plastic behaviour during the incorporation into the host-granitoid magma. Fig. 49 shows the relations between the *ME* and the host rock. Three main structures are generally encountered: a) K-feldspar megacrysts crosscutting the contact between the enclave and the host; b) K-feldspar megacrysts, completely surrounded by the enclave, leaving a trail with complex textures; c) enclaves exhibiting a schlieren-like trail are suggestive of movements inside the partially molten host. These characteristics, together with the ellipsoidal to rounded shapes, the cuspidate margins, and the magmatic texture indicate that the *ME* are fragments of mafic magmas injected and mechanically disrupted (mingling) into the host-granitoid magma (e.g., Bacon, 1986; Campbell and Tumer, 1985, 1986; Poli & Tommasini, 1991).

The paragenesis of the ME Is similar to that of the host-granitoid (MP), although they have higher biotite and plagioclase contents. The chemical composition of the large plagioclase and K-feldspar crystals IS identical to the corresponding mineral in the host-granite, pointing to a xenocrystic origin for these minerals which were incorporated into the ME during the physico-chemical interaction between the basic and acid magmas (e.g., Vernon, 1984; Frost & Mahood, 1987; Poli et al., 1989a). *ME* can be readily distinguished from the angular and metamorphic enclaves occurring along the contacts between the Monte Capanne pluton and the country rock.

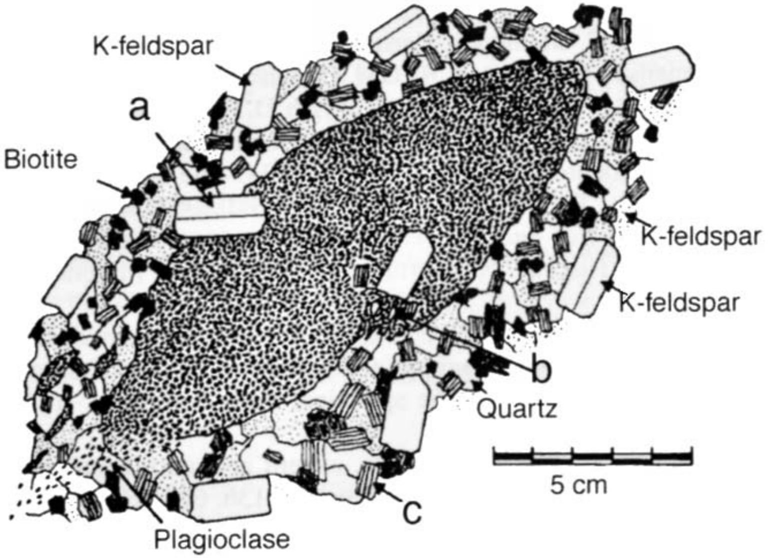

Fig. 49 - Cartoon showing the main textural characteristics of the enclave-host contact. For explanation see the text (after Coli e al., 2001).

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Structural analysis. The structural study was performed by Boccaletti & Papini (1989) at the meso- and microscopic scale, in order to obtain the orientations of the internal structures of the different magmatic bodies of the Western part of Elba Island to be compared with the trend of dykes and fractures which affect the whole Monte Capanne pluton itself. The internal structures consist of planes and lineations, defined in the field by the average orientation of the enclaves and xenoliths occurring in the *MF* and by the c-axis of K-feldspars (Fig. 46), and plagioclase, and the (001) plane of biotites and muscovites (Pitcher, 1979; Marre, 1982). The fabric of the internal structures gives information both on the intrusive body shape and on its emplacement conditions (Fernandez & Tempier, 1977; Femandez et al., 1983). The internal structures, therefore, are the witnesses of the stresses the magmatic mass underwent during the uplift and solidification phases in the high crustal levels.
The internal structures formed during the emplacement of the magma, from a heterogeneous distribution of crystals and enclaves flowing in suspension in the melted mass, through higher viscosity states (crystal mush) to the complete solidification (Pitcher & Berger, 1972). Since the magmatic phase solidifies with continuity, foliations in granitoids may result from different mechanisms, such as magmatic flow, submagmatic flow, solid state deformations at high temperature, moderate and low temperature, as explained by Paterson et al. (1989), which also suggest some criteria to recognise the foliation origin. For example, a pronounced parallelism of internal structures near the intrusion margins is a good indicator of magmatic foliation that can be used to infer the shape of the intrusive body, as the degree of mineral isoorientation usually increases at the intrusion margins (e.g., Balk, 1937; Femandez & Templer, 1977).

In the study of Monte Capanne pluton, linear and planar structures were determined by the iso-orientation of K-feldspar and biotite crystals both at micro- and mesoscale in the monzogranitic and in the porphyric bodies. Plagioclase and muscovite crystals have been studied at the microscope only as regards the aplitic bodies, because of their fine texture. In particular, biotite crystals and K-feldspar phenocrysts are good markers in the field of the internal structure fabrics because of their crystalline habitus, as the first tend to orient themselves according to the (001) planes and the second arrange themselves parallel to the (010) planes, giving also rise, in the field, to spectacular alignments (Fig. 46). Linear structures were also measured in the field through the iso-orientation of mafic microgranular enclaves (ME), which tend to assume ellipsoidal shapes during the emplacement phases, rotating the major axis subparallel to the direction of the maximum strain (Marre, 1982; Ramsay, 1989).

The structural study was completed with the measurement of the orientations of brittle tensional structures, such as dykes and fractures, which develop during the cooling phases. Dykes in the Monte Capanne body usually contain microgranitic or aplitic material and are persistently iso-oriented in the external part of the intrusion. They have radial and concentric attitude, showing regular angular relationships with respect to the internal structures, so that they have been classified as longitudinal and cross joints (Balk, 1937).

When metric to decametric dykes have been sampled, the iso-orientation of the crystals both in and near the dyke parallelises to its maximum elongation (Fig. 47). Both biotite crystals and K-feldspar megacrysts may display flow structures and accumulations in the monzogranite that indicate a faster degree of cooling Their presence is not very common and they are usually developed near the monzogranite margins, as can be seen at Punta del Cotoncello (Figs. 50 and 51).

Altogether, the internal structures of the monzogranite have an arcuate attitude near the margins, that indicates how the outcropping mass corresponds to the entire pluton. This is also confirmed by the presence of flow structures near the monzogranite margins (e.g.,

Fig. 50 - Accumulations and fluidal structures determined by K-feldspar phenocrysts in the granodiorite at Punta del Cotoncello (after Coli et al., 2001).

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Fig. 51 - Fluidal whirling structures (schlieren) evidenced by biotite crystals at Punta del Cotoncello. It is a particular feature of this zone, indicating a rapid cooling, which allowed to maintain this fluidal structure (after Coli e al., 2001) .

Capo Sant’Andrea-Punta del Cotoncello area) and by the attitude of the dykes. Only in the eastern part of the monzogranite the internal structures do not rotate, instead, they show a constant WNW-ESE direction, which allows to infer that the granitic mass 15 not completely outcropping, but probably continues under the country rocks and the alluvial deposits to the east. In the internal part of the monzogranite the magmatic foliation evidences two magmatic domes, corresponding to the Giove and Capanne peaks.
We walk back and reach Punta del Cotoncello along the coast east of Capo Sant’Andrea village. Here the iso-orientation of the c-axis of K-feldspar megacrysts and fluidal whirling structures evidenced by both biotites and K-feldspar phenocrysts are visible (Figs. 50 and 51). The presence of these features indicates a rapid cooling of the margins of the pluton. We take the car and return to Zanca. We continue along the panoramic road of Western Elba to Colle d’Orano-Mortigliano. After these villages, we enter from the Monte Capanne granitoid to the metasedimentary rocks of the contact metamorphic aureole and then (Sedia di Napoleone area) in the meta-serpentinites. We stop at the cross-road to Casa Peria locality.

THE OPHIOLITIC UNITS OF WESTERN ELBA

The Ophiolitic successions of Western Elba (e.g. those of Chiessi-Punta Nera-Punta della Fornace area in Fig. 52a and of Fetovaia-Pomonte area in Fig. 52b) are mostly constituted by metaophiolites (serpentinites, gabbros with basaltic dykes) and a metasedimentary cover (cherts, Calpionella limestones and Palombini shales). This unit directly lies on the Monte Capanne monzogranitic intrusion (~6.9 Ma radiometric data: Jateau et al., 1984; Ferrara & Tonarini, 1985; Dini et al., 2002) which produced an evident thermometamorphic imprint on the oceanic rocks. The thermally metamorphosed rocks were extensively studied by Marinelli (1959), Barberi & Innocenti (1965; 1966), and Bouillin (1983) which related the Ophiolite unit to the Complex IV of Trevisan (1951) thermometamorphosed and deformed by the intrusion of the Monte Capanne monzogranite. Perrin (1975), Spohn (1981), Reutter & Spohn (1982) and Coli & Pandeli (2001) recognised a pre-granitoid tectono-metamorphic framework of these rocks which the former Author referred to the evolution of the Alpine chain, while the others ascribed it to the Apenninic tectogenesis. Coli & Pandeli (2001) suggested a possible correlation of this ophiolitic unit with the *Schistes Lustrés* of the Alpine (NE) Corsica.

According to Spohn (1981) and Reutter & Spohn (1982), the structural setting of Fetovala-Pomonte and Punta Nera Ophiolite unit is constituted by a series of synmetamorphic east-vergent folds, later flattened and westward discharged (Daniel & Jolivet, 1995; Coli & Pandeli, 2001) by the uplifting of the Monte Capanne intrusion. The latter produced also the recrystallisation of the oceanic wall-rocks up to the medium-high grade (hornblende- to pyroxene-hornfels facies: Barberi and Innocenti, 1965; 1966; Spohn, 1981).

In the Fetovaia area (Fig. 52b) the thermometamorphosed Ophiolite unit is overthrust by a substancially unmetamorphic flysch unit (Perrin, 1975; Bouillin, 1983; Spohn, 1981; Reutter & Spohn, 1982). This latter is characterised by a calcareous-marly flysch which overlays a basal serpentinite. Moreover, the lower part of the calcareous-marly flysch is characterized by ophiolitic sandstones and breccias and an olistostrome horizon including calcareous, cherty and ophiolitic clasts in a dominant foliated shaly matrix. In the ruditic horizons (Fetovaia breccia Auctt.), Paleocene-Eocene fossils were also found (Lotti, 1886; Bouillin, 1983; Perrin, 1975; Spohn, 1981). This flysch unit, which show only a local weak recrystallisation, was correlated by Barberi et al. (1969) to the similar Tertiary sequences of the Trevisan's Complex V, widely outcropping in the Central Elba.

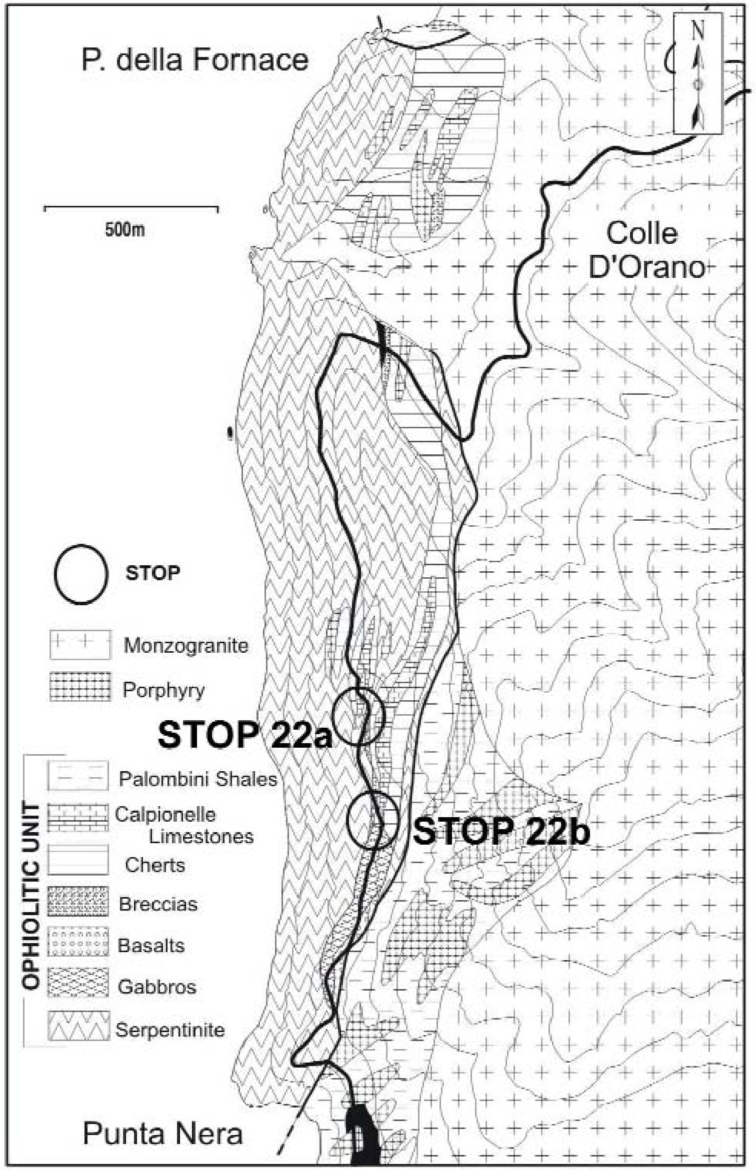

Fig. 52a - Geological sketch maps of Punta Nera-Punta della Fornace area (modified from Coli & Pandeli, 2001).

The structural and petrographic studies, performed by the Authors during the CARG Project, substancially confirmed the maps and structural data of Spohn (1981) and Coli & Pandeli (2001) about the Ophiolite unit in the westernmost Elba, but suggest a more important role in the ductile main folding and shearing event of the Monte Capanne intrusive body.

Stop 22. The ophiolitic rocks of Punta Nera area

Moving southwards, the road crosscuts two F2 synclines made up of metaophiolites (limbs) and of the metasedimentary cover (at the cores) (Stop 22a in Figs. 52a and 53a, Stop 22b in Figs. 52a and 53b). The F2 synclines are tight to isoclinal, eastward facing with axial plane dipping of about 60° towards west. At the core, Calpionella limestones and also Palombini shales (Stop 22a) are present. Both the synclines are flattened and refolded by F3 open folds, facing towards west with sub-horizontal, fracture axial plane cleavage, resulted from the discharge of the Monte Capanne uplift. Ophiolites appear to be strongly foliated in continuous type 1 cleavage. Thermometamorphic garnet is present in the metacherts, whereas wollastonite (locally rosette-like)+pyroxene can be locally recognised in the recrystallised Calpionella limestones. A thin levels of strongly foliated metaophiolites marks the anticline hinge between the two synclines. The outcrops of metacherts and Calpionella cherty limestone are locally characterised by tight to isoclinal mesofolds with refractions of the S_2 discrete spaced axial plane crenulation cleavage (Fig. 54a) and intrafoliar isoclinal rootless hinges (Fig. 54b).

Under the microscope - The microscopic features of the Calpionella limestone are represented by foliated rocks imprinted by HT-LP minerals (monocline pyroxene+wollastonite); the thin pyroxene+wollastonite+k-feldspar+biotite skarn levels with probably correspond to previous lepidoblastic phyllitic or calcschist intercalations within the marbles. These HT-LP minerals are sometimes mimetic on the foliation (S1?//S0). Peculiar in these samples are spherical to ellipsoidic radial aggregates of wollastonite. Frequent are the millimetric to centimetric tight/isoclinal fold (parassitic structures of the F2 mesofolds) that deformed the previous foliated structure (S1) and has a variously penetrative millimetric-spaced axial plane cleavage which is often obliterated by thermometamorphism at the microscopic scale. Local intrafoliar isoclinal rootless hinges and boudinated layers of polycrystalline quartz are probably referred to primary cherty layer or to syn-tectonic veins. The deformed foliation, imprinted by thermometamorphic minerals, is dissected (also millimetric faults are present) by a later spaced fracture cleavage which Is likely referable to the discharge open D3 folds; these fractures are filled by calcite; veins of calcite+quartz±adularia are also present.

We continue the trip to Chiessi. Along the road, the spectacular panoramic Stop place of Punta Nera is characterised by outcrops of medium-high grade thermometamorphosed dark green serpentinites with the blastesis of neo-olivine+talc+clino-amphibole and ortho-amphibole (anthophyllite). After this, we cross the a tectonic contact (syn-intrusion

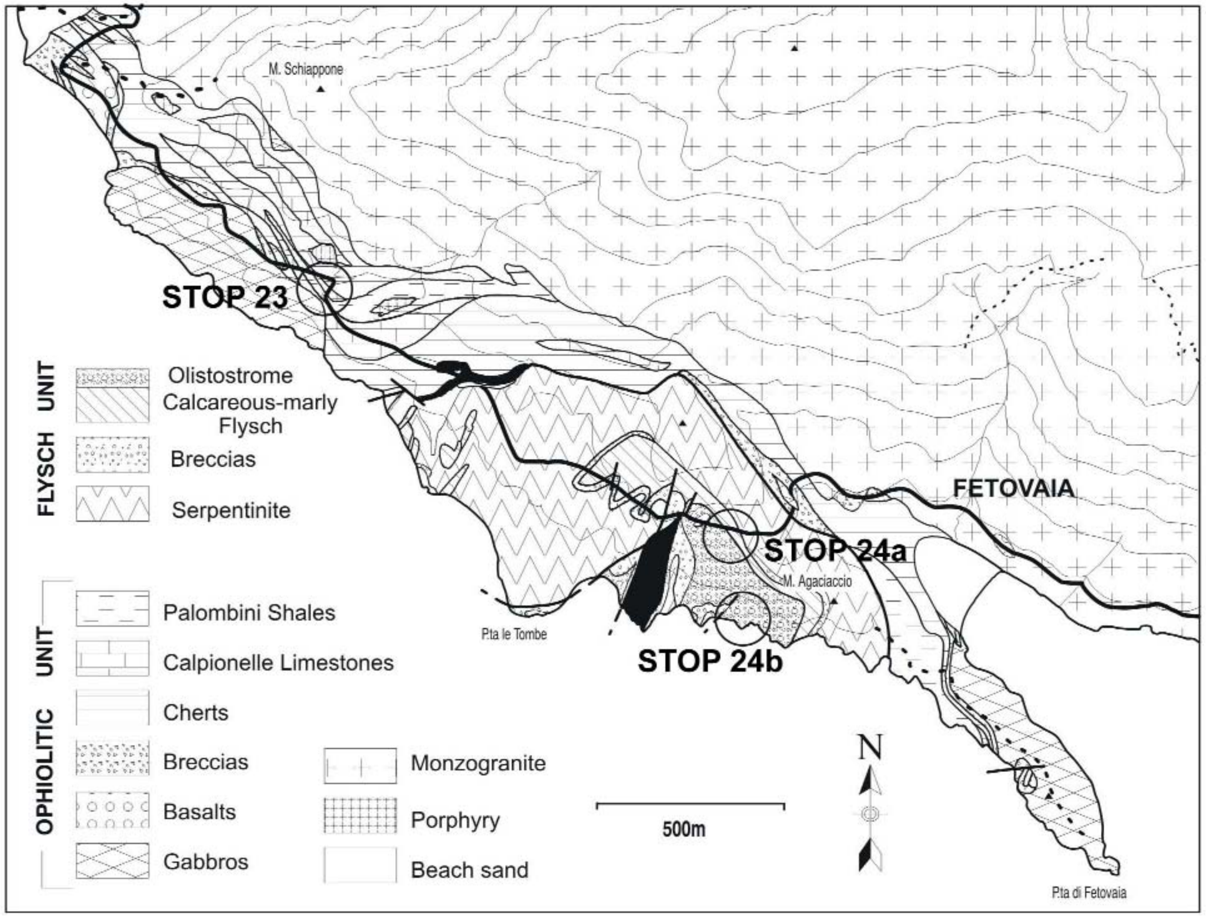

Fig. 52b - Geological sketch maps of Fetovaia-Pomonte area (modified from Coli & Pandeli, 2001).

detachment fault?) which separates the metaserpentinites from the underlying thermally metamorphosed Palombini shales intruded by several dykes of Portoferraio porphyry, of leocogranites linked to the Monte Capanne stock and of Orano porphyry. At Punta del Timone, close to the intrusive contact with the Monte Capanne pluton, some of the Portoferraio porphyry dykes are foliated as thermometamorphosed host rocks (Palombini shales). We cross Chiessi and continue to Pomonte. Just before Pomonte, at Punta della Testa, the pluton preserve some outcrops of its ophiolitic contact aureole made up of gabbro. The gabbros are locally flaser and are cross-cut by undeformed basaltic dykes. The flaser structures of the gabbro are due to oceanic metamorphism. These structures are well-studied in the Northern Apennines and are linked with a HT-LP (up to 700^{0}C) metamorphic blastesis (brown hornblende, pyroxene and plagioclase) overprinted by retrograde mineralogical phases (tremolite/ actinolite, chlorite, etc.). This HT-LP metamorphism is referred to ductile shear zones nearby the oceanic ridge. We cross Pomonte and continue along the panoramic road. In front of the Ogliera Isle, the contact between the metabasalt and the overlying metachert is well exposed. Moreover these rocks are crosscut by whitish aplitic dykes and sills. We reach the bridge above the Ogliera creek (Fig. 52b).

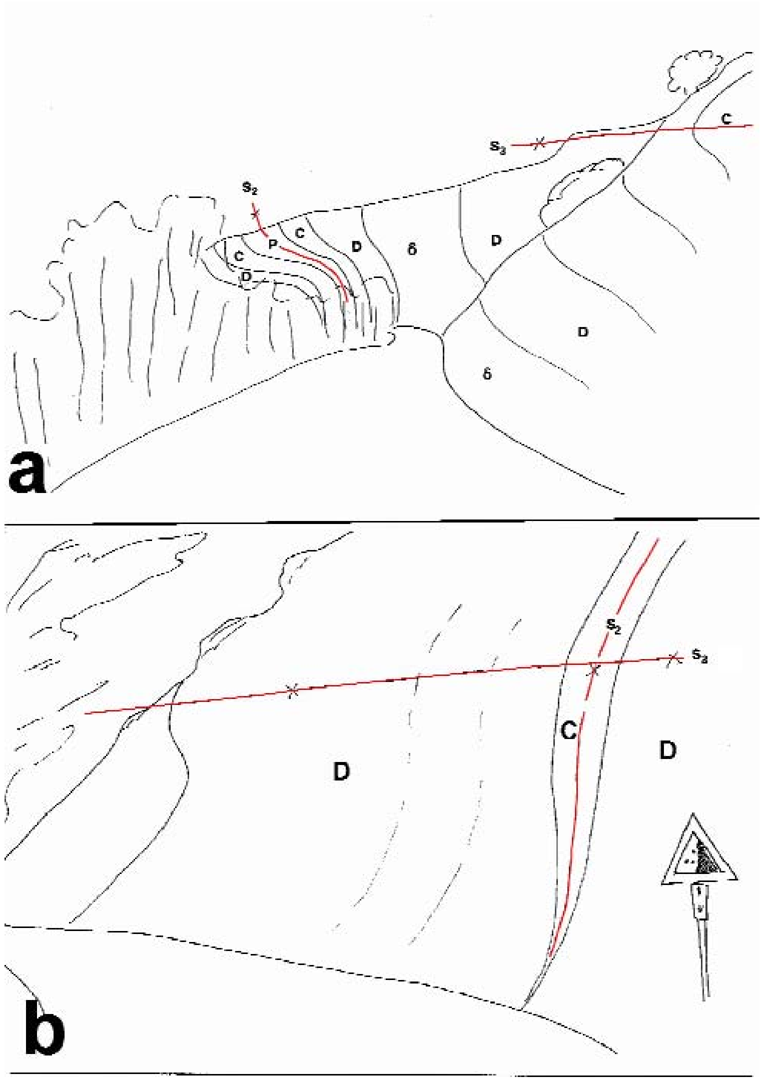

Fig. 53 – Stops north of Punta Nera: **a)** (Stop 22a) The road cross-cuts two D2 synclines pre-dating the Monte Capanne intrusion, both the synclines are flattened and refolded by an D3 fold, facing towards west; in the cliff on the right-side of the road there is a good outcrop cut into that late fold. δ=ophiolites, **D**=cherts, **C**=Calpionella limestone, **P**=Palombini shales; **b)** (Stop 22b) Nucleation of a D2 syncline, gently refolded by a D3 fold related to the Monte Capanne uplift and discharging towards west (after Coli & Pandeli, 2001).

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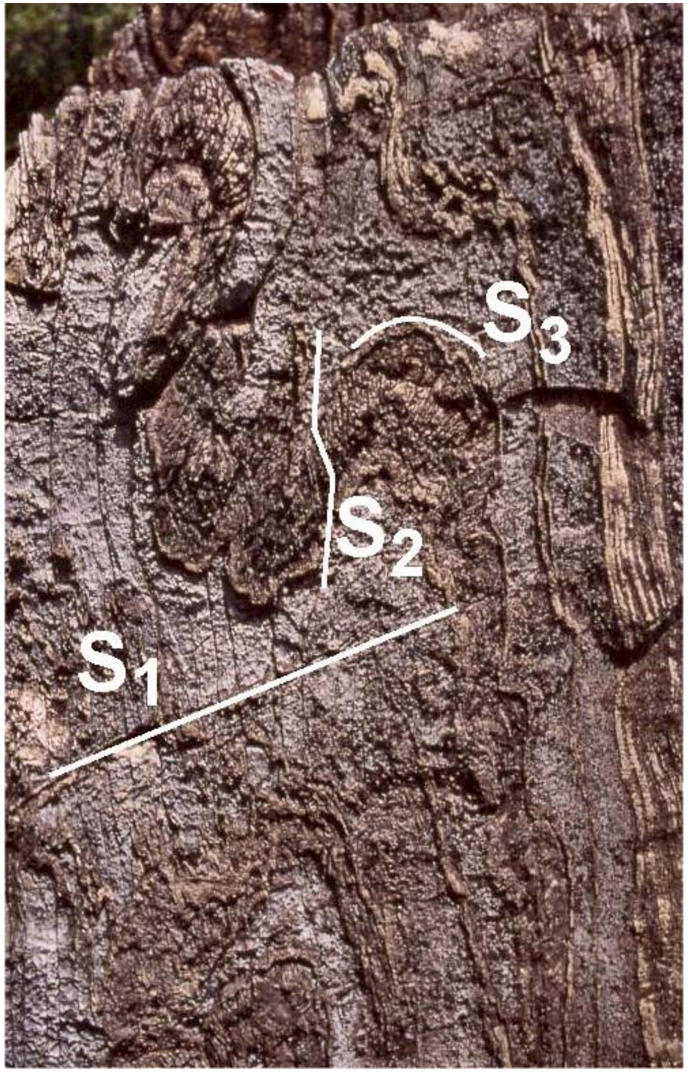

Fig. 54a - Structural features of the meta-cherty limestone (Calpionella limestone): cleavage refractions of the axial plane spaced S2 crenulations cleavage (looking down the plunge of the folds axis) which is gently folded by the discharge D3 event (S3 cleavage) (after Coli & Pandeli, 2001).

Fig. 54b - Structural features of the meta-cherty limestone (Calpionella limestone): intrafolial isoclinal rootless hinges record the occurrence of a previous tectono-metamorphic deformation event (after Coli & Pandeli, 2001).

THE OPHIOLITIC UNITS OF POMONTE-FETOVAIA AREA

Stop 23. The metamorphic metasediments of the Ogliera Bridge area

Walking along the road it is possible to cross a well exposed east-facing F2 syncline (Figs. 52b and 55). The syncline is tight to isoclinal with the axial plane plunging towards west of about 50°**.** The F2 folds deformed at

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the mesoscale the main S1 foliation (//S0?) which is parallel to the lithologic partitions. The core of the syncline is constituted by Calpionella limestones, including boudins of Palombini shales, the limbs are drawn by cherts. Within the axial plane foliation (S_2), relics of intrafolial isoclinal rootless hinges are present and probably testify a tectonometamorphic event (D1) which pre-dates that of the F2 meso-folds. The whole outcrop is cross-cut by a large spaced (1÷2 cm) crenulation to fracture cleavage C3 allowing a kinematic discharge westwards, related to the uplift of the Monte Capanne. In the gate-yard of a cottage there is a good outcrop of poly-folded metacherts. Thin aplitic dykes are often injected along the main foliation of the rocks.

Under the microscope - All the sampled rocks are characterised by a medium-grade thermometamorphism. In the less recrystallised dark grey/black slaty lithotypes of the Palombini shales a mimetic or static blastesis of brown biotite on the white micas+chlorite±quartz slaty cleavage is present. Other samples show a strong thermometamorphic imprint: whitish strings and irregular areas/spots of monocline pyroxene+feldspar±biotite ±quartz; the same mineral assemblage fills also a later fracture cleavage (at a medium angle respect to the main foliation). These rocks are finally cross-cut by Fe oxides/hydroxides or adularia±epidote veins. The Calpionella limestone (as the calcareous intercalations of the Palombini shales) are dark grey or grey-greenish to whitish striped meta-limestone characterised by a granolepidoblastic foliation (alternating fine-grained crystalline limestone and probably phyllitic or calcschist levels) which predates the thermometamorphic minerals. The latter are well represented in the ex-phyllitic interbeds that are

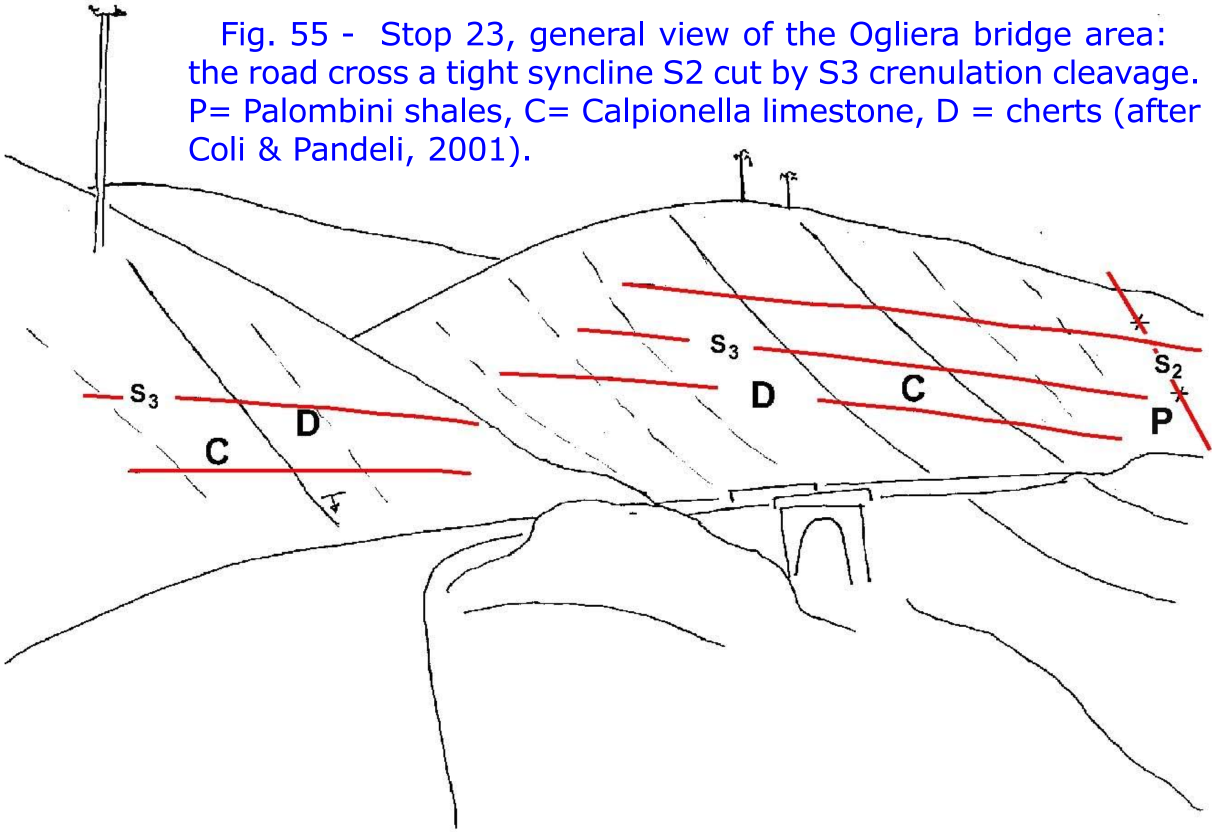


Fig. 55 - Stop 23, general view of the Ogliera bridge area: the road cross a tight syncline S2 cut by S3 crenulation cleavage. P= Palombini shales, C= Calpionella limestone, D = cherts (after Coli & Pandeli, 2001).

transformed into a whitish monocline diopsidic pyroxene+feldspar+garnet±quartz skarn; scattered monocline pyroxene and garnet are also present in the alternating fine to medium-grained marble levels which locally contain porphyroblasts or granoblasts of quartz and small cubic pyrite crystals. Particularly in the skarn levels, weak crenulations (about perpendicular to the foliation) and static garnets (which overprinted the foliation) are present. Locally millimetric/centimetric tight folds deform the foliation and are characterised by "ghosts" of a weak axial plane crenulation cleavage. These rocks are cut by later veins of calcite+adularia±chiorite±epidote?. The samples collected close to the aplitic dykes (sometimes without tourmaline and including poikiloblastic diopsidic pyroxene) are massive wollastonite + clinopyroxene + garnet + scapolite (after feldspar) ± vesuvianite ±plagioclase/K-feldspar ± amphibole? skarn without evidence of foliated structures. Either the dykes or the skarn are affected by calcite veins. The grey-greenish cherts are granoblastic biotite quartzites with later secondary quartz veins and locally with pegmatitic dykelets (quartz + K-feldspar + tourmaline with blue-green pleochroism + muscovite) The static blastesis of quartz+green-brown biotite often obliterates, at the microscopic scale, the previous fold structures and foliations (alternating of quartzites and phyllitic quartzites) Locally the biotite is instead mimetic on previous sheet-silicates (muscovite and/or chlorite?) of the foliation. In some less recrystallised samples, tight to isoclinal folds with pervasive, spaced zonal crenulations clearly deformed the foliation. A lot of small magnetite or pyrite crystals are frequently scattered in these rocks. We continue the trip and reach a panoramic Stop in front of the Fetovaia promontory and Punta Le Tombe.

Stop 24. The Tertiary flysch unit of the Fetovaia area

The outcropping lithologies at the Stop 24a (Fig. 52b) are represented by alternating centimetric to decimetric-thick beds of dark grey (pale grey-yellowish by weathering) marly-limestones and marls and minor grey-black shales and grey calcareous sandstones and siltstones. A gabbro olistolith is also present. The bedding is generally dipping of about 30°÷40° towards west. No penetrative tectonic-fabric or evidence of thermometamorphic imprinting are present. A large spaced (1÷2 cm) crenulation cleavage locally affected the rocks; the crenulation cleavage gently dips towards west and allows a discharge kinematic related to the uplift of the Monte Capanne intrusion. Calcite veins (with euhedral crystal growth) cross-cut vertically the rocks and testify a flattened episode of deformation in overpressured carbonate fluid-rich environment.

At the microscope - The marly and marly-limestones lithotypes show a local weak recrystallisation. The primary sedimentary structures are well preserved (ex. bedding and laminations). These rocks contain variable

amounts of quartz grains, white micas and scattered oxides and carbonised plant debris. The shaly lithotypes are made up sheet silicates (including abundant white micas)±quartz and organic pigment. Particularly in these latter lithotypes weak zonal crenulations (locally marked by alignments of opaque minerals) are present. Secondary veins of calcite are common and generally postdate the crenulations.
We go down to the sea (Stop 24b in Fig. 52b) where the ophiolitic sandstone and breccias lenticular beds are present and overlie a decametric olistostrome horizon. The latter is made up of millimetric to metric calcareous, (Calpionella limestone, Palombini limestone), cherty (Monte Alpe cherts) and ophiolitic clasts in a dominant black, foliated silty-shaly matrix. These ruditic deposits, dated Paleocene-Eocene through foraminifers (e.g. Nummulites), also include olistolites that are mainly represented by serpentinites. A peculiar olistolith, preserving the contact between basalts and overlying cherts, is present along the slope between the road and Punta Le Tombe.

We continue along the panoramic road crossing the tectonic contact between the serpentinite (at the base of the Fetovaia Tertiary flysch unit) and the underlying Monte Capanne monzogranite with local outcrops of thermally metamorphosed rocks. We go on to Fetovaia and Seccheto-Cavoli as far as the Colle di Palombaia. Here the high-angle normal Eastern Border fault downthrown towards east the Cretaceous flysch of Central Elba (intruded by pre-Capanne dykes) respect to the thermally metamorphosed ophiolite rocks. We reach Marina di Campo and take the road to Lacona. A wide laccolitic body of S.Martino porphyry intruding the Cretaceous flysch unit is well exposed along the road. At the pass, beautiful views of the eastern side of the M.Capanne massif (including the Eastern Border fault) and of the central (Lacona)-Eastern Elba (Porto Azzurro-Capoliveri-Calamita promontory).
Before reach Lacona, we turn on the right to the Punta della Contessa. We arrive at a camping and continue along the path to the seaside (Stop 25 in Fig. 41).

Stop 25. The Tertiary flysch unit of the Central Elba

Along the path the typical lithologic association of the Tertiary flysch unit crops out (Colle Reciso fm.). It is made up of highly fissile grey shale, which occurs in thick beds, and that shows minor intercalations of limestones and marlstones, and of rare turbiditic calcarenites and fine-grained sandstones. The limestone beds are dark grey, siliceous calcilutites, some dm thick, very similar to the “palombini” beds described above. The bedding surfaces are generally covered by a dark green smear. The marlstone beds are some dm thick and dark grey. Due to the intense tectonisation, all these intercalations are generally strongly fragmented and do not constitute continuous levels. Macro and microforaminiferal faunas (*Nummulites, Globorotalia*; Collet, 1934, in Raggi et al., 1965; Raggi et al., 1965) point to a Middle(?) Eocene age.

We reach the Punta della Contessa where a serpentinite, interpreted as a olistolite body, crops out. We continue along the sea towards North beyond the cape. Here polymictic breccias are well exposed and include clasts of ophiolite (serpentinite, gabbro), basalt and minor marly limestones in a carbonate matrix containing macroforaminifera (Nummulites). Serpentinite olistolith and the ophiolitic breccias are related to an olistostrome horizon within the Teriary flysch unit similar to that seen in the Tertiary flysch unit of Fetovaia (see Stop 24).

The trip continue crossing Lacona and taking the road to Portoferraio (Colle Reciso Pass). During the climb to the pass, the Tertiary flysch unit is exposed on the eastern slope of the road (Stop 26 in Fig. 41).

Stop 26. The low-angle tectonic contact (Colle Reciso detachment fault) between the Ophiolitic unit and the underlying Tertiary flysch unit

Upslope (western slope of Monte Orello), just above the typical lithofacies of the Colle Reciso fm., a track (running to SW towards an old Calpionella limestone quarry) crosses the low-angle tectonic contact, outlined by a polymictic cataclasite horizon (Colle Reciso cataclasite), between the Ophiolitic unit and the underlying Tertiary flysch unit. Here the tectonic relationships between Ophiolitic unit and the Tertiary flysch unit are inverted with respect to the eastern Elba as well as the movement that suggest a backthrust of the former above the latter unit. The fault surface is marked by a tectonic breccia (Colle Reciso cataclasite) that consists of clasts up to pluridecametric blocks of basalts, serpentinites, Colle Reciso fm., Capo Bianco aplites and San Martino porphyrites, in a shaly matrix which probably derives from the Colle Reciso fm.

We think that the Colle Reciso detachment fault occurred during or slightly before the Zuccale detachment fault activity and might have triggered (as seen for Zuccale fault) by the uplift of the La Serra-Porto Azzurro pluton (see Fig. 18B). We continue trough the pass (on the right, a road leads to the present quarry of Calpionella limestone, whereas to the left, limestone-dominated facies of the Colle Reciso fm. crops out) and about 300 m beyond we reach a bend curve on the left. Here a peculiar of sheeted dyke complex associated to gabbro is exposed (Stop 27 in Fig. 41).

Stop 27. The sheeted dyke complex of the ophiolitic unit at Colle Reciso

This sheeted dyke complex consists of diorites, micro-gabbros and plagiogranite dykes intruding gabbro. The diorites show holocrystalline structure, with euhedral pl crystals, minor subhedral quartz and magmatic, rarely metamorphic, amphiboles (hornblende). They also show fluidal structures with aligned pl and amphibole crystals. The accessory minerals are titanite and zircon. The micro-gabbros show holocrystalline structure with small crystals. The main component are euhedral crystals of pl, partially amphibolised pyroxenes and subordinate oxides. The accessory mineral is zircon. The plagiogranites have granular holocrystalline structure with euhedral pl crystals, a few subhedral qz and subordinate magmatic amphiboles (hornblende). The accessory minerals are epidote, oxides and titanite. The maximum thickness of the complex is about 50m.
A radiometric age obtained with fission tracks indicates 161.23 Ma (Bigazzi et al., 1973) (Callovian). Very similar ages (157 Ma, Bortolotti et al., 1995, $^{40}Ar/^{39}Ar$) were found for the ferrodiorites of Southern Tuscany and plagiogranites of central Tuscany, linked to the basalts. We return to Portoferraio.

THE MONTE CALAMITA PROMONTORY AND ITS IRON ORES

Some of the most important Fe-ore bodies of Elba Island occur in the southern part of the Calamita peninsula (South-Eastern Elba) within the Porto Azzurro unit (Barberi et al., 1967b; Tanelli, 1977; Benvenuti, 1997). The present-day field trip will take us to visit the Calamita mine (Northern and Southern sectors).

Introduction

The Monte Calamita promontory is mainly made up the Porto Azzurro unit which is the deepest tectonic unit of the central-eastern Elba structural pile (Figs. 1, 2, 3 and 56) of Tuscan, Ligurian and Ligurian-Piemontese Nappes (Bortolotti et al., 2001a; Garfagnoli et al., 2005). This unit was intruded by Late Miocene-Lowermost Pliocene granitoids (e.g La Serra-Porto Azzurro monzogranite) and mainly acidic dykes. Moreover, in this part of the island, the relationships between the emplacement of the plutonic bodies and the final deformations of the tectonic stack are easily detectable: e.g the low-angle Zuccale fault that directly superimposes the

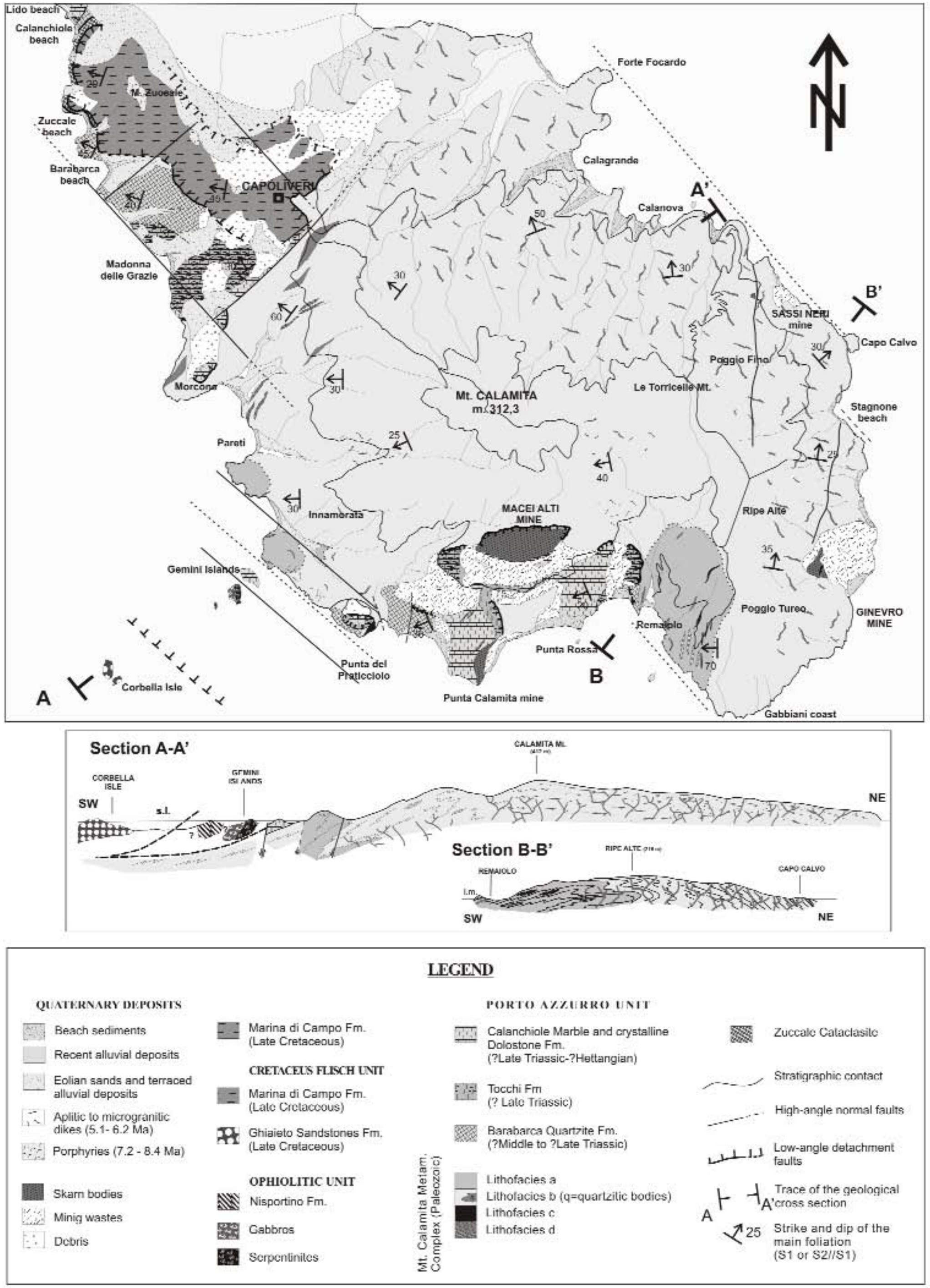


Fig. 56 – Geological sketch map and geological cross-sections of the Monte Calamita promontory (after Garfagnoli et al., 2005).

Cretaceous flysch unit above the Porto Azzurro unit (Fig. 56). The Porto Azzurro unit (Figs. 56 and 57) consists of a Paleozoic, probably pre-Carboniferous basement (Monte Calamita metamorphic complex), which is unconformably overlain by the ?triassic Verrucano metasiliciclastics (Barabarca quartzites) and ?Upper Triassic-?Hettangian metacarbonates (Tocchi fm. and the overlying Calanchiole marble and crystalline dolostone). In the Monte Calamita metamorphic complex, five main lithofacies were recognized and mapped. Garnet-bearing-, albite mica-schists (lithofacies a) geometrically underlie a phyllitic-quartzitic unit (lithofacies b); porphyroids (lithofacies e), metabasite bodies (lithofacies d) and graphite-rich siliciclastics (lithofacies c) are also present. The rocks of lithofacies a are similar to those of the ?pre-Paleozoic-?Paleozoic micaschist complex of the Larderello geothermal field, whereas the other lithofacies can probably be correlated with the ?Ordovician formations of the Tuscan metamorphic succession (e.g. Apuan Alps). The complex deformation-metamorphic evolution of the Porto Azzurro unit consists of the following events

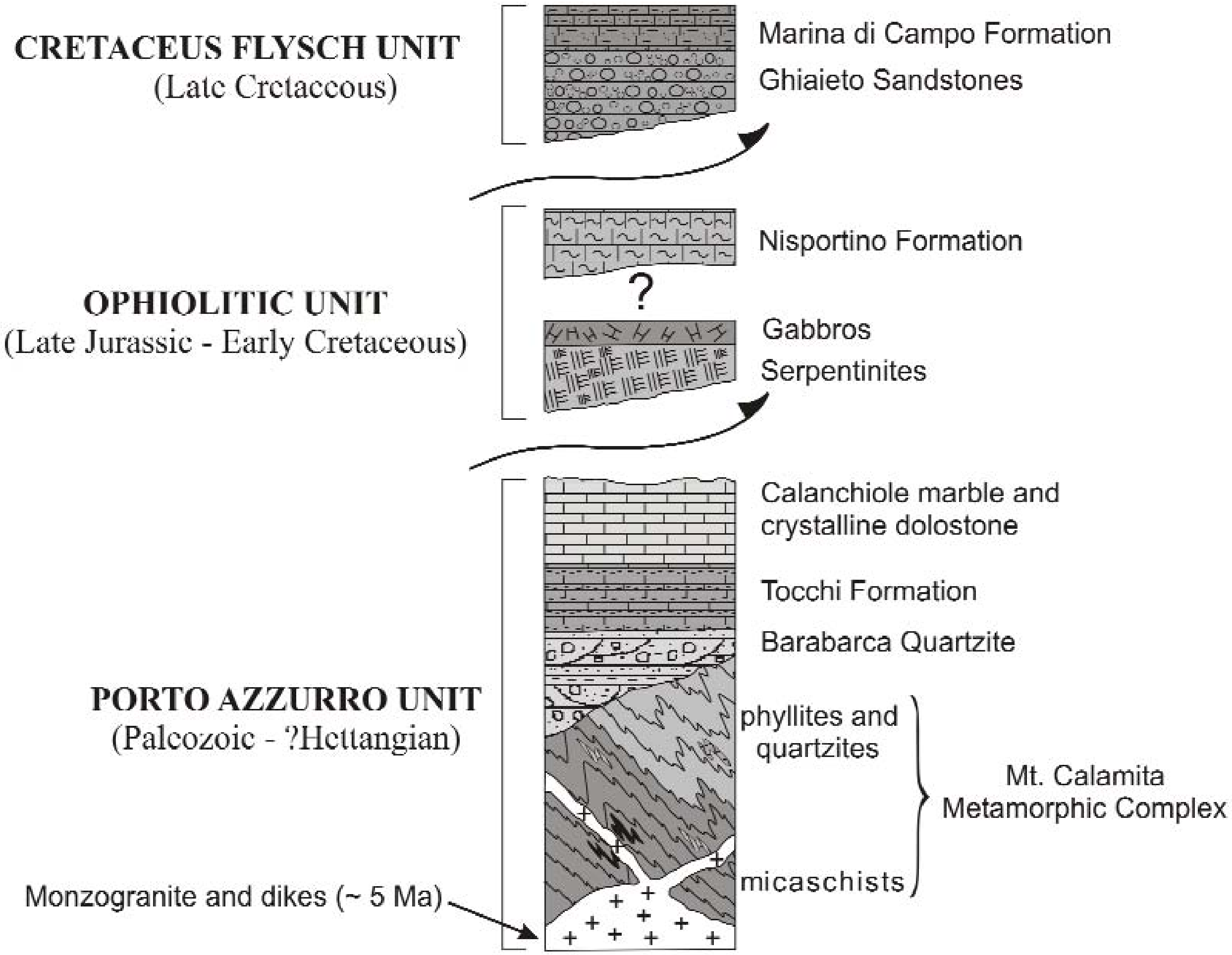
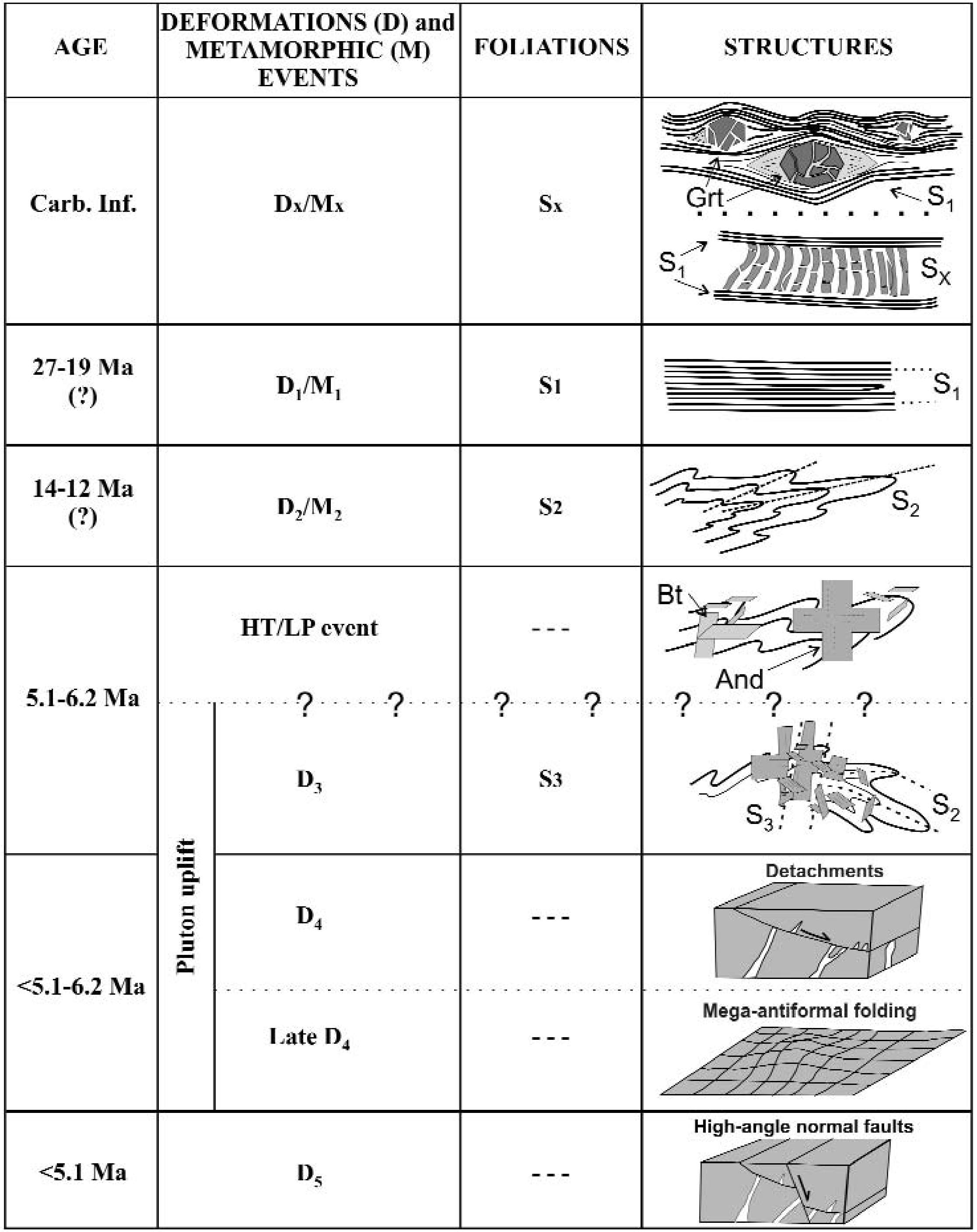


Fig. 57 – Stratigraphic and structural sketch of the units cropping out in the Monte Calamita promontory (after Garfagnoli et al., 2005).

(Fig. 58): a) a Variscan tectono-metamorphic event (D_x), recognized in the Monte Calamita metamorphic complex, which is defined by a pre-Alpine foliation and mineral relicts (garnet); b) two Alpine tectono-metamorphic folding events (D_1 and D_2) in the greenschist facies, which also deformed the Mesozoic cover; c) a later folding event (D_3) which probably occurred during or immediately after the thermometamorphic imprint (including the magnetite-rich skarn bodies), caused by Neogene magmatic intrusions; d) subsequently, the uplift of the magmatic bodies caused low-angle detachments within the Porto Azzurro unit (between the Monte Calamita metamorphic complex and the Mesozoic cover) and between the latter and the overlying tectonic units (e.g. Zuccale fault between the Porto Azzurro unit and the Cretaceous flysch). A final weak antiformal folding (D_4) of the whole promontory took place before the development of NW-SE and N-S trending high-angle normal fault systems, locally sealed by hydrothermal, sometimes Fe-rich mineralizations. The lithostratigraphical, tectonic, metamorphic and magmatic evolution of the Porto Azzurro unit is similar to that detected for the Larderello geothermal region. Thus, the Monte Calamita area can be considered as an older, but similar geological model for the deep structure of southern Tuscany.



AGE	DEFORMATIONS (D) and METAMORPHIC (M) EVENTS		FOLIATIONS	STRUCTURES
Carb. Inf.	Dx/Mx		Sx	Grt S_1 S_1 S_X
27-19 Ma (?)	D_1/M_1		S1	S_1
14-12 Ma (?)	D_2/M_2		S2	S_2
5.1-6.2 Ma	HT/LP event		- - -	Bt And
	? ?		? ?	? ? ?
	Pluton uplift	D_3	S3	S_3 S_2
<5.1-6.2 Ma		D_4	- - -	Detachments
		Late D_4	- - -	Mega-antiformal folding
<5.1 Ma	D_5		- - -	High-angle normal faults

From Portoferraio we take the road to Porto Azzurro. In the Mola plain (west of Porto Azzurro), then we take the road to Capoliveri with outcrops of Cretaceous flysch. Just at Capoliveri, the tectonic superposition of the flysch unit onto the Porto Azzurro unit (made up Monte Calamita fm. and Barabarca quartzites: Figs. 56 and 57) is recognizable. We keep on moving within the Monte Calamita fm. (Paleozoic grey to brown micaschists, phyllites and quartzites locally intruded by aplitic dykes: see also the Terranera Stop in eastern Elba). Just above the village of Pareti (visible looking down the slope) we can observe some lenticular dark green bodies of amphibolites (tremolite+andesinic plagioclase +chloritespheneapatite) which Puxeddu et al. (1984) referred to WPB metabasites intercalated within the metasediments of the Monte Calamita fm.. We finally reach the former seat of Calamita mine headquarter ("Palazzo") (Figs. 59 and 60).

Fig. 58 – Sketch of the deformation-metamorphic evolution of the Porto Azzurro unit (chronological data after Klingfield et al., 1986; Saupe et al., 1982; Brunet et al., 2000; Deino et al., 1992) (after Garfagnoli et al., 2005).

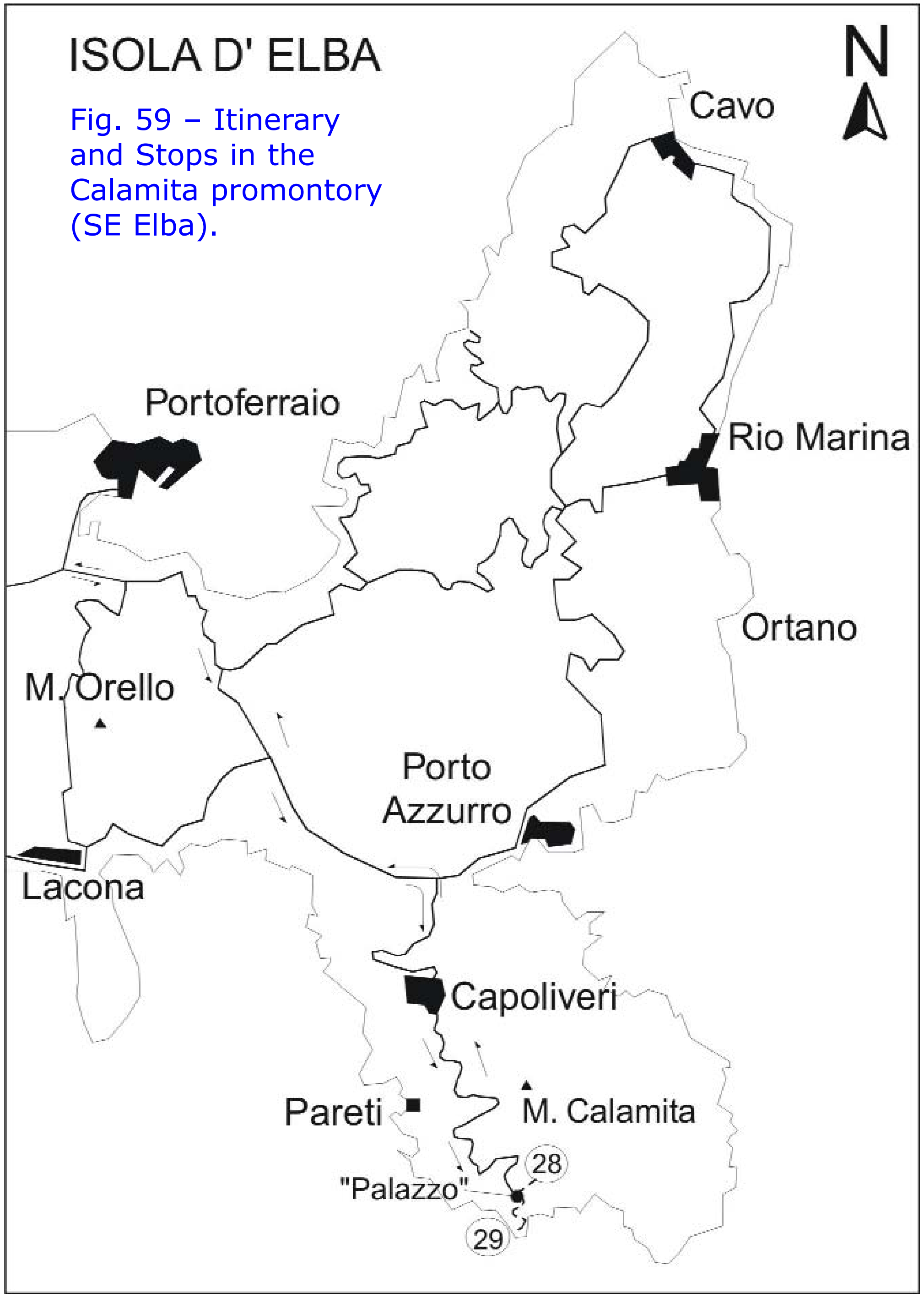
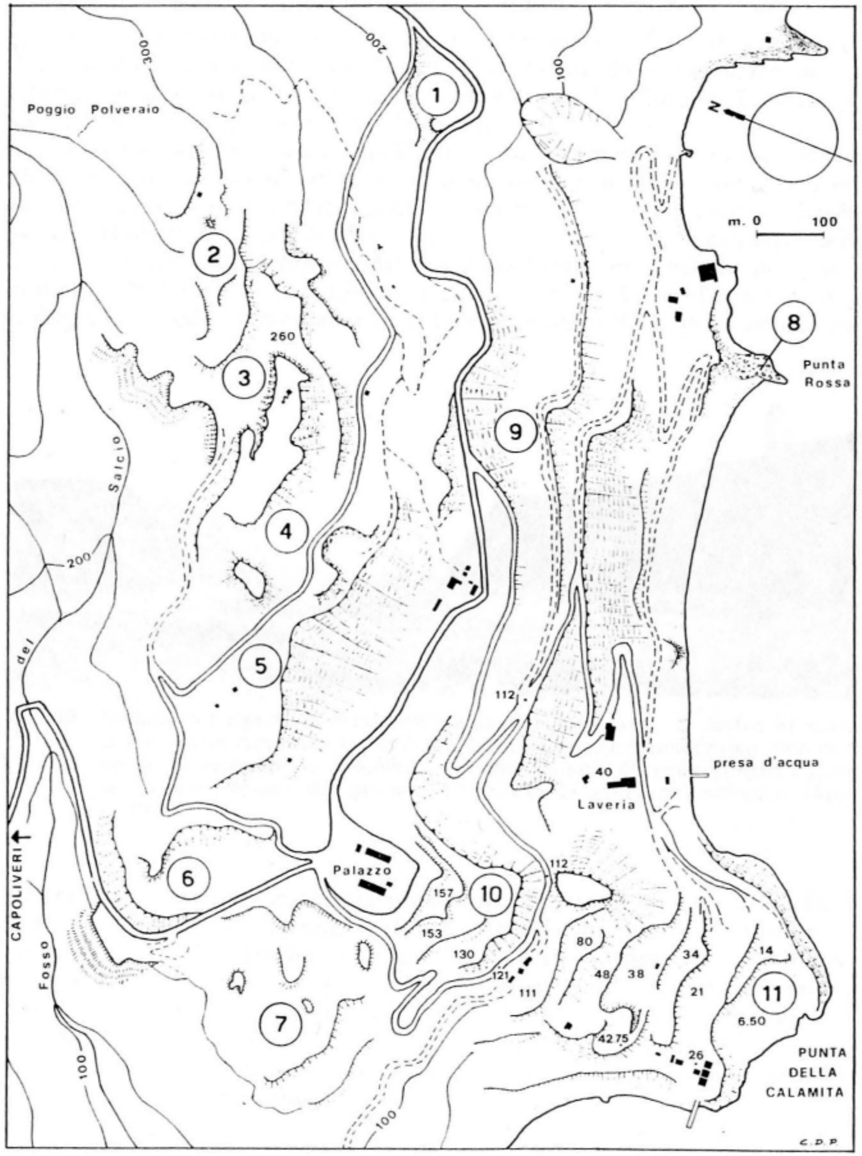


Fig. 59 – Itinerary and Stops in the Calamita promontory (SE Elba).

Fig. 60 – Location of the principal mine workings at Calamita Mine (after Calanchi et al., 1976).



1 Civetta; 2 Albaroccia; 3 Nuova Zona; 4 Macei Alto; 5 Polveraio; 6 Coti Nere; 7 Le Piane; 8 Punta Rossa; 9 Macei Basso; 10 Vallone Alto; 11 Vallone Basso.

Stop 28. The Calamita mine: Northern sector

(Polveraio-Macei mines in Figs. 60 and 61)

In this area thermometamorphic Mesozoic carbonate rocks are present. In particular they are mainly represented by stratified crystalline dolostone and dolomitic limestone, grey-whitish in colour, with local phyllitic intercalations (Tocchi fm., ?Upper Triassic). To the east, along the road, massive or poorly stratified whitish saccaroidal marbles (?Hettangian) with local grey dolomitic levels are also present. These carbonate rocks may represent a portion of the pristine Mesozoic cover of the Monte Calamita fm.. Farther to the west, a quartzitic sequence ("Barabarca quartzite"=Middle-Upper Triassic Verrucano) is interposed between the Monte Calamita fm. and the carbonate rocks. The latter have been affected by extensive hydrothermal metasomatism, which led to the development of two main types of skarn: a garnet (andradite)-rich skarn, quantitatively the most abundant, and an ilvaite-hedenbergite skarn (Torrini, 1990). As shown in Fig. 61, the skarn bodies mainly occur at the tectonic contact between metacarbonates and the underlying Monte Calamita fm..

Iron exploitation at Calamita probably started in pre-Roman times, but only in the middle of the past century (around 1860) it was performed at an industrial scale. Stella (1921, 1933) estimates that at least 2 million tonnes of iron

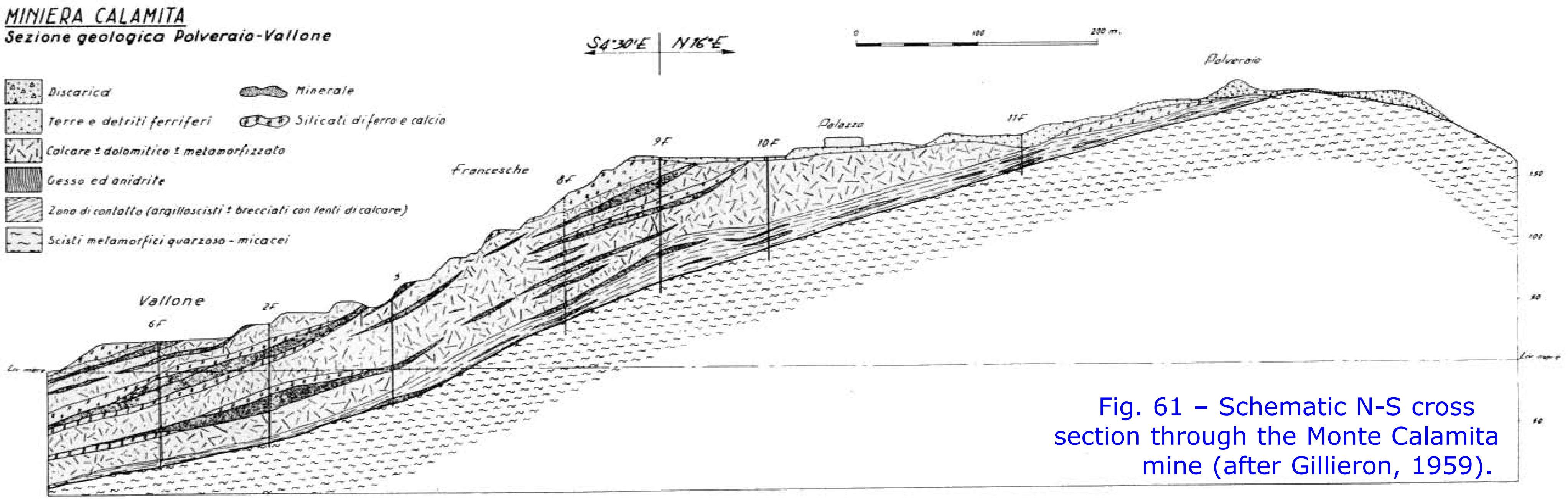


Fig. 61 – Schematic N-S cross section through the Monte Calamita mine (after Gillieron, 1959).

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ore had been exploited since 1860 up to his times, and that the reserves were apprioximately of the same order of magnitude. The northern sector of the Calamita mine is subdivided into several mine working areas (Fig. 60): Civetta, Albaroccia, Macei, Polveraio, Coti Nere. The exploited ores were strictly associated with both types of skarns above described, and consisted of lenses and massive bodies of magnetite (±kenomagnetite, hematite). Additional phases include goethite and trace amounts of sphalerite, chalcocite, arsenopyrite, bornite and pyrite. Moreover, masses of Fe-Cu sulfides (pyrrhotite, pyrite, chalcopyrite ± malachite, azurrite, chalcantite, etc.) were locally exploited at the contact between the garnet skarn and the magnetite lenses. (Torrini, 1990).

Stop 29. The Punta Calamita mine: Southern sector

We move southward along the road to the Vallone (Alto and Basso) mine workings (Fig. 60). In this southern sector of the Calamita mine the exploitation activity focussed on several magnetite lenses associated with hedenbergite-ilvaite skarn bodies, beautiful examples of which can be observed just on the seaward cliffs (Punta della Calamita). The skarn and ore bodies are mostly elongated parallel to the contact between the metacarbonates and the M.te Calamita fm. (Fig. 61). A U-shaped trench (altitude: 112 m. a.s.l.) excavated in the metacarbonates and easily visible from the road separates the two main mine working areas (Vallone Basso and Vallone Alto). At the beginning of the past century the production mainly involved the limonitic gossan of iron ores, which were subsequently exploited almost exclusively for magnetite. At the so-called “Grotta Rame” (=Copper Cave) site, just below the U-shaped trench, Cu-rich veinlets have been described from which a wealth of fine copper minerals have been reported (including malachite, azurrite, atacamite, paratacamite, etc.). At Vallona Alto, moreover, rare “organic” minerals like minguzzite ($K_3Fe(C_2O_4)_3 \cdot 3\ H_2O$) and oxalite ($FeC_2O_4 \cdot\ 2\ H_2O$) have been reported by Cocco & Garavelli (1954). From a textural point of view, at Calamita mine magnetite commonly occurs as pseudomorph after earlier hematite. This is a very peculiar feature with respect to common iron skarns, where magnetite is the primary iron oxide, and may indicate that the deposition of iron concentrations preceeded the skarn formation (cf. Tanelli, 1977).

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memorandum

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