GEOLOGY OF CENTRAL AND EASTERN ELBA ISLAND, ITALY

Valerio Bortolotti, Milvio Fazzuoli, Enrico Pandeli, Gianfranco Principi, Amedeo Babbini and **Simone Corti**

Department of Earth Science, University of Florence and Centro di Studio di Geologia dell'Appennino e delle Catene Perimediterranee, C.N.R., Via G. La Pira 4, I-50121, Florence, Italy (e-mail: bortolot@geo.unifi.it; fazzuoli@geo.unifi.it; pandeli@geo.unifi.it; principi@geo.unifi.it; amedeo@geo.unifi.it; scorti@geo.unifi.it).

Keywords: *stratigraphy, tectonics, geodynamics, geological map. Elba Island, Northern Apennines, Italy.*

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 (carta geologica allegata alla scala 1:15.000) 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 (comprese Unità Ligure-Piemontesi). 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 8,5 e 5,4 Ma.

Dal basso, le Unità riconosciute sono:

1- **Unità Porto Azzurro** (**PU**). E' costituita da filladi, micascisti e quarziti (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 (6,0-5,4 Ma). Localmente sono stati riconosciute anche 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 Cretaceo inferiore. Al tetto è presente una lama tettonica di serpentiniti. Questa unità è stata attribuita al Dominio Ligure (Unità Ligure-Piemontesi), 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 (Lamprofiri 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** (**TN**). A Sud della Parata è rappresentata solo da brecce calcareo-dolomitiche spesso a "cellette" (Calcare Cavernoso), 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 cretacea, è stata attribuita al Dominio Ligure e, per le sue litologie poco confrontabili con quelle della Falda Toscana e per la sua tipica impronta metamorfica anchizonale alle Unità Ligure-Piemontesi.

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-cretacea 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) si intrude in faglie normali nella Subunità Volterraio presso Porto Azzurro. Alcuni filoni a composizione calc-alcalina (Filoni di M. Capo Stella) attraversano i basalti liguri della 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: 7,9 Ma) talora sericitizzati ("Eurite" Auctt.), e porfidi (Porfidi di Portoferraio, 8,2 Ma e di S. Martino, 7,4-7,2 Ma) intrudono i suddetti litotipi, ma verso il basso non proseguono nell'Unità Ofiolitica.

9- **Unità del Flysch Cretaceo** (**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 cretacea, ed infine ad una potente sequenza torbiditica da arenaceo-conglomeratica (Arenarie di Ghiaieto) a calcareo-marnoso-arenacea (F. di Marina di Campo) di età Cretaceo 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 (**GU/TN**: Unità Gràssera su Falda Toscana; **CU/EU**: U. del Flysch Cretaceo su U. del Flysch Paleogenico), altri (**TN/MU**: Falda Toscana su U. Monticiano-Roccastrada; **CU/OU**: U. del Flysch Cretaceo su U. Ofiolitica; **UO/PU**: U. Ortano su U. Porto Azzurro; **CSU/GU**: U. Ofiolitica -Subunità Cavo- su U. Gràssera; **VSU/EU**: U. Ofiolitica -Sub. Volterraio- su U. del Flysch Paleogenico; **BSU/SSU, TSU and VSU**: U. Ofiolitica -Sub. Bagnaia- su U. Ofiolitica -Sub. M. Serra, Sassi Turchini e Volterraio-, e infine le Unità 2-9 su **PU**: 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 (**AU/UO**: U. Acquadolce su U. Ortano; MU/AU: U. Monticiano-Roccastrada su U. Acquadolce; **OU/GU**: 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 (**ZDF**) sembra interrompere. Un ultimo evento deformativo, che ha interessato l'intero edificio strutturale, è rappresentato da faglie normali 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 Cretaceo 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 Cretaceo, 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 Ligure-Piemontesi (Acquadolce e Gràssera; S_1 e S_2 nell'Acquadolce datate 19 Ma), nonché, iii- l'impilamento delle Unità Liguri e Ligure-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 Cretaceo superiore - Attuale.

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 geological survey of Elba I. performed at a scale of 1:10,000 and 1:5,000 (geological map at 1:15,000) 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 in the Elba's tectonic pile during the 8.5 to 5.4 Ma time interval, some of these units were intruded by two acidic plutons (Mt. Capanne and La Serra-Porto Azzurro monzogranites), and by dikes of variable composition.

A total of nine units were recognised, from bottom to top:

1- **Porto Azzurro Unit** (**PU**). It is made up of phyllites, quartzites and micaschists (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., crystalline dolostones and dolomitic marbles were recognised and were attributed to its Mesozoic cover. The aplitic dikes are cut along the tectonic contact (Zuccale Detachment Fault) with the overlying units described below.

2- **Ortano Unit** (**UO**). It includes metavolcanites (Porphyroids) and quartzitic-phyllitic metasediments (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 Valley.

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 Cretaceous age. At its top a serpentinite slice crops out. 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 Lamprophyries) also occur. Locally, the carbonate lithotypes are transformed into Fe-skarn bodies (e.g., Torre di Rio skarn).

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 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: 7.9 Ma), locally sericitised (the so-called "Eurite"), and porphyries (Portoferraio Porphyries: 8.2 Ma and San Martino Porphyries: 7.4-7.2 Ma) 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 Late 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 1, by a low-angle detachment fault marked by a decametric cataclastic horizon (Zuccale Fault and related cataclasite). The thrust surfaces (Late 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, 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 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 **OU**, **EU** and **CU**, with production of ophiolitic-carbonate breccias within **PU**, and the D_1 tectono-metamorphic event (S_1 relics) in **AU**, related to Eocene intra-oceanic deformation events; c- main deformation and metamorphic events of Tuscan (**PU**, **UO**, **MU**) and Ligurian-Piedmontese Units (and 19 Ma S_2 in **AU**), overthrusting of the oceanic units (**AU**, **OU**, **GU**, **EU**+**CU**) onto the Tuscan ones, and a later refolding of the tectonic units, probably related to the Oligocene-Early Miocene collisional events; d- 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 stage 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 north- or north-eastwards gliding of **CSU**, completed the present tectonic pile 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.

Finally, our reconstructions of the tectonic evolution of the Elba I. is fitted in the geodynamic context of the orogenic system Corsica-Northern Apennines, as shown by a series of tectonic sketches starting from the Late Cretaceous.

INTRODUCTION

The Elba Island is located in the central Tyrrhenian Sea, midway between Southern Tuscany and Corsica. The Island is formed by the westernmost outcrops of the Northern Apennines, and thus it constitutes a key area of paramount importance for the understanding of the relationships between the Northern Apennines chain and the "Alpine" Corsica. This study, performed in the central and eastern parts of the Island, is a detailed geological survey (1:10,000 and 1:5,000).

Stratigraphic and structural evidences indicate that the tectonic units of Elba belong both to the Ligurian[1] branch of the Western Tethys Ocean, and to the continental margin of Adria. Of particular interest is the coexistence of tectonic structures which represent different deformative events which were superimposed in the Island. In fact, after the compressional events linked to the Apennine orogenic phases, the Mio-Pliocene extensional tectonics played a leading role, triggered in part by the uplift of two plutons, located in the western and eastern ends of the Island.

The geologic model that we propose for the Island has been tentatively framed in the context of the tectono-sedimentary evolution of the Northern Apennines - Corsica orogenic system.

Before this study, many geologists studied the Elba Island from different points of view. For a detailed historical review of the different interpretations of the geology of the Elba, see Bortolotti et al. (2001a, this volume).

We here briefly report only the interpretation of Trevisan (1950; 1951), slightly modified by the Pisa working group (Raggi et al., 1965; Barberi et al., 1967a; 1969a; 1969b) and Pertusati et al.(1992), which has provided to date the starting point for all geological studies on the Elba Island. The formations cropping out in this area were subdivided into five tectono-stratigraphic units ("Complexes") (Fig. 1).

The Tuscan Units (Complexes I, II and III) are overlain by Ligurian Units (Complexes IV and V).

Complex I (= Calamita Gneiss Auctt). This metamorphic Complex includes at the base a succession of muscovite-biotite schists with andalusite and plagioclase, with 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 cornubianitised and intruded by aplitic dikes linked to the La Serra-Porto Azzurro monzogranite.

Complex II. This Complex includes a metamorphic Tuscan Succession similar to the Apuan Alps one. From

[1] The terms "Piedmontese Domain" or "Ligurian-Piedmontese Domain" are used in the geologic literature of the Northern Apennines with different and not always definite meanings, however they usually define the successions deposited in the Ligurian branch of the Western Tethys ocean which suffered a tectono-metamorphic evolution. These terms do not refer to a "Domain", but indicate the portion of Ligurian Domain, which had a tectono-metamorphic history similar to the correspondent metamorphic oceanic units of Western Alps. So, we propose to abandon the term "Domain" and, since these successions are always allochthonous, to adopt "Ligurian-Piedmontese Units", to emphasise that these tectonic units deposited in (and coming from) the Ligurian oceanic branch, underwent a tectono-metamorphic evolution.

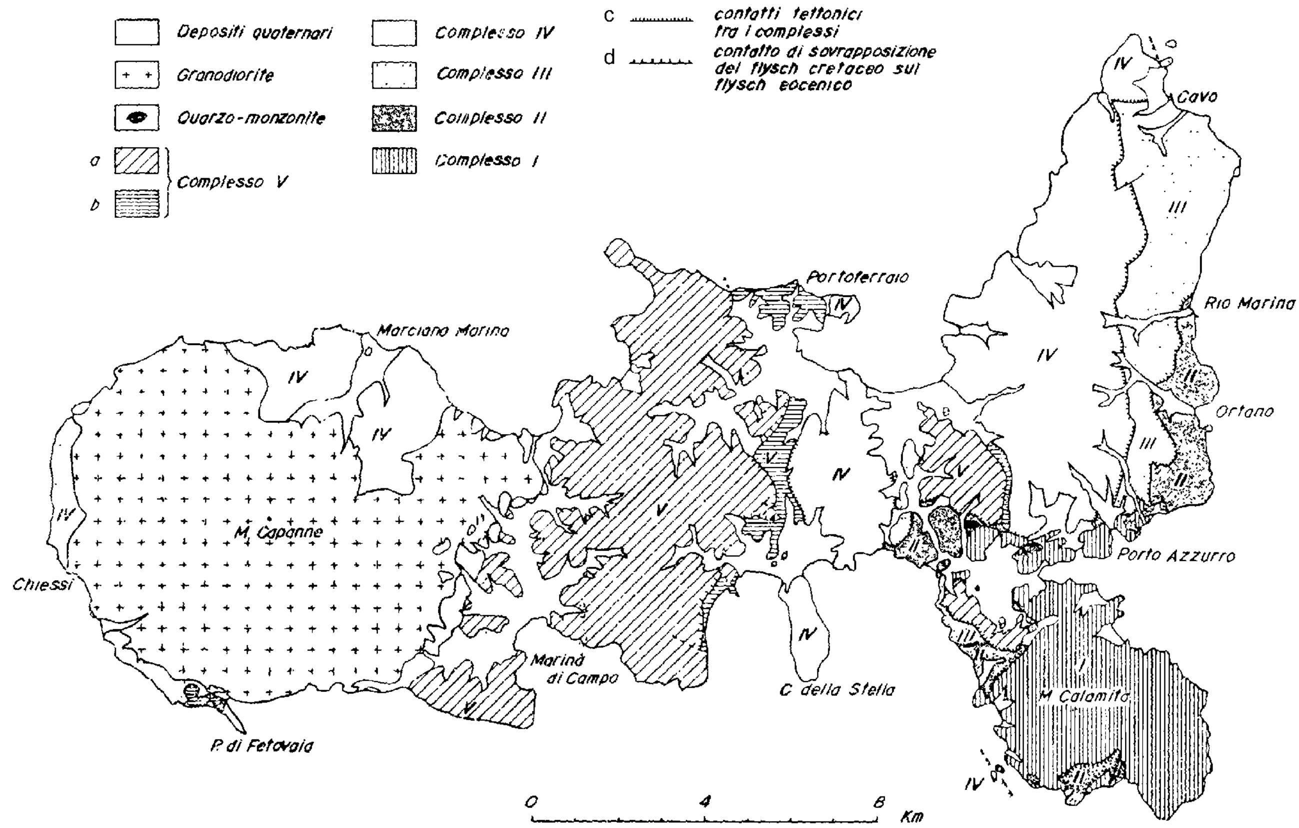

Fig. 1 - Geological sketch map of the Elba Island according to Raggi et al. (1965).

bottom to top, we can recognise: **a**. “Scisti macchiettati” (= “Spotted schists”, thermometamorphic schists with biotite and andalusite spots), often graphitic, overlain by porphyroids and porphyritic schists, probably of Permo-Carboniferous age; **b**. Yellowish vacuolar dolomitic and calcareous-dolomitic rocks of Norian-Rhaetian age; **c**. Marbles, grading upwards to calcschists and “Cipollini” (Liassic); **d**. Calcareous phyllites (Dogger) with calcschist levels. This Complex is overlaid by a sheet of tectonised serpentinite.

Complex III. It corresponds to the Tuscan Succession of La Spezia; from the base, it includes: **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**. More or less dolomitic vacuolar limestones, heteropic with black limestones with intercalations of marlstones with *Rhaetavicula* (Norian-Rhaetian); **d**. Massive limestones (Hettangian); **e**. Cherty limestones (Liassic); **f**. Varicoloured marly shales and rare cherty calcareous levels (Dogger).

Complex IV. This represents the lower Ligurian Complex and consists of: **a**. Lherzolitic-harzburgitic serpentinites; **b**. Gabbros; **c**. Basalts; **d**. Radiolarites of the Malm; **e**. Calpionella Limestones (late Tithonian?-Early Cretaceous); **f**. Shales with siliceous limestones (Palombini Shales, Early-“mid” Cretaceous)

Complex V. It includes two tectonically superimposed flysch formations. 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 upwards to a marly-calcareous succession.

In eastern Elba the four, uppermost complexes lie directly on the substantially autochthonous Complex I. The Authors consider this particular setting as a consequence of a polyphase east-verging tectonics which first caused the emplacement, in a compressive regime, of the Ligurian Units onto the Tuscan ones; then, the tectonic pile was emplaced by gravity onto the Complex I. This late extensional event was interpreted as due to the uplift of the Mio-Pliocenic stocks of Mt. Capanne and Serra-Porto Azzurro (Trevisan, 1951; Marinelli, 1959a).

According to our interpretation the structure of central and eastern Elba Island is more complex than suggested by the previous authors. We recognised nine major tectonic units, pertaining to both the Tuscan and the Ligurian Domain. Some of these units were intruded by Messinian-Pliocene magmatic bodies and related dike swarms. Usually, these units are characterised by an eastern vergence. From bottom to top they are (Figs. 2 and 24, and Tectonic scheme in the map)

1- Porto Azzurro Unit (**PU**); 2- Ortano Unit (**UO**); 3- Acquadolce Unit (**AU**); 4- Monticiano-Roccastrada Unit

[2] For all the acronyms, see Table 1.

(**MU**); 5- Tuscan Nappe Unit (**TN**); 6- Gràssera Unit (**GU**); 7- Ophiolitic Unit (**OU**) subdivided in seven subunits; 8- Paleogene Flysch Unit (**EU**); 9- Cretaceous Flysch Unit (**CU**). Units 1, 2, 4 and 5 belong to the Tuscan Domain, the other units belong to the Ligurian Domain (3 and 6 are Ligurian-Piedmontese units).

1, 2) The two lowermost units (**PU** and **UO**) belong to the Tuscan Domain, and consist mostly of Paleozoic rocks affected by tectono-metamorphism of both Variscan and Alpine orogens. On top of **PU**, some outliers of a metamorphic succession crop out, possibly representing fragments of the Mesozoic cover. These Units are cut by the La Serra-Porto Azzurro monzogranite and related dikes (6.0-5.4 Ma).

3) The Acquadolce Unit (**AU**), consists of the Santa Filomena serpentinitic Subunit (**FSU**) lying on the Porticciolo Subunit (**PSU**), probably a metamorphic Mesozoic slice with Piedmontese affinity ("Schistes Lustrés" Auctt.); rare porphyritic dikes (kersantite dikes of Debenedetti, 1950; see later: Casa Carpini Lamprophyries) occur north of the Terranera area.

4, 5) The Monticiano-Roccastrada Unit (**MU**) is a Tuscan succession (Late Carboniferous to Oligocene) which suffered Alpine epi-metamorphism. This unit is overlain by the non metamorphic Late Triassic to Dogger Tuscan Nappe.

6) The anchimetamorphic Gràssera Unit (**GU**) is attributed to the Ligurian Domain, Ligurian-Piedmontese Units.

7) The Ophiolitic Unit (**OU**) consists of seven sub-units, which from bottom to top are: i- Acquaviva (**ASU**), ii- Mt. Serra (**SSU**) and iii- Capo Vita (**CSU**), iv- Sassi Turchini (**TSU**), v- Volterraio (**VSU**), vi- Magazzini (**MSU**) and vii- Bagnaia (**BSU**). A 5.8 Ma shoshonitic dike is present west of Mt. Castello (see later: Mt. Castello Dike) in **VSU**. In the same subunit near Mt. Capo Stella some mafic dikes were found (see later, Mt. Capo Stella Dikes).

8, 9) The Flysch Units mainly comprise flysch successions, the lower one having Paleogene age (**EU**, Paleogene Flysch Unit), and the upper one of Late Cretaceous age (**CU**, Cretaceous Flysch Unit). It is peculiar of these units the occurrence of some porphyritic bodies of 8.5-8.2 Ma porphyrites (Portoferraio Porphyries), 7.4 Ma porphyrites (San Martino Porphyries) and 7.9 Ma aplitic dikes (Capo Bianco Aplites). In the Mt. Orello area the tectonic relationships between the Ophiolitic Unit (**OU**) and the Flysch Units (**EU** and **CU**) are inverted, and **OU** overlies **EU**.

Thus, if we add the eight subunits of **AU** and **OU**, the Elba tectonic pile includes seventeen main slices.

STRATIGRAPHY

Porto Azzurro Unit (PU) ("Mt. Calamita Unit" Auctt.)

Outcrops of this unit occur in the southern part of the studied area along an E/NE-W/NW trending belt which extends from Spiaggia del Lido to the Terranera Mine. The occurrence of rocks belonging to **PU** in the subsurface of the area North of Porto Azzurro-Terranera is testified by mining wells data which, together with outcrop observations, suggest an overall northward plunge of the top of **PU** below the overlying imbricate tectonic units. This important tectonic contact (Zuccale Fault Auctt.) is locally outlined by a metric- to decametric thick polymictic cataclastic horizon (Zuccale cataclasite) (Fig. 3).

In this unit, two distinct formations were defined; from bottom to top they are:

Mt. Calamita Formation (*Cl*)
("Gneiss del Calamita" Auctt.)

This formation forms the main part of PU and is well exposed along the road between Cala di Mola Residence and Porto Azzurro, at the Barbarossa and Reale beaches.

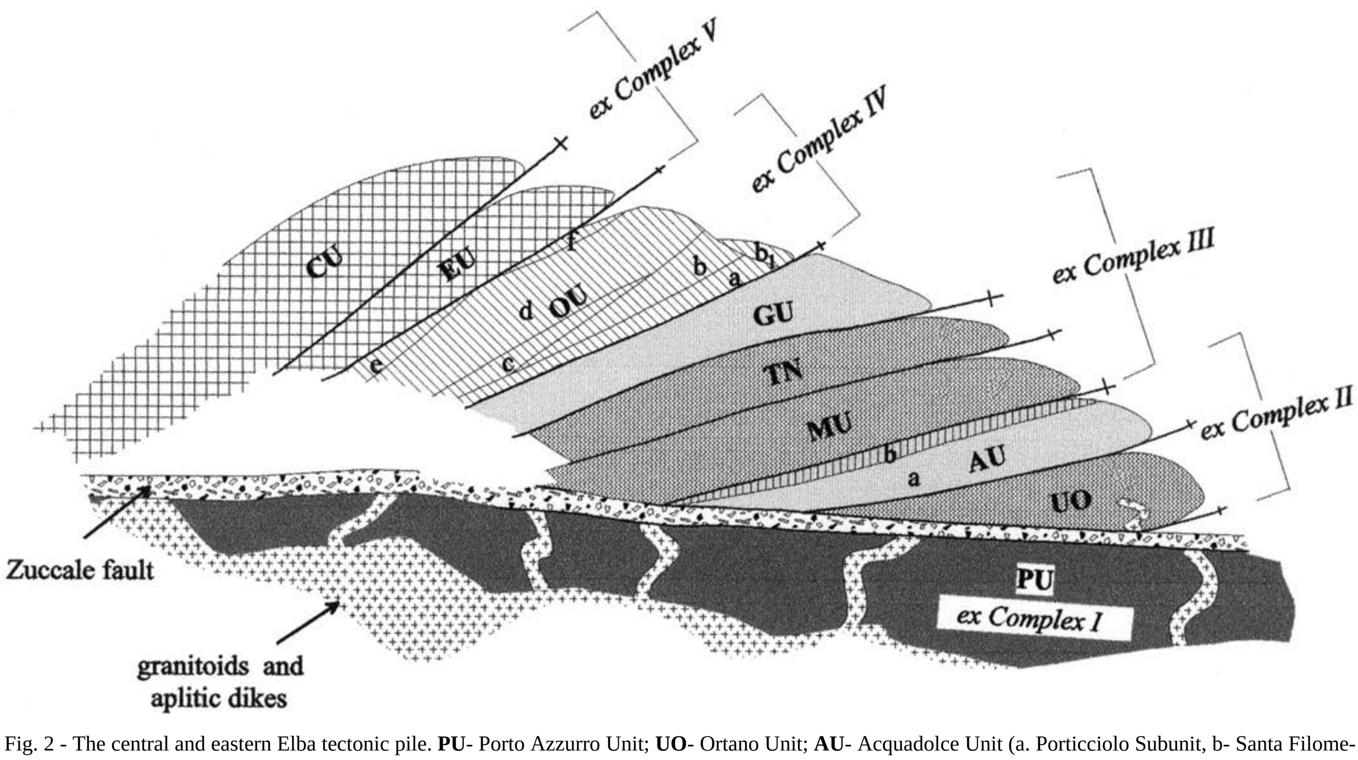

Fig. 2 - The central and eastern Elba tectonic pile. **PU**- Porto Azzurro Unit; **UO**- Ortano Unit; **AU**- Acquadolce Unit (a. Porticciolo Subunit, b- Santa Filomena S.); **MU**- Monticiano-Roccastrada Unit; **TN**- Tuscan Nappe; **GU**- Gràssera Unit; **OU**- Ophiolitic Unit (a- Acquaviva Subunit; b- Mt. 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.

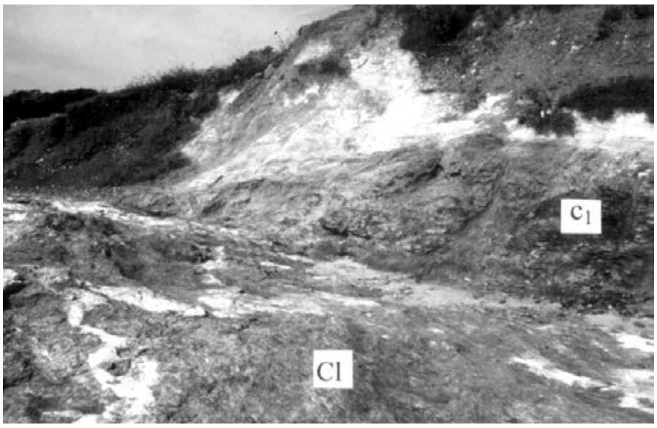

Fig. 3 - Contact between the Mt. Calamita Fm. (Cl) and the overlying Zuccale cataclasite (C_1) at Terranera. The aplitic dikes, intruded in the Mt. Calamita Fm., abruptly end against the cataclasite.

The Mt. Calamita Fm. is made of grey-greenish to brown cornubianitic quartz-muscovite-biotite micaschists with syn- and post-tectonic quartz veins. Beyond the evident thermometamorphic imprint (static muscovite+biotite±k-feldspar±andalusite), a previous polyphase tectono-metamorphism is still recognisable. Petrographic and geochemical data presented by Barberi et al. (1967b) and Puxeddu et al. (1984) indicate a Paleozoic age for these rocks. The maximum exposed thickness of the formation is about 70 m.

The micaschists are frequently crosscut by several, at times tourmaline-bearing, millimetric to metric white aplitic dikes of the La Serra-Porto Azzurro monzogranite (see later: Acidic dikes of eastern Elba). The primary contact of this intrusion and the host Mt. Calamita Fm. is well exposed on the eastern side of the Mar di Carpisi stream. Only in three localities (see next paragraph) the Mt. Calamita Fm is covered by recrystallised carbonate rocks, probably through a tectonic (or tectonised) contact.

Crystalline dolostones and dolomitic limestones (*dc*)

This informal stratigraphic unit occurs in scattered small outcrops located NW of the Mola Beach and E of La Serra. It comprises white to yellow-brown crystalline, sometimes coarsely crystalline dolostones and dolomitic limestones, with a granoblastic to locally granolepidoblastic (muscovite±biotite±quartz) texture. Several thermometamorphic minerals were also recognised (tremolite, epidote, garnet, clinopyroxene). These rocks are generally referred to the Triassic-Hettangian sedimentary cover of the Mt. Calamita Fm. (Barberi et al., 1969b). This unit tectonically underlies **CU** and **EU** (outcrops E of La Serra) and has a maximum exposed thickness of 10 m.

Ortano Unit (UO)

The Ortano Unit (Fig. 4) is exposed on the eastern coast of the Elba Island (from Capo d'Arco Residence to the northern side of Ortano Cape, including the Ortano Island). It also occurs north-east of the Stella Gulf (from the Lido Beach to Valdana).

These non-fossiliferous phyllitic-quartzitic rocks were attributed to the Early Paleozoic by Pandeli and Puxeddu (1990) because of their similarities to the Ordovician successions of Sardinia and Apuan Alps (Tuscany). The Capo d'Arco Schists are at the geometrical base of the succession of the unit (under the Porphyroids), and therefore have been affected by a stronger thermometamorphic imprint due to the La Serra - Porto Azzurro monzogranite. The Capo d'Arco Schists show strong lithological-petrographical similarities with the "Silver-grey phyllites and quartzites", at the geometrical top of the succession (over the Porphyroids). These affinities are also pointed out by geochemical data (see Puxeddu et al., 1984). It is likely that Capo d'Arco Schists and Silver-grey phyllites and quartzites represent one single folded stratigraphic horizon: thus, they would form the limbs of a pre-thermometamorphism, Apennine-vergent overturned fold with the Porphyroids at its core. We prefer to maintain here the distinction between the Capo d'Arco Schists and the Silver-grey phyllites and quartzites, because these stratigraphical units were defined in previous papers (e.g. Duranti et al., 1992). The Porphyroids are here considered as the oldest stratigraphic unit.

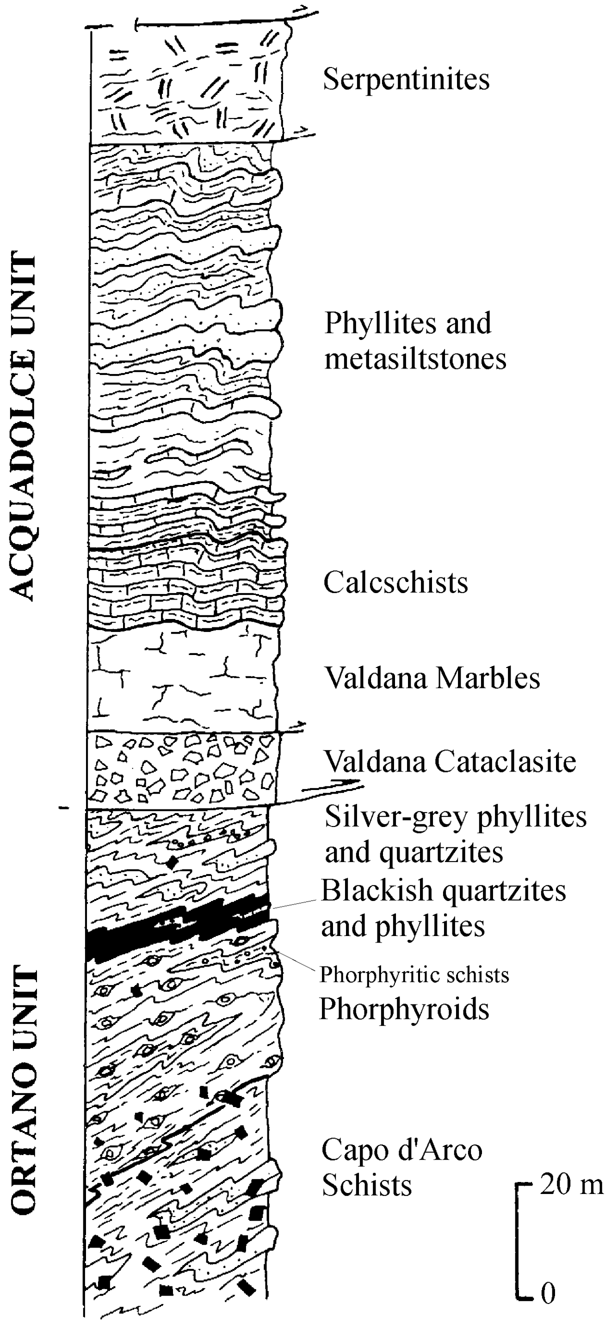

Fig. 4 - Schematic stratigraphic-structural log of Ortano and the Acquadolce Units.

From bottom to top the following formations and informal stratigraphical units are distinguished (for further petrographic details see Pandeli and Puxeddu, 1990):

Porphyroids (*Π*)

Their typical outcrops are located on the two sides of the Ortano Valley and in the northern part of the Lido Beach. They are massive or roughly stratified (up to some metres thick) grey, brownish and sometimes violet, coarse grained, phyllitic quartzites, characterised by an evident augen texture due to millimetric (max. 4 mm), at times sub-idiomorphic, quartz and feldspar porphyroclasts (Plate 1a). These rocks are considered acidic metavolcanics and are correlated to the Middle Ordovician Porphyroids of Sardinia (Pandeli and Puxeddu, 1990). Decimetric to metric horizons of grey to brown volcanic metasandstones and quartzitic phyllites (Porphyritic schists, "Scisti porfirici" Auctt.) are locally present both within the formation and at its top. The maximum thickness of the Porphyroids is about 180 m in the Ortano area; to the south (Capo d'Arco Residence) the formation pinches out probably due to the southward termination of a main antiform structure. The contact with the overlying "Silver-grey phyllites and quartzites" (north of the Ortano Valley), with the lenticular "Blackish quartzites and phyllites" (South of the Ortano Valley and at Spiaggia del Lido) and the Capo d'Arco Schists is sharp.

Blackish quartzites and phyllites (*qf*)

This informal stratigraphic unit, defined by Duranti et al. (1992), is well exposed between the Capo d'Arco Residence and the southern side of the Ortano Valley. It is made up of locally stratified (10-15 cm-thick beds) graphitic quartzites associated with black, at times quartzitic, phyllites. North of Spiaggia del Lido, this unit is represented only by a decimetric to about 1.5 m-thick bed of black phyllitic quartzite (not portrayed in the geological map) (Plate 1b). The thickness of the formation (probably of Middle-Late Ordovician age) varies from 0 (north of the Ortano Valley) to about 10 m. The contact with the overlying formation (Silver-grey phyllites and quartzites) is sharp and marked by the disappearance of the graphitic lithotypes.

Capo d'Arco Schists (*Ar*)

This formation ("Ortano Schists" of Perrin, 1975; "Capo d'Arco Micaschists" of Duranti et al., 1992) geometrically lies below the Porphyroids and was previously interpreted as the basal siliciclastic unit of the Ortano succession and for this reason correlated to the Lower Quartzites and Phyllites of the Apuan Alps (Pandeli and Puxeddu, 1990; Duranti et al., 1992). However, its petrographic and geochemical evidences (see also Puxeddu et al., 1984) suggest a correlation with the metasiliciclastics (Silver-grey phyllites and quartzites) which stratigraphycally overlie the Porphyroids. The best exposures of this formation are located along the coast of the Capo d'Arco Residence and at the Ortano Cape (Plate 7a). The main lithotypes are brown-grey to grey-greenish phyllites, quartzitic phyllites and micaschists with millimetric to centimetric quartz ribbons, syn- and post-tectonic veins. Whitish to pale brown quartzites and poorly sorted quartzitic microconglomerates, locally occur as intercalations up to 50 cm thick and as metric- to dm-thick lenticular bodies (*ar*, "**Quartzitic levels**" in the map). Sub-centimetric graphitic levels are locally present, but graphite is particularly frequent in some phyllitic-quartzitic lithotypes of the Capo d'Arco-Ortano Isle area. Post-tectonic andalusite±cordierite (generally replaced by pinninite) are frequently observed as "spots" in the phyllites and micaschists. Along the coast between Capo d'Arco Residence and Ortano as well as in the Ortano I., these polydeformed schists are crosscut by aplitic and pegmatitic dikes (a few cm to 40 cm thick). This formation (defined by Duranti et al., 1992), probably of Ordovician age, shows a maximum exposed thickness of 150 m.

Silver-grey phyllites and quartzites (*fi*)

This informal stratigraphic unit, first defined (as the Capo d'Arco Schists) by Duranti et al. (1992), lies on top of the Ortano succession. The best outcrops occur on both sides of the Ortano Valley and along the Golfo Stella (SW of Casa Rubini). They mainly consist of silver and grey phyllites and quartzose phyllites with grey-whitish, centimetric to metric quartzitic metasandstone and metaconglomerate intercalations. Locally, these coarse lithologies can constitute 15-20-thick lenticular bodies. These rocks can be correlated to the Caradocian (Late Ordovician) transgressive siliciclastic deposits of Central Sardinia.

This formation underlies the Valdana cataclasite (see after: Cataclasites) at the base of the Acquadoce Unit (Plate 1c) and shows a maximum thickness of 50 m.

Acquadolce Unit (AU)

This unit occurs extensively along the eastern coast, from Terranera to Rio Marina, and in the Golfo Stella - Valdana area. The Porticciolo Subunit (**PSU**), at the base, and the serpentinitic Santa Filomena Subunit (**FSU**), at the top, can be distinguished (Fig. 4).

Its carbonate-phyllitic succession (Valdana Marbles, Calcschists, and Phyllites and metasiltstones) was generally correlated to the epimetamorphic Mesozoic-(Tertiary?) formations of the Apuan Alps (e.g. Barberi et al., 1969b; Perrin, 1975). Because of the occurrence of Early Cretaceous age microfossils, Duranti et al. (1992) correlated the Calcschists and the Phyllites and metasiltstones (affected by both thermometamorphism and shearing due to the Serra-Porto Azzurro monzogranite intrusion) to the Palombini Shales of **OU**. On the contrary, Corti et al. (1996) correlated all the succession of the Unit, comprising the top serpentinites, to the Ligurian-Piedmontese metamorphic rocks of the Gorgona I. ("Schistes Lustrés" Auctt.; see also Termier, 1910).

The following formations were defined from the bottom upwards (for petrographic details see Pandeli and Puxeddu, 1990):

Valdana Marbles (*mV*)

The typical outcrops of the Valdana Marbles (Ortano Marble Auctt.) are located in the Capo d'Arco Residence (Cava dei Marmi) and in both sides of the Ortano Valley. This formation consists of coarse- to medium-grained saccharoid and dolomitic marbles, grey-whitish in colour, with yellowish bands (Plate 1d). At Capo d'Arco, Ortano and Valdana areas, the marbles are either massive or roughly stratified with discontinuous, millimetric, green-grey phyllitic levels. Conversely, at Golfo Stella (SW of Casa Rubini) bedding is often prominent, and is due to millimetric to decimetric phyllite and calcschist intercalations. In the latter locality, the uppermost part of the formation is characterised by the occurrence of dolomitic horizons. As mentioned before, most of the previous authors (e.g. Barberi et al, 1969b and Duranti et al., 1992) correlate this formation to the Hettangian carbonates of the Tuscan Succession. According to

Corti et al. (1996) we suggest a possible correlation of these rocks with the Lower Cretaceous Calpionella Limestones. The formation shows a variable thickness (0-20 m). The gradual transition to the overlying Calcschists is a 0.5-1 m-thick horizon of alternating marble and calcschist beds. However, the contact is locally tectonised and mineralised (Fe oxides and hydroxides).

Calcschists (*ci*)

This formation is well exposed in eastern Elba, along the Ortano Valley road (Plate 1d). It consists of grey and grey-greenish calcschist beds up to 50 cm in thickness. Each bed consists of alternating millimetric to centimetric, medium- to fine-grained marble and minor phyllitic, at times graphite-bearing layers. Centimetric whitish siliceous bands and nodules are locally observed (e.g. near Ortano Residence) in the middle-upper part of the formation (Plate 1e). Duranti et al. (1992) included the Calcschists in the overlying Phyllites and metasiltstones of Early Cretaceous age (see below). The thickness of the Calcschists varies from 20 to 100 m, but locally, they disappear because of tectonic obliteration. In the Valdana area they are about 1 m thick (in the map they are included in the Valdana Marbles). The transition to the "Phyllites and metasiltstones" is gradual and is marked by increasing of the in number and thickness of the phyllitic levels.

Phyllites and metasiltstones (*fm*)

This informal stratigraphic unit forms most of **AU**. Good exposures occur along the roads of the Ortano Valley and Rio Marina-Porticciolo, and along the coast of the Golfo Stella. This unit is mainly made up of dark grey to grey-greenish phyllites, with local intercalations of metasandstones, black quartzitic phyllites and metasiltstones (Plate 1f).The former are grey metagreywackes (generally feldspatic metagreywackes) that in a few areas (e.g. south of Punta dell'Acquadolce) form metric to decametric bodies. Grey, lenticular calcschist beds of variable thickness (from 10 cm to 5-6 m) also occur ("*ci*" lenses in the map, Plate 1g), particularly between the Ortano Valley and Rio Marina (Plate 1g). They are locally transformed into skarn bodies (e.g. the ilvaite+hedembergite+epidote skarn of Torre di Rio, south of Rio Marina) due to the effect of thermal and hydrothermal metamorphism.

The outcrop of the Porticciolo area shows a peculiar lithofacies (max. 30 m thick) of dark grey to black phyllites and calcareous phyllites ("*fc*" in the map, Plate 1h) with 3-50 cm-thick intercalations of: i- medium to coarse grained, at times cherty, grey marbles; ii- grey-greenish calcschists; iii- quartzites. This stratigraphic unit is attributed to the upper part of the Early Cretaceous by Duranti et al. (1992), due to the microfossil fauna (radiolarians, calpionellids and foraminifers) observed in a carbonatic bed located between Punta dell'Acquadolce and Porticciolo.

This stratigraphic unit, which maximum thickness is ~300 m, is tectonically overlied by the serpentinite of the Santa Filomena Subunit (**FSU**).

Serpentinites (σ_1)

Typical outcrops of serpentinite are in quarries of Mt. Fico and Ortano Valley.

These rocks are made of massive to locally foliated, fine- to medium-grained, green serpentinised lherzolites and harzburgites (Bortolotti et al., 1994a; Tartarotti and Vaggelli, 1994). This formation is characterised by porphyroclastic texture and tectonic fabric. Opx exsolutions in cpx porphyroclasts, cpx neoblasts rimming porphyroclasts and parallel subgrain boundaries in olivine, immersed in a serpentine mesh-structure are present. The serpentinites suffered a deformation not accompanied by dynamic recrystallisation, which produced shear bands and kinking of cpx porphyroclasts

The above features suggest that they are tectonitic peridotites derived from sub-oceanic mantle like the serpentinites of **OU**; in fact, they show the classic substructure of deformed mantle rocks (Bortolotti et al., 1994a). The maximum thickness of the formation is about 200 m (Mt. Fico). It is tectonically covered by **MU**. The uppermost part of the Serpentinites locally (e.g. at Vigneria, north of Rio Marina) shows cataclastic texture and also includes wedges of the overlying Rio Marina Fm. (**MU**).

Monticiano-Roccastrada Unit (MU)

This epimetamorphic Unit (Rio Marina Fm. and "Verrucano" Group, Fig. 5) is well exposed in several outcrops of the eastern Elba, where it hosts the famous hematite ores of Rio Marina-Mt. Calendozio and Terranera. During the last few years, low grade metamorphic Jurassic to Oligocene formations of the Tuscan Succession have been found (exposed along the eastern coast at Capo Scandelli-Capo Castello-Topi I. and Capo Pero; Pandeli et al., 1995), and considered the upper part of the stratigraphic succession of

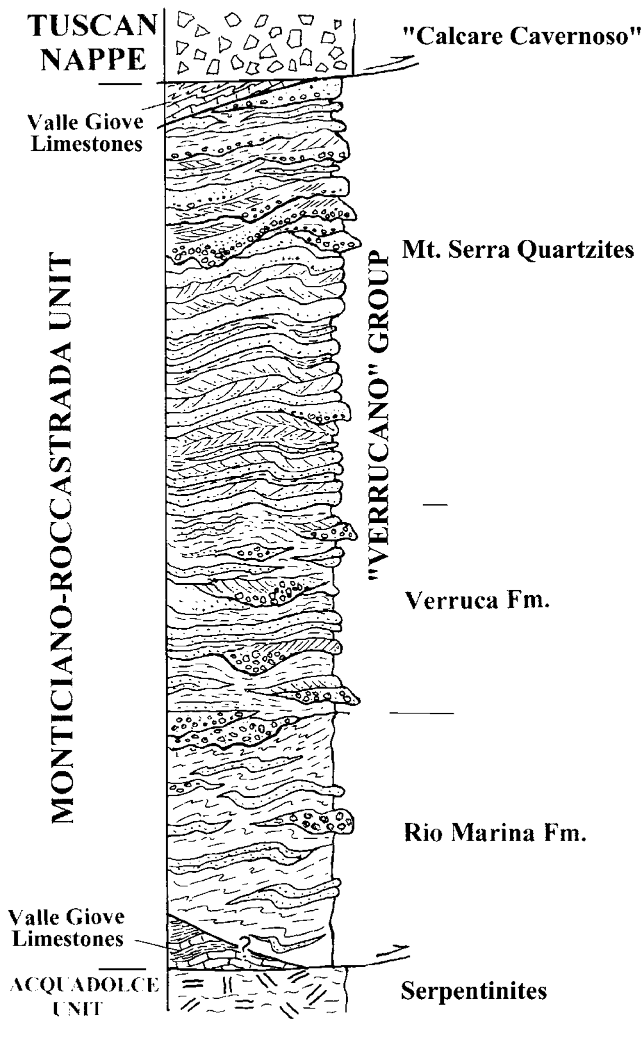

Fig. 5 - Schematic stratigraphic-structural log of the Monticiano-Roccastrada Unit (Rio Marina mining area).

this Unit. In this paper, we interpret the carbonate-phyllitic bodies found within the "Verrucano" (in the Valle Giove mining area; Deschamps, 1980) and at the base of the Rio Marina Fm. (in the subsurface of Vigneria, the "Vigneria Limestone" of Gillieron, 1959) as tectonic slices of the Jurassic to Oligocene succession and named "Valle Giove Limestones" in the map. Within the non-fossiliferous "Verrucano" Group two formations were distinguished: Verruca Fm. and Mt. Serra Quartzites, because of their lithological-stratigraphic analogies with the Mt. Pisano type-succession (see Rau and Tongiorgi, 1974). Detailed petrographic data on the Rio Marina Fm. and the "Verrucano" Group can be found in Deschamps (1980) and Deschamps et al. (1983).

Rio Marina Formation *(RM)*

The lithological features of this formation are well shown along the coastline between Vigneria and the Rialbano creek, along the road Rio Marina-Cavo, and along the cliffs north of Capo Pero. The formation consists of graphitic black to grey phyllites and metasandstones, sometimes yellowish-ochre or whitish by alteration, with decimetric fine to medium-grained grey quartzose metasandstones. Metaconglomerates, with rounded, whitish and, subordinately, grey to black quartz pebbles, up to 15 cm in size, and coarse-grained metasandstones locally occur either in lens-shaped beds or at the bottom of the thickest, roughly graded beds (Plate 2a). The metasandstones show parallel to planar cross-bedded laminations. Thermometamorphic biotite and/or andalusite spots were observed south of Mt. Arco and in the Mt. Fabbrello-Golfo Stella area. The lithologic-sedimentologic features and the fossil content (pelecypods, brachiopods, crinoids, echinids, foraminifers and floating vegetal debris: De Stefani, 1914; Bodechtel, 1964a; Kahler and Kahler, 1969; Vai, 1978) suggest a Late Carboniferous (Westphalian/Stephanian boundary)-Early Permian age and a littoral-deltaic depositional environment. The thickness of the Rio Marina Fm. ranges from 40-50 m to about 250 m, and these lateral changes can be related to tectonism. The Rio Marina Fm. is stratigraphically overlain by the "Verrucano" (Plate 2b), which locally shows an erosional contact, even though this transition is often tectonised.

"Verrucano" Group

This metasiliciclastic succession is correlatable with the "Verrucano" type-sequence of the Mts. Pisani in which Rau and Tongiorgi (1974) distinguished two formations: the Verruca Fm. and the overlying Mt. Serra Quartzites.

Verruca Formation (*Ve*)

The basal formation of the Elba "Verrucano" Group is well exposed in the Rio Marina mining area (e.g. Valle Giove Mine; Plate 2b) and near Punta di Rialbano. It consists of alternating siliciclastic lithologies which are often arranged in metric to decametric, fining- and thinning-upwards sequences. The main lithotypes are: a) pink to white, metaconglomerates ("Anagenite" Auctt.) with centimetric (up to 6 cm) quartz pebbles. These occur in decimetric to more than 5 m-thick, massive or poorly graded beds, often lenticular and with erosional base. Sometimes within the same bed, the conglomerates vertically grade to a microconglomeratic or coarse-grained quartzitic top horizon often characterised by planar cross-bedding; b) Grey to grey-pinkish and, subordinately, green quartzites, a few centimetres up to about 3 m thick; c) Violet-reddish, at times greenish phyllites and metasiltstones, occur in millimetric to decimetric intercalations between a) and b), or as distinct horizons up to 5 m thick.

The previous lithologies are similar to those observed in the "Scisti violetti" and "Anageniti minute" members of the Verruca Fm. of the Mt. Pisano (Rau and Tongiorgi, 1974), which are interpreted as meandering river deposits of late Ladinian?-Carnian age. The thickness of this formation is 130-150 m. A metric to decametric alternation of parallel to cross-laminated, varicoloured quartzitic and phyllitic beds locally characterises the transition to the overlying Green Quartzites Member of the Mt. Serra Quartzites.

Mt. Serra Quartzites (*Se* and *se*)

This formation includes two members:

1) **Green Quartzites Member** (*se*). Excellent outcrops of this member are exposed along the mining road from Le Conche to the Pistello mines, on the northern side of the Rialbano Creek. It consists of well-bedded (30 cm to about 2 m-thick) green to grey-greenish and fine- to medium-grained quartzites which show planar and herring-bone cross-bedding (Plate 2c). Green millimetric to decimetric phyllitic intercalations are also present. Some pale grey-greenish conglomeratic beds were locally observed in the lower part of the member, while metric horizons made up of wavy/lenticular greenish thin bedded quartzites and phyllites ("Scisti verdi" Auctt.) are typical of the middle-upper part. The correlatable shelf metasediments of the Mt. Pisano succession have a Carnian age (Rau and Tongiorgi, 1974). The thickness of this member is about 160 m. The transition to the overlying White-pink Quartzites Member is gradual, and is marked by a decametric alternation of grey-greenish to grey-pink pebbly quartzites, quartzites and varicoloured phyllites.

b) **White-pink Quartzites Member** (*Se*). This member is best exposed in the southern side of Mt. Sassera and consists of beds of pale grey-pink quartzose metaconglomerates (maximum clast size 5 cm) grading upwards into coarse- to medium- grained, at times pebbly, quartzites. These beds, which locally show trough cross-stratification and erosional base, alternate with millimetric to centimetric lenses of violet-green phyllites. These metasediments of probable Carnian age, are referable to low/medium-sinuosity river deposits, or to coarse deltaic facies similar to those found in the correspondent member of the Mt. Pisano type-succession (cfr. Rau and Tongiorgi, 1974). The thickness of this member is more than 100 m.

The contact with the "Calcare Cavernoso" of **TN** is tectonic and generally marked by normal faults (e.g. the N-S trending main fault, which trace extends from Porto Azzurro to the Cavo area: Santa Caterina Normal Fault "**CNF**"); only in a few places (e.g. Mt. Calendozio and Reale Valley) the thrust contact is exposed.

Valle Giove Limestones (*VG*)

This formation consists of some lenticular tectonic slices intercalated in the "Verrucano" of the Valle Giove mine. It is made up of grey, pink and grey-greenish, metacalcilutite and metacalcarenite beds, millimetric to metric in thickness, alternating with grey to greenish phyllites and calcschists and local carbonatic breccias. These lithotypes grade upwards into more or less carbonatic phyllites, green to reddish in colour. The stratigraphic attribution of these non-fossiliferous rocks is problematic: they were interpreted by Deschamps (1980) and Deschamps et al. (1983) as stratigraphic horizons of the "Verrucano" Triassic succession. However, we cannot exclude a younger Mesozoic-Tertiary age. A similar carbonate-phyllite succession, tectonically interposed between the Serpentinite of **FSU** and the Rio Marina Fm. of **MU** was recognised in the sub-surface of the Rio Marina mining area ("Vigneria Limestone" of Gillieron, 1959), and, in this paper, included in the Valle Giove Limestones. The thickness of the formation ranges from 0 to 15-20 m in the Valle Giove mine outcrops, while it reaches at least 75 m in the subsurface of the Vigneria area.

Capo Pero Limestones (*Pe*)

They crop out exclusively at Capo Pero, and consist of green and grey-greenish, fine grained crystalline limestone beds, centimetric to some metres in thickness, with green and minor reddish calcschist and phyllite intercalations. The latter lithotypes can occur locally clustered in decimetric to metric horizons. Centimetric lenses and levels of grey-brownish metacherts were sometimes recognised within carbonate beds.

This non-fossiliferous formation could be Mesozoic in age, because of its lithologic similarities with the Upper Lias-Dogger Calcschists of the Apuan Alps. Its thickness is at least 30 m and the base is not exposed. The Capo Pero Limestones geometrically underlie the Varicoloured Sericitic Schists thorough a mineralised cataclastic horizon about 9 m-thick (see after: Capo Pero cataclasite, c_3).

Capo Castello Calcschists (*Cs*)

The only outcrop of this formation is located at Capo Castello, at the core of a hectometric synform anticline. Its basal part is constituted by a centimetric-decimetric alternance of whitish-brown crystalline calcschist and limestone beds, locally showing chert nodules and lenses, and varicoloured phyllites. Yellowish-brown, violet and green calcschists prevail in the upper part. These lithotypes, which contain calcitised radiolarians of probable Dogger-Malm age, can be correlated with the uppermost portion of the Tuscan Cherts ("Calcari ad Aptici"). The thickness is at least 60 m (however the base is not exposed) and the contact with the overlying "Maiolica" is sharp.

"Maiolica"-type Limestones (*ma*)

It forms part of the limbs of the Capo Castello synform. The formation is constituted by well bedded (max. 20 cm-thick beds), grey to blackish metalimestones with rare grey cherty nodules and bands (Plate 2d). The microfossils assemblage includes calcitised radiolarians and rare calpionellids, this pointing out to a Tithonian-Neocomian age. The thickness of the formation is 25-30 m and the stratigraphic top contact with the Varicoloured Sericite Schists is sharp.

Varicoloured Sericitic Schists

Nice exposures were found in Cala dell'Alga (between Capo Castello and Capo Scandelli). The lower part of the formation is characterised by reddish-violet to green phyllites and calcschists (Plate 2e) with centimetric/decimetric, at times cherty, metacalcilutite and metacalcarenite intercalations which are locally organised in metres-thick bodies. The upper part is mainly made up of green, grey to black phyllites with local decimetric (up to 50 cm-thick) metacalcilutites, Tb-e and Tc-e metacalcarenite and calcareous metasiltstone beds. The carbonate-calcschist lithotypes contain abundant fossils (*globigerinidae*, *globorotalidae*, *orbitoididae* and *alveolina*) of Late Cretaceous (Maastrichtian) to Eocene age (Perrin and Neumann, 1970; Centamore in Keller and Pialli, 1990). The thickness varies from 15-20 m up to 40-50 m, due to the ductile behaviour of its pelitic lithotypes. At places, the gradual transition to the Pseudomacigno is recognisable in a metric horizon of alternating varicoloured phyllites, metasiltstones and minor calcareous metasandstones.

Pseudomacigno

The formation is well exposed in the eastern part of the Topi Island. It mainly consists of grey, decimetric up to 3 m-thick and medium to coarse-grained metagreywacke beds with centimetric intercalations of grey to black phyllites and calcareous phyllites (Plate 2f). Ta, Ta/c-e and T/de Bouma sequences are locally recognisable. The bottom of the beds are locally erosive and characterised by centimetric microconglomerate levels. Thin bedded (max. 15-20 cm-thick) Tb-e, Tc-e and Tde metasiltstones and fine-grained metasandstones are also present, and sometimes form some metres-thick bodies. Fossils were rarely found (planktonic microforams and reworked *Discocyclina* or *Lepidocyclina*) in these Oligocenic rocks. The thickness of the formation is not less than 40-50 m, but its stratigraphic top is missing.

Tuscan Nappe

In eastern Elba, along a narrow belt that extends from Cavo to Porto Azzurro, and west of the Valdana Creek, in central Elba, a "reduced" Tuscan Succession crops out (Cocchi, 1871; Lotti, 1886; Trevisan, 1950; Barberi et al., 1969a; 1969b; Perrin, 1975; Boccaletti et al., 1977), under the Gràssera Unit (Fig. 6). In particular, south of La Parata and west of the Valdana Creek, the Tuscan Succession is represented only by the Triassic "Calcare Cavernoso". North of La Parata the succession goes up to the Dogger (Fig. 7). All formations show a weak recrystallisation. The investigation on nannoplancton associations (carried out by V. Reale, with acknowledgements) on the Jurassic pelagic formations did not result in any age determination. Moreover, the older carbonate formations ("Calcare Cavernoso", Pania di Corfino Fm., "Calcare Massiccio" and, subordinately, Mt. Cetona Fm.) have been more or less intensely dolomitised and recrystallised. The recrystallisation can be related to the burial pressure of the overlying thick pile of tectonic units, and to the Neogene hydrothermal fluids, as pointed out by the high content of Fe-oxide microcrystals and by the strong recrystallisation in proximity of the main extensional faults, where the main Fe-ores are also located.

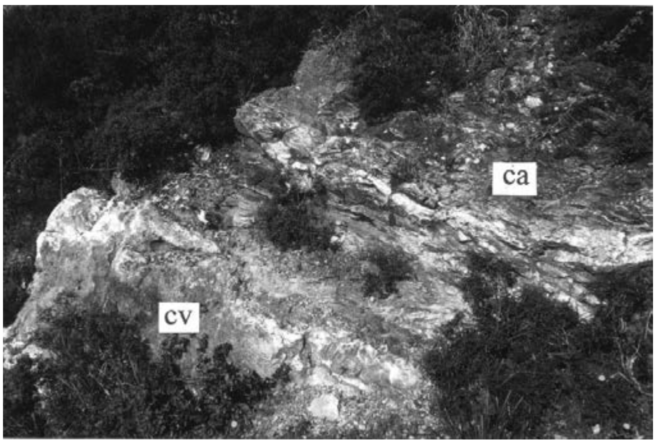

Fig. 6 - Tectonic contact between the "Calcare Cavernoso" (**TN**) ant the overlying Calcschist Member of Cavo Fm (**GU**), near La Parata (north of Rio nell'Elba).

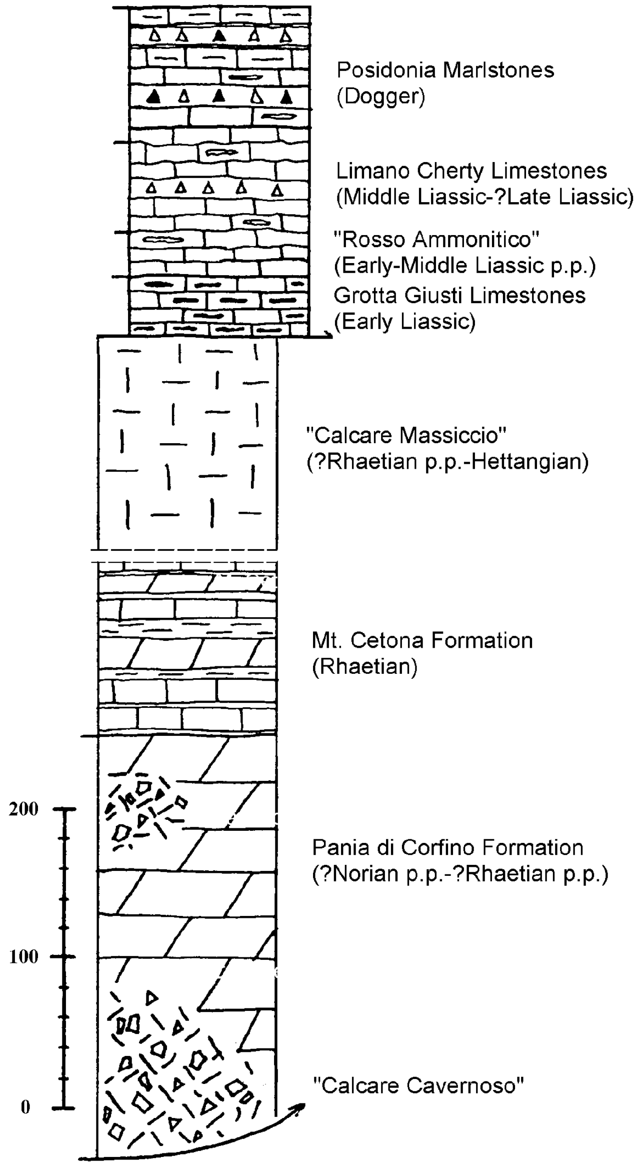

Fig. 7 - Stratigraphic logof the Tuscan Nappe, north of La Parata.

"Calcare Cavernoso" (*cv*)

It crops out with its typical features in the Rialbano mine, along Fosso del Giove and the road to Punta d'Arco.

It consists of massive or vacuolar clasts-supported monomictic breccias made up of coarsely crystalline, more or less dolomitic limestone clasts, dark to pale grey, whitish or pink (due to occurrence of Fe-oxide microcrystals) and of scarce microcrystalline matrix. Vacuoles, mm to cm in size and show irregular shapes (Plate 3a). In areas of limited extent, the rock is pervasively fractured, with the fragments showing sub-millimetric size, and constituting a dolomitic "powder", made up of small crystals, which partially fills the vacuoles.

Karst features, mainly pockets of calcitic silts, are frequent. Close to the cemetery of Rio Marina and along the Ortano Valley, carbonatic breccias include also small clasts of slates belonging to the Cavo Fm. (**GU**, see later). This polymictic breccia is linked to karst structures, in particular in the upper portion of the formation.

Upwards, in the "Calcare Cavernoso" a faint bedding appears, the vacuoles and the density of fractures decrease and the rock grades to a fractured dolomitic limestone and passes to the overlying Pania di Corfino Fm, through a more or less tectonised contact.

The previous features suggest a tectonic origin for the breccias, due to mechanical fracturing of a rigid carbonatic body which can be identified with the overlying Pania di Corfino Fm. This process can be linked to the emplacement of the Tuscan Nappe on the metamorphic **MU**. Later on, these cataclasites suffered further karst processes, mainly consisting of a complete filling of the cavities by crystalline calcitic sand and silt, and a final cementation by microcrystalline calcite.

The occurrence of slaty clasts of **GU** within the karst structures, suggest that **GU** was thrust onto the Tuscan Nappe (**TN**) before the breccia was formed.

No fossils were found, but a Late Triassic age of the original carbonate rock can be hypothesised, based on its similarity with the lithologic content of the Pania di Corfino Fm. The thickness of this formation is not computable, because the base is not visible and no key-beds are present.

Pania Di Corfino Formation (*PC*)

Typical outcrops of this formation are located north of Mt. Gorgoli, south of Mt. Magnani and south of Fosso del Giove. The main lithotypes are m-thick bedded, dark grey to grey-yellowish and whitish dolomites (pinkish in some places, due to a high content of Fe-oxide microcrystals) (Plate 3b). Subordinate and almost limited to the upper portion of the formation, are dm-thick, more or less dolomitic limestones with rare marly interbeds. The texture of dolomites is coarsely crystalline; however, some ghosts of well sorted grainstones, probably oolitic, were also observed. Bodies of limited extent of vacuolar and brecciated dolomitic limestones are locally linked to fractured or faulted zones. No fossils were found: the inferred age, in analogy with the Tuscany outcrops, is Norian-Rhaetian p.p. As dolomitisation and recrystallisation shaded most sedimentary structures, it is difficult to infer the depositional environment: a sheltered margin of a carbonate platform may be suggested. This hypothesis well agrees with the features of the formation in the type area (Fazzuoli et al., 1988) The thickness of the formation is about 200 m. The presence of more calcareous and marly beds in the upper part of the formation, suggests an upward, conformable gradation to the Mt. Cetona Fm.; however, the contacts are always tectonised.

Mt. Cetona Formation (*Ce*)

A typical outcrop of this formation is located at Mt. Bicocco and on the southern side of Mt. le Paffe. The main lithotype consists of dark grey calcilutite beds, 10 cm to 1 m thick, with centimetric to decimetric marlstone intercalations and, subordinately, well bedded dolomitised calcilutites or coarsely crystalline dolomites, which are 1 to 2.5 m thick (Plate 3c). In the upper portion of the formation dark grey calcarenite beds, 20-50 cm thick, dm-thick coquina beds, with features of storm-layers and marly beds up to 2.70 m thick occur. Calcilutite beds consist of mudstones and bioclastic wackestones (with pelecypods, gastropods, planktonic foraminifers and possibly algae); calcarenites consist of bioclastic and oolitic grainstones and packstones; coquinas consist of bioclastic floatstones (mostly with pelecypods) (Plate 4a).

Microfossils are strongly recrystallised and their identification is difficult; however probable *Triasina hantkeni*, *Glomospirella* sp., *Aulotortus* sp. and *Gandinella falsofriedli* were observed (Ciarapica, pers. comm., 1998); they point to a Rhaetian p.p. age. The environment of sedimentation can be referred to a subtidal ramp with calcareous and marly deposits, often sheltered by storms, as in Tuscany outcrops (Ciarapica and Passeri, 1982; Stefani and Trombetta, 1989).

The total thickness of this formationis more than 100 m, as indicated by the thickness of a section exposed along the Rio Marina-Cavo road. The stratigraphic transition to the overlying "Calcare Massiccio" is never exposed.

"Calcare Massiccio" (*cm*)

It crops out extensively on Mt. le Paffe and on both sides of Fosso Baccetti; a spectacular outcrop is located in a big quarry, along the road Rio Marina-Cavo. The formation consists of massive, pale grey or whitish calcarenites and grey calcilutites, sometimes recrystallised and dolomitised; in some places the colour is pink, due to abundant Fe-oxide microcrystals (Plate 3d). In the lower portion, textures consist mainly of coarsely crystalline, dolomitised limestones and oolitic and intraclastic grainstones, with pellets and bioclasts (pelecypods, echinoderms and gastropods) (Plate 4b). In the upper portion, wackestones and packstones with intraclasts, oncoids, cortoids, faecal pellets and bioclasts (pelecypods, gastropods, echinoderms and rare benthonic foraminifers) as well as mudstones were also found. No key fossils were observed and the inferred age for this formation is ?Rhaetian p.p.-Hettangian, in analogy with the outcrops of Tuscany.

The environment of deposition is a shallow subtidal, well sheltered, carbonate platform margin (Boccaletti and Manetti, 1972; Fazzuoli and Sguazzoni, 1986)

The inferred thickness in the area of Mt. le Paffe is about 150 m. The stratigraphic transition to the overlying Grotta Giusti Limestones is not visible, as the contact is always tectonised, probably due to different mechanical properties of the two formations.

Grotta Giusti Limestones (*GG*)

This formation crops out near Cavo, on both sides of Fosso Baccetti; the lower section is well exposed south of Mt. Belvedere and close to the "Calcare Massiccio" quarry, along the road Rio Marina-Cavo, while the upper section crops out close to the Cavo Cemetery and along Via delle Fornacelle.

The lower portion of the formation consists of 5-15 cm thick beds of dark grey (paler upwards) fine calcarenites and calcilutites, horizontally laminated and locally silicified, with abundant beds and nodules of dark grey cherts (Plate 3e). The upper portion is made up of 5-100 cm thick (mostly 10-20 cm thick) beds of grey calcilutites and subordinately fine calcarenites with rare chert nodules and frequent horizontal laminations. Cm-thick dark grey marly beds are frequent, as well as dm-thick beds of more or less shaly marlstones. Fe-oxide microcrystals are abundant. Textures of the fine calcarenites consist of microsparitic mudstones/wackestones, with abundant silt-sized detrital quartz and rare bioclasts (pelecypods, sponge spicules) and faecal pellets; textures of calcilutites consist of mudstones with silt-sized quartz grains and silicified areas (Plate 4c). No significant fossils were observed, and the age, inferred by the stratigraphic position between "Calcare Massiccio" and "Rosso Ammonitico", is probably Early Liassic, and possibly Sinemurian p.p. The environment of sedimentation is pelagic, probably a deep ramp: the laminated fine calcarenites can be interpreted as distal tempestites. The inferred thickness is about 50 m. The stratigraphic transition to the overlying "Rosso Ammonitico" is very gradual: the colours of limestone and marlstone beds become at first paler and then whitish or pink.

"Rosso Ammonitico" (*ra*)

The formation crops out with typical features at Mt. Belvedere, Mt. Gorgoli and north-east of Mt. Magnani. It consists mainly of light grey, light brown, pink or pale grey calcilutite beds, up to 40 cm thick (mostly 5-20 cm), with cm-thick, grey or pink marly beds (Plate 3f); grey chert nodules occur only rarely. These rocks show abundant styloliths, which are wavy or parallel to bedding and very closely spaced, thus sometimes beds look nodular. The textures consist of mudstones with silt-sized quartz grains, and bioclastic wackestones with pelecypods, crinoids and radiolarians (Plate 4d). Fe-oxide crystals are abundant. Some metres above the base, a calcirudite bed (45 cm thick) crops out, it consists of cm-sized well-packed calcilutite clasts and grades upwards to calcarenite. No significant fossils were observed; according to findings of rare and deformed ammonites of Lotti (1886) at Cala del Telegrafo, identified as *Arietites*, and in analogy with the outcrops of Tuscany, the inferred age is Early Liassic p.p.-Middle Liassic p.p.

The environment of deposition is pelagic, with rare redeposition events. The thickness of the formation is about 100 m. The transition with the overlying Limano Cherty Limestones is very gradual and was placed where the thickness of both the beds and of the chert nodules markedly increase.

Limano Cherty Limestones (*Li*)

Outcrops of this formations are exposed near Mt. Le Paffe and, with a minor extent, to Mt. Belvedere-Mt. Malpertuso and at Mt. Bicocco.

Whitish to grey and pale brown or pinkish calcilutites with some grey chert nodules constitute the main lithotype. The lower portion of the formation (which crops out along the road west of Mt. Le Paffe) is characterised by beds up to 140 cm thick, with styloliths parallel to the bedding. In the upper portion thinner beds (5-40 cm) prevail; bedding joints consist of styloliths and mm-thick shaly and marly beds (Plate3g). Some grey calcarenite beds, up to 250 cm thick and calcirudite beds, up to 80 cm thick with slump structures and mm to cm-sized calcilutitic intraclasts in a slightly more shaly matrix can also be observed. The textures of the calcilutites consist of mudstones with abundant silt-sized quartz grains, sometimes bioturbated (Plate 4e) and of bioclastic wackestones with radiolarians. Silicified areas and abundant Fe-oxide crystals occur. The environment of deposition is pelagic, with many re-sedimentation episodes. The inferred age is Middle Liassic p.p., probably to Late Liassic p.p., as suggested by the analogy with the age of the corresponding formation in Tuscany. The thickness, is probably more than 36 m (the thickness of a partial section measured along the Rio Marina-Cavo road. The contact with the overlying *Posidonia* Marlstones is stratigraphic and transitional: the shaly portion becomes more abundant in both the calcareous and marly beds, the colour becomes grey and the cherts disappear almost completely.

***Posidonia* Marlstones** (*mp*)

Good exposures of this formation occur along the road Rio Marina-Cavo and at the cliff, north-west of Punta le Paffe.

The main lithotypes consist of pale brown, occasionally pink, more or less marly and silty bedded calcilutites, which sometimes show very fine laminations, parallel to bedding; grey shaly and marly beds, cm- to dm thick, often with slaty cleavage, are also abundant. The lower portion of the formation is characterised by the abundance of beds, usually 100 to 360 cm thick, which generally show styloliths parallel to bedding, and inclined cleavage joints. Bedding joints consist either of styloliths, or millimetric shaly and marly layers. Some of the coarse beds show a calciruditic base, sometimes amalgamated, grading upwards to laminated calcarenites.

In the upper portion of the formation, calcilutite (and marly) beds are generally thinner (less tnan 150 cm) and show a few chert nodules. Some dm thick beds of dark grey finely laminated calcarenites, with *filaments* are also present. Four calcirudite beds 50 to 210 cm thick contain mm- to cm-sized calcareous clasts, sometimes with stylolithic contacts (Plate 3h), and some cm-sized, cherty clasts; calcareous-marly matrix is scarce. The texture of the calcilutites consists of mudstones with abundant fine silt-sized clasts of quartz and clay minerals; authigenic crystals of quartz and of Fe-oxide are also present. Some beds are deformed by slumping structures. The texture of the calcarenites consists of bioclastic packstones/floatstones, with *filaments* and crinoids (Plate 4f). The microfacies with *filaments* and the occurrence of *Posidonomya bronni* (Lotti, 1886; = *Posidonia alpina* Gras) indicate a Dogger age. The environment of deposition is pelagic, and characterised by abundant shaly supply. Sedimentological features indicate also redeposition by turbidity, debris-flow and slumpings, possibly triggered by tectonic movements. The maximum thickness recorded for this formation is about 40 m. The top is not visible, as the formation is cut by a tectonic contact with the overlying **GU**.

Gràssera Unit (GU)

This tectonic unit (Bortolotti et al., 1994b; Elter and Pandeli, 2001) constitutes a thin N-S belt which occurs both in central and eastern Elba, tectonically sandwiched between **TN** and **OU**. It can be correlated to the “Argille Variegate” which Trevisan (1950) considered the basal formation of the Ophiolitic Unit (Complex IV). Barberi et al. (1969b) attributed it to the *Posidonia* Marlstones (Dogger) of the Tuscan Nappe, the uppermost part of Trevisan’s Complex III. Given its peculiar lithologies and tectonic relationships with **OU** and **TN**, we consider it as an independent tectonic unit that, according to Corti et al. (1996), belongs to the Ligurian-Piedmontese Units of the Ligurian Domain. This unit comprises only a single formation (Cavo Fm.) in which a basal Calcschist Member is locally distinguishable. The outcrops of **GU** form a N-S trending band from Porto Azzurro to the Cavo area, in eastern Elba; it also occurs near Golfo Stella (for further petrographic details see Elter and Pandeli, 2001; Pandeli et al., 2001).

Cavo Formation (*Ca*)

Its best exposures occur along the Parata road from Cavo to Rio nell’Elba and in particular at Parata locality (north of Rio nell’Elba) and in the Solana area (west of Cavo).

The basal part of the formation (*ca,* **Calcschist Member**), is up to 15 m-thick, and is well exposed in the Parata area (Fig.6) where it tectonically overlies the “Calcare Cavernoso”. It is made of polyschistose, centimetric-bedded calcschists, grey-brownish in colour, with millimetric grey phyllitic intercalations.

The remaining part of the formation consists of varicoloured (grey-greenish to red-violet and, minor, pale brown) slates characterised by a centimetric-spaced slaty cleavage and syn- and post-tectonic quartz veins (Fig. 8). Centimetric (up to 40 cm-thick) varicoloured siltstone and green to black, often manganiferous, chert and/or silicified limestone beds are locally intercalated. Only in the Parata area a metric lenticular body of alternating grey to grey-brown, at times cherty, crystalline limestone and calcschist beds was recognised within the slaty lithotypes

The thickness of this formation is not well defined because of the tectonic nature of its base and top, due to internal plastic deformations. However a maximum apparent thickness of 200 m was measured.

The Ophiolitic Unit (OU)

As commonly found for many outcrops of the Internal Ligurids, the Ophiolitic Unit is composed by an “oceanic basement” formed by serpentinised peridotites and gabbros, and by a volcanic and sedimentary cover (Fig. 9). The magmatic rocks (gabbros, sheeted dike complex and basalts) have MORB characteristics.

As mentioned before, the Ophiolitic Unit (**OU**), which extensively crops out in both central and eastern Elba, is composed of five main subunits, topped by two minor subunits. From bottom to top they are: **a**- Acquaviva Subunit (**ASU**), **b**- Mt. Serra Subunit (**SSU**), with **c**- Capo Vita Subunit (**CSU**), **d**- Sassi Turchini Subunit (**TSU**), **e**- Volterraio Subunit (**VSU**), and **f**- Magazzini Subunit (**MSU**) and **g**- Bagnaia Subunit (**BSU**). Their stratigraphic successions show some differences:

Fig. 8 - Varicoloured slates of the Cavo Fm., with typical syntectonic quartz veins (Parata road, near Cavo).

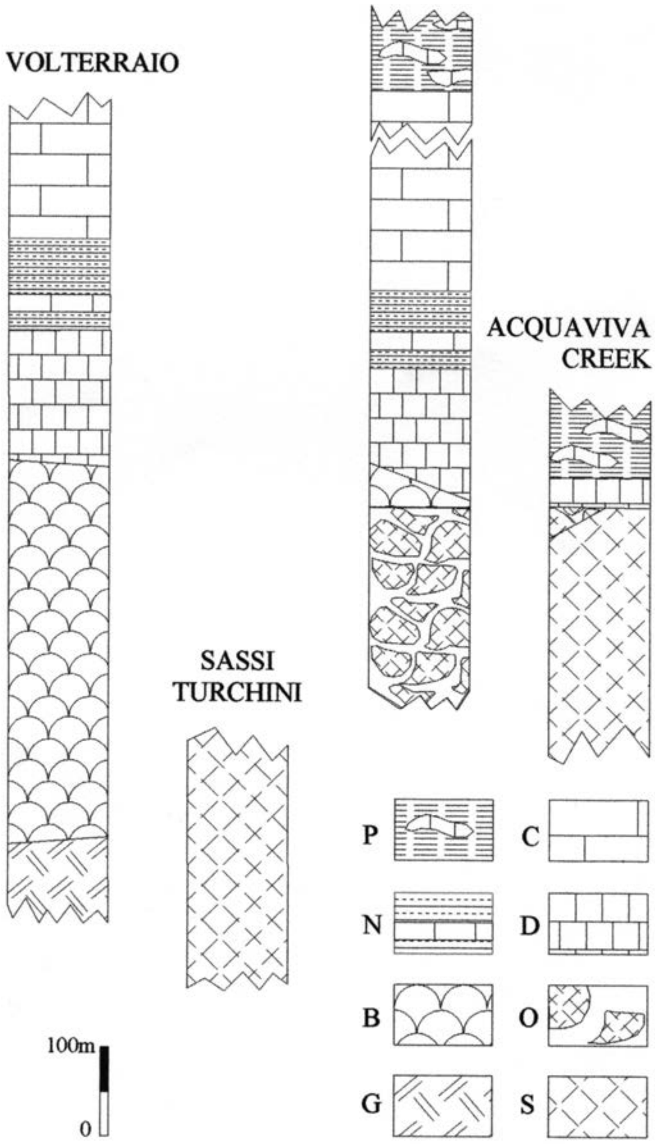

Fig. 9 - Stratigraphic logs of the main subunits of the Ophiolitic Unit (**OU**). 1- Serpentinites; 1a- Ophicalcites; 2- Gabbros; 3- Basalts; 4- Mt. Alpe Cherts; 5- Nisportino Fm. with 5a- Rivercina Member; 6- Calpionella Limestones; 7- Palombini Shales.

ASU is a highly tectonised complex consisting of serpentinite and ophicalcite lenses which geometrically overlie and underlie, with no clear (tectonic?, stratigraphic?) relationships, reduced sequences of Mt. Alpe Cherts-Palombini Shales, and tectonised Palombini Shales outcrops.

SSU starts with ophicalcites at the base, that at places seem to be stratigraphically covered by basalts, followed by Mt. Alpe Cherts, Nisportino Fm, Calpionella Limestones.

CSU crops out only in the northernmost side of Elba, and includes only Calpionella Limestones and Palombini Shales. It probably represents the uppermost portion of **SSU**, slid away along the Cavo Detachment Fault (**CDF**).

TSU is made up only of serpentinites.

VSU shows a thick sequence which includes gabbros, covered by basalts, Mt. Alpe Cherts, Nisportino Fm., Calpionella Limestones and, only in central Elba, Palombini Shales.

Both **MSU** and **BSU** consist of basalts, Mt. Alpe Cherts, Nisportino Fm.; Calpionella Limestones are present only in **BSU**.

The previous formations will be described in stratigraphic order, mentioning their position within the different subunits (Fig. 9).

It is worth noting that no Upper Tertiary acidic dikes cut anywhere the ophiolitic succession, which is intruded only by very rare shoshonitic and calc-alkaline dikes (see later).

Serpentinites (σ) **and Ophicalcites** (*of*)

Serpentinised peridotites occur in three different tectonostratigraphic positions: **a**- most of them pertain to **OU** (as all the ophicalcites), **b**- a thick lens crops out at the top of **AU**; **c**- some thin slices occur in the shear complex cropping out north-west of Porto Azzurro, which we interpret as the dismembered basal portion of **CU**. The following is a description of types a- and c-. Furthermore, metre to decametre bodies of very altered or ophicalcitised serpentinites crop out along minor thrusts.

In **OU**, the serpentinites compose all **TSU**, and tectonic slices within **ASU**, south of Santa Caterina; north of this locality the serpentinites are substituted by ophicalcites. The latter constitute also two basal outcrops of **SSU** (San Felo and Mt. Serra).

Serpentinites. Fine exposures of these rocks within **TSU** can be found along the skyline of Sassi Turchini, whereas the serpentinites of **ASU** are always badly exposed. The rocks that, in spite of serpentinisation better preserve the primary paragenesis were found in the Sassi Turchini ridge (Bortolotti et al., 1991; 1994a; Tartarotti and Vaggelli, 1994). They are cpx-poor lherzolites and spinel harzburgites. Olivine, in most cases intensely serpentinised (Plate 5a and b), shows scarce dislocation structures; the cpx, consisting of fine isolate porphyroclasts, is occasionally recrystallised; the opx, which is generally serpentinised, shows porphyroclasts with an irregular shape; spinel occurs either with a holly-leaf shape or as massive idiomorphic grains, or in relict grains into plagioclase patches, often prehnitised, suggesting a partial equilibration from spinel- to plagioclase-peridotite. Some of serpentinite samples show interstitial plagioclase (with a strong saussuritisation) concurrent with stable spinel and cpx, devoid of exsolutions. These minerals, not evenly distributed form, in some cases, basic dikelets. Near the dikelets, cpx can appear as fine poikiloblasts enclosing (serpentinised) olivine grains. We can interpret the previous features as the consequence of an extensive impregnation by mafic melts. When the rock is an harzburgite, thin lenses of completely serpentinised dunite also occur. These characteristics suggest that they are tectonitic peridotites derived from sub-oceanic mantle (Bortolotti et al., 1994a; Tartarotti and Vaggelli, 1994).

Ophicalcites. Typical outcrops occur along La Parata road (**ASU**), and along the road Porto Azzurro - Rio nell'Elba, south of San Felo. As mentioned before, north of Santa Caterina in **ASU** and in the two only outcrops at the base of **SSU**, the serpentinite bodies are transformed, especially towards the stratigraphic top, into ophicalcites (Levanto and Framura Breccias, Cortesogno et al., 1978). In all of the outcrops of **ASU**, the ophicalcites consist of pervasively fractured serpentinites, with scattered calcite veins without any preferential trend (Levanto Breccia). Serpentinite fragments, fine-grained serpentinitic sandstones and micritic carbonates occur only in rare widest fractures. All these rocks are extremely weathered. They are considered tectonic-hydrothermal breccias with a complex structural evolution (Cortesogno et al., 1978; Treves and Harper, 1994; Treves et al., 1995).

In the outcrops of **SSU**, this tectonic facies gradually grades upwards to a sedimentary facies (Framura Breccia), with small fragments of serpentinite dispersed in a calcitic matrix plus cement.

The maximum thickness of the serpentinites is between 200 and 300 m in **TSU** and **ASU**, and is of a few tens of metres in **SSU**.

In **ASU** the ophicalcites are probably at the base of the Mt. Alpe Cherts; while in **SSU** they are covered by basalts.

Mg-Gabbros (*Π*)

Mg-gabbros of MORB-type (see Serri, 1980) crop out either at the base of **VSU**, or as minor bodies and dikes into the serpentinites of **TSU**. The small slices of gabbro that crop out north-west of Porto Azzurro, above the thrust contact with the **OU**, probably pertain to the **CU** (see later).

Weathering of these rocks is so intense that in most of the outcrops they occur as fine crystal gravel. The best exposure can be found in the eastern slope of Mt. Orello. Gabbros are medium- to coarse-grained (Plate 5c), and rarely also pegmatoid. The pl is sub-idiomorphic; cpx and opx are all allotriomorphic. These original mineral phases are altered: pl to sericite, prehnite or albite-epidote aggregates, opx and cpx (not always) to chlorite, on which actinolitic amphibole aggregates successively grew; all this frame is due to a mild oceanic metamorphism.

Within weathered gabbro (on the left flank of the Acquaviva Creek, near the Porto Azzurro-Rio nell'Elba road) a decametric body of mafic-ultramafic cumulates was found. These cumulates consist of spinel-wehrlites and spinel-melatroctolites, with ol and sp as cumulus, cpx and pl as intercumulus phases. Their relationship with the embedding gabbros is not clear. Alteration partially transformed ol into serpentine, sp into magnetite, pl into prehnite (Bortolotti et al., 1994a; Tartarotti and Vaggelli, 1994). The maximum thickness of the gabbros was estimated to be about 60-70 m. This gabbro body is cut at the base by the thrust which separates **VSU** from **ASU** and/or **TSU**. At the top, pillow lavas directly overlie the gabbros, as well exposed along the road Rio nell'Elba - Volterraio, a little after Rio.

A radiometric age of 164±14 Ma is available only for the gabbros of the Ligurian Apennines (Rampone et al., 1998).

Sheeted dike complex (*cf*)

The sheeted dike complex crops out south of Portoferraio, and probably belongs to the **VSU** exposed west of the Zuccale Fault. It is well exposed along the road of Colle Reciso, south of San Giovanni. However, the relationships with the nearby rocks are not clear.

This complex consists of diorites, micro-gabbros and plagiogranite dikes intruding the basalts. 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.

Basalts (*β*)

These rocks are included in both **SSU** and **VSU** (Plate 5e). They are absent in the reduced sequences of **ASU**. The best outcrops occur along the Volterraio road, east and south of the Volterraio (**VSU**).

They are mostly pillow lavas, tubular or spheroidal, with a maximum diameter of about 1 m and subordinately pillow breccias. When the pillows are well preserved, their surface presents the typical spherulites: fibrous aggregates of pl crystals, included in a glassy or microcrystalline groundmass. In some of the outcrops, the pillow interiors show pillow shelves, marked by cavities either empty or filled by siliceous sediments (these structures are useful to individuate, the original position of the sea floor). Near the top of the formation, fragments of recrystallised red cherts can be present between the pillows.

The pillow lavas show afyric and only rarely porphyritic textures (Plate 5d). In the first case, the structure is ophitic or subofitic; the pl are idiomorphic, manly transformed into albite+epidote or sericite, the cpx, allotriomorphic, are mainly chloritised or sometimes amphibolised. In the second case, the phenocrysts are idiomorphic and subidiomorphic plagioclases, the groundmass has an ophitic or subophitic structure, with pl, cpx and scarce Fe-oxides. They suffered a moderate hydrothermal alteration.

The basalts, with a maximum thickness of about 300 m, are covered by Mt. Alpe Cherts (Plate 5g).

No radiometric datings are reported from the basalts of the Elba Island, however ages of ~157 Ma are reported from Central and Southern Tuscany (Bortolotti et al., 1995).A Callovian to Bathonian age for the basalts of the Island is inferred by the age of the radiolarian microfauna determined at the base of the overlying Mt. Alpe Cherts (see later).

Mt. Alpe Cherts (*Al*)

The formation crops out in **SSU**, **VSU** (Plates 5g, 6a and 6b) and **ASU**; in the latter subunit they occur in very reduced sections. This formation is usually well exposed, such as along Valle delle Foreste and Valle del Frasso, east of Bagnaia, and east of Madonna di Monserrato, on the eastern slope of Mt. Castello (**VSU**); the formation within **ASU** is well exposed along the La Parata road, NE of Mt. Serra.

The mainly lithotypes are: **i**- red, or more rarely greenish, thin-bedded ribbon radiolarites, generally laminated and scarcely recrystallised (except for the greenish ones); sometimes they show sedimentary features related to fine-grained turbidites. The percentage and the preservation of radiolarians is highly variable. **ii**- thin-bedded clay-rich cherts and silty porcellanites red in colour, with frequent lamination. Generally, the silty porcellanites replace the clay-rich cherts upwards in the formation. The radiolarian content is normally very scarce. **iii**- more or less siliceous red shales. The bed thickness is highly variable: from millimetric laminae to decimetric or pluridecimetric beds, going upwards in the sequence.

In the thicker sections (**VSU** and **SSU**) the formation usually shows a stacking of three different lithofacies, which regularly grade into each other: the formation's bottom is characterised by some decimetres of red siliceous shales and/or shaly siltites (Plate 5g) with rare scattered basaltic detritus. Upwards, we observe: **a**- typical thin bedded ribbon radiolarites with very thin rare interbeds of siliceous shales; **b**-ribbon radiolarites, silty cherts and/or porcellanites, alternating with abundant siliceous shales (Plate 6b) and; **c**- siliceous shales and silty porcellanites with very rare ribbon radiolarites, at the top. For more detailed informations on sedimentology, mineralogy and geochemistry of the Mt. Alpe Cherts see Barrett (1981; 1982) and Aiello (1997).

Near the base of the formation, north-west of Porto Azzurro, a peculiar lens-shaped level, with a maximum thickness of a few metres, occurs. It consists of a breccia **(Ophiolitic breccias**, "*al*" in the map) with centimetric to decimetric clasts of basalt and red cherts in an ophiolitic sandy matrix.

The Mt. Alpe Cherts show variable thickness both between and within the different subunits. The maximum recorded thickness is more than 150 m in **VSU** (Fig. 9).

In **VSU**, **SSU** and **BSU**, the Mt. Alpe Cherts are stratigraphically overlain by the Nisportino Formation, through a gradual transition. The boundary between the formations has been set at the base of the first cherty (or siliceous) limestone bed (Bortolotti et al., 1994b). Only in the San Felo outcrop (that we consider the southernmost outcrop of **SSU**) the formation is overlaid by the Calpionella Limestones. In the reduced sequences of **ASU**, the Mt. Alpe Cherts grades upwards directly to the Palombini Shales.

The age of the bottom of the formation was determined with radiolarian biostratigraphy. The age of the top, was indirectly dated by nannofossils and calpionellids found at the base of the overlying formations. In **VSU** the bottom ranges from middle Callovian to early Tithonian (UAZ 8-11), and 6 metres above it is not older than middle Oxfordian (UAZ 9) at Pietre Rosse (Chiari pers. comm., 1998), is middle Callovian-early Kimmeridgian (UAZ 8-10) at Mt. Capannello (Baumgartner 1984; Baumgartner et al., 1995) and late Bathonian-early Kimmeridgian (UAZ 7-10) at Mt. Orello (Babbini, 1996). In the southernmost outcrop of **SSU** (San Felo) the age ranges between middle Callovian and early Tithonian (UAZ 8-11) (Baumgartner, 1984; Baumgartner et al., 1995). No age determinations are available for the Mt. Alpe Cherts in the Acquaviva Subunit (**ASU**). All the previous reported ages are in perfect agreement with those found for the same formation in Southern Tuscany, younger than those found for the formation in Eastern Liguria (see Chiari et al., 1997).

The top of the Mt. Alpe Cherts is probably late Tithonian-early Berriasian, according to the age of the bottom of the overlying Nisportino Fm. (see below).

Nisportino Formation (*Ni*)

The Nisportino Fm. crops out in **SSU**, **VSU**, **BSU** and **MSU**. The typical outcrops of this formation occur along the road from San Pietro to Nisportino, just before the pass.

A transitional level between Mt. Alpe Cherts and Calpionella Limestones was first reported by Bodechtel (1964a "Zwischenserie" = Transition series); also Perrin (1969) recognised the presence of thin sublithographic limestone beds in the uppermost portion of the Mt. Alpe Cherts, and distinguished a basal level in the Calpionella Limestones with massive grey limestones, reddish shales and rare siliceous levels.

This transitional level was formerly recognised as formation by Bortolotti et al., (1994b). It can be subdivided in three portions, that from bottom to top are:

a-Rare siliceous, light grey to greenish cherty limestone thick beds, intercalated in reddish siliceous, locally marly, siltstones and shales. (At the top one or two beds of grey calcilutites, 1-3 m thick). The thickness of this section can vary from 20 to 30 m.

b- A well recognisable horizon, (**Rivercina Member** "*Ri*", Bortolotti et al., 1994b) follows (Plate 6c), which consists of faintly bedded grey marly calcilutite with lozenge foliation. The thickness can vary from 10 to 30 m.

c The third portion begins with an about 10 m thick level of reddish siltstones and shales with rare siliceous-cherty limestone interbeds. Upwards, a massive level (9 to 20 m thick) of marly-silty shales with some calcilutite beds and red siliceous siltstones occurs. Then, a 30 metres thick level of calcilutites and subordinate siliceous siltstones and marly siltstones, is overlaid by 15 metres of thin-bedded pinkish calcilutites. The formation ends with tawny marly-silty shales, up to 5 m thick (Plate 7e). This horizon can vary from 50 to 70 m in thickness.

In the northernmost outcrops (**SSU**), the basal section **a**- is often lacking, and the formation begins with the Rivercina Member.

The total thickness of the formation, can vary from 90 to 130 m.

Semiquantitative X-ray analyses of siltstones and shales and clay mineralogy highlight the common occurrence of quartz, calcite and phyllosilicates (which occur in different proportions according to the lithologies) and, in a few samples, traces of feldspars. Phyllosilicates are composed of kaolinite, chlorite, cl-vermiculite and hydrate illite. The occurrence of hydrate illite suggests that the Nisportino Fm (as well as the whole sedimentary cover of the ophiolites succession) never reached temperatures exceeding 140-150° C, and thus underwent only diagenesis. The anchimetamorphism of the sedimentary covers, which occurs in same places in the Liguria successions (Cobianchi and Villa, 1992; Marroni and Pandolfi, 1996), is lacking in the Elba I. (Bortolotti et al, 1994b). The clay composition might indicate that the source area of these very fine rocks was probably from a continental crystalline basement, probably the crystalline massifs of the southern European margin.

The age of this formation based on both calcareous nannofossils and Calpionellids, is Berriasian (Bortolotti et al., 1994b). In the horizon **a**- the presence of calcareous nannofossil assemblages (*Microstaurus chiastius* Zone) and of *Calpionella elliptica* point to an early Berriasian age. In the Rivercina Member (section **b**-) the nannofloras are more abundant and diversified: *Nannoconus steinmanni* and *Retecapsa angustiforata* Zones, and *Assipetra infracretacea* and *Percivalia fenestrata* Subzones, as the FO of *Cruciellipsis cuvillieri*, *Rucinolithus wisei* and *Tubodiscus verenae*, the LO of *Umbria granulosa* have been identified and point to a "middle" Berriasian age. The limestone beds of horizon **c**- bear Calpionellids of *Cs. simplex* and *Cs. oblonga* Zone D indicating a "middle"-late Berriasian age in agreement with the nannofossil (NK 2A and NK 2B Zones) and Calpionellids data (*L. ungarica* Zone D3 of Remane, 1985) that indicate a latest Berriasian - earliest Valanginian age (Bortolotti et al., 1994b).

The sedimentation of the Nisportino Fm. probably took place in a deep, oceanic environment next to CCD, as supported also by the presence of abundant cherty sediments.

This formation is overlied by the monotonous sequence of the thin-bedded Calpionella Limestones (Plate 7e).

The Nisportino Fm. is present, with very reduced thickness, also in Southern Tuscany (e.g. near Castellina Marittima, Leghorn and Gambassi, Florence), where it is sometimes substituted by a similar formation, the Murlo Fm., (Signorini, 1963), characterised by marlstones with rare levels of marly limestones and siliceous-marly siltstones. Preliminary biostratigraphic analyses of the Murlo Fm. revealed a similar Berriasian age for this formation too (Bortolotti et al., in progress).

Calpionella Limestones (*cc*)

The Calpionella Limestones occur in all the subunits, except for **ASU**. The best exposures are located along the cliff north of Bagnaia (**VSU**, **SSU** and **CSU**), and in the quarries north of Colle Reciso (**VSU**)

The formation is a quite monotonous succession of whitish or pale grey, more or less siliceous, at times cherty, very fine-grained calcilutites (Plates 6d, 7c, f and g), with a typical conchoid fracture. They are well stratified, with the beds being one to some decimetres thick; the bedding planes are often marked by millimetric smearing of dark grey or blackish shales. In the very basal portion of the formation, some levels up to one meter thick of light brown-yellowish marly shales are also present, and the calcilutites can be pinkish in colour. The rare cherts, nodules or lenses, are pale brown. Some beds show clear evidence of graded bedding, with calcsiltites or very fine calcarenites at the base. Toward the top, near the overlying Palombini Shales, the beds are separated by thin interbeds of grey shales.

The age of the base of the formation seem to be slightly heterochronous across Elba: it is latest Berriasian-early Valanginian both in **SSU** (Pietre Rosse) and in **VSU** (Mt. Castello) for the presence of the *L. ungarica* Zone D3, where it lies on the Nisportino Fm (Bortolotti et al., 1994b), and early-middle Berriasian, at San Felo (**SSU**) for the presence of *Calpionella elliptica* (Zia, 1955), where the formation it lies directly on the Mt. Alpe Cherts. This might suggest that the Nisportino Fm. is heteropic with the basal portion of the Calpionella Limestones

According to our biostratigraphic data, the age of the base of the Calpionella Limestones in the study area is similar to the age found in Southern Tuscany, and slightly younger than that recorded in Liguria, where Cobianchi and Villa (1992) found a late Tithonian age in the transition beds from Mt. Alpe Cherts to Calpionella Limestone (somehow corresponding to the Nisportino Fm), and an earliest Berriasian age at the base of the formation.

Towards the top, in **CSU**, and in **VSU** west of Mt. Orello, the formation slowly grades into the Palombini Shales, through the increase of the shale and the relative decrease of the limestone.

Palombini Shales (*pb*)

They occur in **ASU**, **VSU** west of Mt. Orello and **CSU** (Plates 6e and 7g). The best outcrops are located along La Parata road, north of the pass (**ASU**), at Cala dei Mangani, along the coast (**CSU**), and on the right side of the big quarry north of Colle Reciso (**VSU**)

The main lithotypes that characterise this formation: **a**- highly fissile decimetric to pluridecimetric beds of dark to grey shales; **b**- 10-20 cm-thick beds of more or less siliceous calcilutites, grey in colour (”palombini”), sometimes showing a gentle graded bedding, with fine calcarenite at the base. Typical is the anvil-shaped profile of the calcilutite beds, due to higher silicification near the bedding planes, which are marked by a blackish smear. The calcareous beds, subordinate at the base of the formation, decrease in frequency up section. Rare thin-bedded, very fine-grained quartzitic sandstones also occur, and they are abundant only in the outcrop near the Ortano Valley.

The thickness of this formation is very difficult to estimate, due to its strong tectonisation, which always affects the formation.

Regarding its age, the only available data, are from a nannoplancton association found in the Palombini Shales of **CU**, which gives a Neocomian-Albian age.

In the study area, as well as in the rest of Tuscany, no other formation stratigraphically overlies the Palombini Shales of **OU**.

PALEOGENE FLYSCH UNIT (“PU”)

This unit includes a single formation (Colle Reciso Formation) with some olistostrome (debris flow) intercalations.

Colle Reciso Formation (*Re*)

The formation crops out in central Elba, west of Colle Reciso, and in eastern Elba in a very thin belt from Casa Galletti to north-north-west. Fine exposures occur along the Colle Reciso road, south of the pass.

The main lithotype is a 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 (Plate 6g). 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 strongly fragmented and do not constitute continuous levels. West of Lacona the formation includes an olistostrome: a lenticular body up to four m thick in which decimetric to metric clasts of serpentinite, gabbro, basalt and minor marly limestones are dispersed in a carbonate matrix.

The formation is cut by dikes of porphyries (San Martino, and Portoferraio Porphyries) and porphyritic aplites (Capo Bianco Aplites), described below.

Macro and microforaminiferal faunas (*Nummulites*, *Globorotaliae*: Collet, 1934, in Raggi et al., 1965; Raggi et al., 1965) point to a Middle(?) Eocene age.

The original stratigraphic position of this formation is still debated. However, two hypotheses have been offered: **a**- it constitutes the top of the Marina di Campo Fm. (**CU**), from which it was separated during its complex tectonic history; **b**- it is a piggy-back deposit, probably correlatable to the coeval deposits of Corsica Channel or of Alpine Corsica (Cornamusini et al., 2000). In this work we agree with the second hypothesis (see below).

CRETACEOUS FLYSCH UNIT (CU)

This unit consists of a Lower Cretaceous-Campanian/Maastrichtian succession which, from bottom to top comprises: Palombini Shales, Varicoloured shales, Ghiaieto Sandstones (not always present, due to their extreme lenticularity), and Marina di Campo Formation. The Unit might be correlated with the upper portion of the Vara Supergroup, which in eastern Liguria is constituted by the Gottero Tectonic Unit. The Unit crops out west of Colle Reciso and east of Fosso Valdana.

As mentioned before, according to our interpretation, the shear complex (made up of ophiolite, Ophiolitic breccia, Calpionella Limestone and Palombini Shale slices) northwest of Porto Azzurro, which lies on the basalts of the **OU** with a thrust contact, could constitute the strongly laminated base of **CU**. Furthermore, the presence of porphyritic dikes, which never cut **OU**, and are widespread in the flysch units indicate that this slice complex was joined to **CU** before the magmatic phase of Neogene age.

Ophiolitic shear complex

Ophiolitic (Serpentinites, Gabbros, Basalts) and pelagic rocks (Calpionella Limestones and Palombini Shales) compose, including a level of Ophiolitic breccias, a shear complex. The single ophiolite bodies do not show clear relationships between them and with the pelagic rocks. All the rocks, except for the Ophiolitic breccias, have been already described in the chapter on OU.

Ophiolitic breccias (*bo*)

This informal stratigraphic unit is a few meters thick and crops out north of Casa Galletti (Plate 6f). The clasts are made of gabbros, microgabbros, and fine-grained plagiogranites with abundant brecciated basalt and microgabbro angular xenoliths. This unit does not show any clear stratigraphic relations with the surrounding rocks. Thus, it can either be part of **CU** or, alternatively, it can be a fragment of the underlying **VSU**, torn from its original position during the emplacement of **OU** on **VSU**.

Palombini Shales (*pb*)

They crop out (besides the shear complex) on the western side of the Lacona Gulf, with the same lithostratigraphic characteristics of the Palombini Shales of **OU**. In this outcrop the clay mineral association is characterised by of illite-smectite, chlorite-vermiculite, chlorite, illite, kaolinite, with prevalence of the two last minerals. The nannoplancton association found in a calcilutite bed gave a Neocomian-Albian age. The stratigraphic base is not exposed and only the uppermost 30 m crop out. The formation grades upwards to the Varicoloured shales.

Varicoloured shales (*av*)

This informal stratigraphic unit lies at the top of the Palombini Shales, with a tectonised contact. It crops out only west of the Lacona Gulf; a typical outcrop is located on the western side of the Gulf. The lower portion of the unit is made up of blackish shales, with scattered thin beds of manganiferous siltites. In the upper portion the siltites disappear and the shales become red and green. The clay mineral association at the base is represented by illite (prevalent), vermiculite, illite-smectite, chlorite-vermiculite and kaolinite, at the top by illite (prev.), smectite, illite-smectite, chlorite-vermiculite, chlorite and kaolinite.

This unit reaches a thickness of 20-30 m.

Upwards, sandstone beds occur more often and the unit grades either to the Ghiaieto Sandstones or directly to the Marina di Campo Fm.

Ghiaieto Sandstones (*Gh*)

This formation is exposed only in the western side of the Lacona Gulf, and the best outcrops are located along the Tombagrande Creek. Two levels can be distinguished (Babbini, 1996): **a**- the lower level is 8-10 metres thick and is composed of thin beds of grey shales which show the same mineralogical composition of the upper portion of the Varicoloured shales, and of grey-greenish fine-grained sandstones; **b**- upwards, the shales disappear and the upper level consists of light grey medium- to very coarse-grained arkosic turbidites (Fig. 10). Scattered conglomerates, thin shale levels (prevalent illite, smectite, illite-smectite, chlorite-vermiculite, chlorite, kaolinite) and, in the upper portion of the formation, marlstone interbeds, are also present. The clasts of sandstones and conglomerates include two-micas gneiss, quartz-porphyries and granitoids. The beds are very lenticular.

A nannoplancton association found in a marly bed near the top of the formation (Fosso dell'Inferno) indicates a Campanian age (Babbini 1996).

According to Aiello et al. (1977) this formation represents a narrow and deep channel (2-3 km wide and 200 m deep) in which turbidite currents coming from the Corsica-Sardinia Massif discharged their detritic load. The thickness is about 300 m.

The Ghiaieto Sandstones underlie the Marina di Campo Fm, but the contact cannot be observed, being always intruded by thick porphyritic dikes.

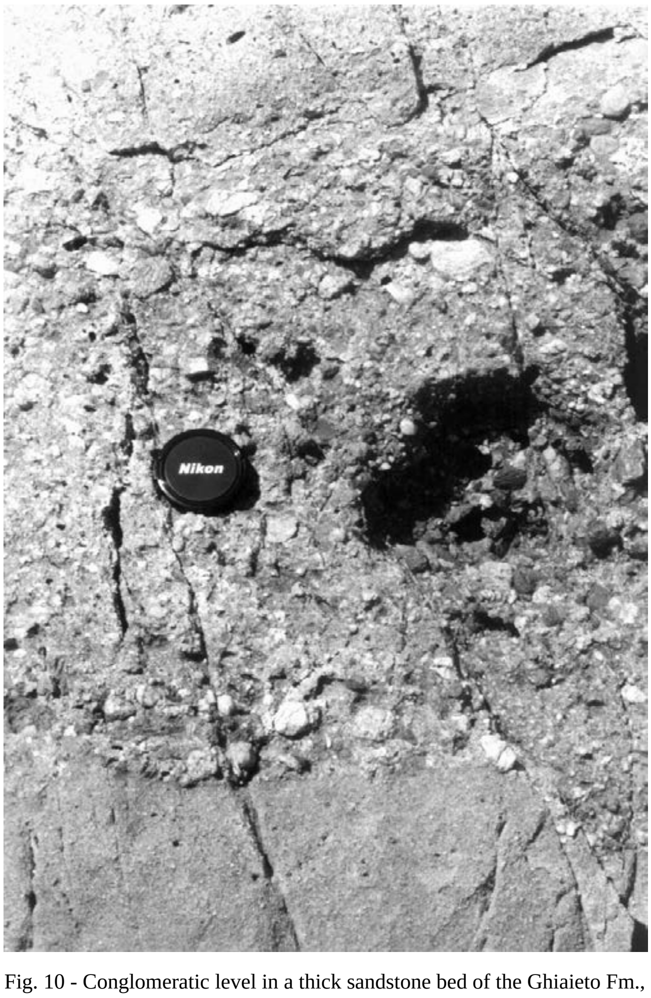

Fig. 10 - Conglomeratic level in a thick sandstone bed of the Ghiaieto Fm., along the Fosso Tomba Grande.

Marina di Campo Formation (*MC*)

This turbiditic formation crops out extensively in central Elba west of Colle Reciso, and east of Fosso Valdana in eastern Elba. Typical outcrops occur along the coast, on the southern side of Lacona Gulf. This formation is characterised by alternation of four main lithotypes (Corti, 1995; Babbini, 1996; Figs. 11 and 12): **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 Ghiaieto Ss., but also includes vermiculite. The lithotypes a- and b-closely alternate at the base of the formation, b-, c- and d-upwards (Aiello et al., 1977). The composition of the arenaceous fraction is the same of the underlying Ghiaieto Fm. (Babbini, 1996).

The thickness of the formation, which is difficult to calculate for the presence of thick Neogene dikes, is estimated to be about 700 m: however, the stratigraphic top is not present. As mentioned before, the formation lies on both the Varicoloured shales and the Ghiaieto Fm., due to extreme lenticular shape of the latter.

The nannoplancton associations found in the marly beds, indicate a Campanian-Maastrichtian age (Babbini, 1996).

QUATERNARY DEPOSITS

Eolian Sands

They occur in the northernmost part of the Island, along the coast from Cala del Pisciatoio to Cala Cancherelli (north of Monte Grosso), from Cavo to Capo Castello and, locally, in the Monte Capo Stella Promontory. They are more or less cemented, yellowish to ochre sands which often show cross-stratification and local microconglomeratic intercalations. Rhyzoconcretions are frequent. Bioclasts (mollusc debris) are rare. The Eolian sands generally show a thickness ranging from 5 to 10 metres.

Landslide debris (*f*)

They mostly consist of talus stabilised accumulations of locally cemented, calcareous angular gravels and/or blocks, deriving from Calpionella Limestones and, subordinately, from the Nisportino Fm., in a calcareous sandy matrix. They are present in the northern part of the map, on the slopes of Mt. Serra - Mt. Grosso. The better example is the landslide located along the Valle delle Fiche.

Terraced alluvial deposits (*aa*)

These old alluvial deposits are generally associated to morphological terraces whose elevation above the present river level ranges from 7-8 m (e.g., Piana di Mola) up to 50-60 m (Mt. Gorgoli). Polymictic, poorly elaborated and cemented gravel is the dominant lithotype which locally can be associated to, or replaced by sand and/or silty mud.

Recent alluvial and beach deposits (a)

The recent alluvial deposits are closely linked to the modern hydrographic network, and only in a few places they form wide alluvial plains (e.g. Piana di Mola, west of Porto Azzurro, Schiopparello and San Giovanni Plains, south of the Portoferraio Bay). These deposits include polymictic, poorly reworked gravels with local sand and mud intercalations.

The beach deposits consist of silicatic-carbonatic, medium- to coarse-grained sands (eg. Lacona Beach). Hematite-rich sands locally occur close to the mining areas, and were exploited in the past (e.g., Spiagge Nere). Moreover, gravel (up to boulders) beaches are sometimes present at the bottom of the cliffs (e.g. south of Capo Pero).

Debris (*d*)

The debris cover consists of locally roughly stratified eluvial and colluvial deposits. Their composition is generally related to that of the underlying and surrounding rocks. They usually occur associated to the outcrops of “Verrucano” Group quartzites (**MU**), Basalts, Mt. Alpe Cherts and Calpionella Limestones (**OU**), and they can reach thicknesses of several metres.

Mining waste (*r*)

They are anthropic, locally stratified gravel accumulations which consist of more or less mineralised host rocks (the so-called gangue minerals) of the Fe-ore bodies, or of rejects from the mining industry. These deposits generally occur within, or close to the mining areas, but evident fan-like wastes also occur along the coast (e.g. south of Cala del Telegrafo).

Fig. 11 - The Marina di Campo Fm along the coast, east of Capo di Fonza. Sandstone levels alternate with marly-arenaceous levels.

Fig . 12 - San Martino sills intruded into the Marina di Campo Fm., along the coast at Capo di Fonza.

TUSCAN PROVINCE MAGMATIC ROCKS

Capo Bianco Porphyritic Aplites (α)

These rock bodies crop out at La Crocetta mine, Portoferraio and Santa Lucia (W of Colle Reciso) where metric to decametric-thick dikes intruded the Flysch Units (CU and EU). These whitish aplitic rocks are named "eurite" and they are characterised by a fine-grained, homogeneous texture with scarce millimetric phenocrysts of quartz, k-feldspar, oligoclase and muscovite (Dini, 1997a). In some localities (e.g. Portoferraio) it contains black-blue aggregates of tourmaline. The "eurite" can be classified as a subalkaline and peraluminous alkali feldspar granite (Dini, 1997a) which was affected by hydrothermal recrystallisation of the acidic plagioclase and of the k-feldspar into sericite (Maineri et al., 1999). The Rb/Sr radiometric study of the magmatic rock indicates an age of about 7.9 Ma (Dini, 1997a), while the hydrothermal alteration occurred about 6.7-6.8 Ma ago ($^{39}Ar/^{40}Ar$ radiometric data by Maineri et al., 1999).

San Martino and Portoferraio Porphyries (π)

These porphyritic rocks are well exposed in the western and central part of the study area. They and occur as metric to pluridecametric dikes (Fig. 12) and laccoliths within the Flysch Units (CU and EU) (Westerman et al., in prep.). They consist of a quartz-feldspatic groundmass including plurimillimetric phenocrysts of plagioclase, k-feldspar, quartz and biotite and k-feldspar megacrysts (up to 15 cm in size) and local granodioritic-tonalitic mafic enclaves. The petrographic, mineralogic and geochemical data point to a subalkaline and peraluminous monzogranitic composition similar to that of the Mt. Capanne stock (Dini, 1997b). The Rb/Sr and $^{39}Ar/^{40}Ar$ data suggest an age of about 7.2-7.4 Ma. More recently, Westerman et al. (2000) separated from the San Martino Porphyries the 8.2 Ma Portoferraio Porphyries, monzogranitic to syenogranitic in composition.

Mt. Castello Dike (μ)

This mafic dike was intruded in **VSU** along two SW-NE trending normal faults (Monte Castello, **MNF** and Acquacavalla, **ANF** Faults) and, in between, crosscuts the Mt. Alpe Cherts and the Nisportino Fm., NW of Porto Azzurro (Conticelli et al., 2001). It consists of dark grey to brownish, porphyritic rock with phenocrysts of plagioclase, clinopyroxene and olivine and xenocrysts of large (up to 10 cm in size) k-feldspar. The groundmass is made up of clinopyroxene, k-feldspar, plagioclase and minor magnetite and apatite. The whole rock composition suggests that the parental magma had a shoshonitic nature. $^{39}Ar/^{40}Ar$ age determinations point to 5.8 Ma (Conticelli et al., 2001).

La Serra-Porto Azzurro Monzogranite (γ)

This granitoid body (quartz-monzonite: Marinelli, 1959a; monzogranite: Serri et al., 1991; 1993), which intrudes the Mt. Calamita Fm., crops out both west (Fosso di Mar dei Carpisi-La Serra area) and east (Barbarossa Bay) of Porto Azzurro. Its occurrence in the subsurface north of Porto Azzurro is testified by mining boreholes (see cross sections in the geological map). The monzogranite is a medium-grained porphyritic rock, mostly grey to whitish in colour, characterised by typical centimetric orthoclase phenocrysts in a medium to fine- grained groundmass made up of quartz, plagioclase, k-feldspar, biotite (locally abundant and sometimes chloritised) and minor cordierite (often pinnitised), apatite and zircon. Rare tourmaline was also found close to the contact with the Mt. Calamita Fm. The K-Ar and Rb/Sr radiometric data obtained for the La Serra-Porto Azzurro monzogranite point to an age of about 4.9-5.4 Ma, according to Saupé et al. (1982) and Ferrara and Tonarini, (1985; 1993), and 6.0 Ma according to a more recent work of Maineri et al. (2000; $^{40}Ar/^{39}Ar$).

Acidic Dikes of Eastern Elba

These whitish rocks (not distinguished in the geological map) constitute the locally intricate dike swarms of the La Serra-Porto Azzurro pluton, intruded in the Mt. Calamita Fm. (e.g. Spiagge Nere area, Fig. 3). Some dikes were also recognised in the Capo d'Arco Schists (OU), north of the Capo d'Arco Residence, along the coast south of Ortano and in the Ortano I. Their size is centimetric to metric and the composition granitic to aplitic (Marinelli, 1959; Saupé et al., 1982). These rocks, hypidiomorphic to xenomorphic, consist of orthoclase (sometimes perthitic), quartz, plagioclase (locally scarce or absent) and minor amounts of biotite, black tourmaline, andalusite or cordierite, muscovite. Apatite and zircon are accessory minerals. Veins of quartz+tourmaline can be locally associated to the aplitic rocks. The K-Ar radiometric ages of the aplites are in the range of those obtained from the La Serra-Porto Azzurro monzogranite (5.4-5.1 Ma; Saupé et al., 1982; Ferrara and Tonarini, 1985; 1993).

Mt. Capo Stella Dikes (*)

Along the eastern coast of the Mt. Capo Stella Promontory, some grey-greenish dikes, decimetric in size, fill NW-SE-trending fractures within the basalts of the Ophiolitic Unit (OU). The preliminary analyses performed on these porphyritic rocks reveal abundance of sub-centimetric phenocrysts of plagioclase, ortho- and clinopyroxene. Biotite is also abundant as microphenocrysts and in the feldspatic groundmass. The textural and compositional features point to a calc-alkaline nature for these magmatic rocks.

Casa Carpini Lamprophyries (+)

These magmatic rocks occur as E-W-oriented, metre-thick dikes within the phyllites of **AU**. They crop out along the road to Capo d'Arco (just a few tens of metres beyond the entrance of the Residence) and along the trail from the Residence to Mt. Arco. These porphyritic, grey-whitish to ochre (if altered), lamprophyries probably correspond to the kersantite dikes of Debenedetti (1951; 1953), but preliminary analyses point to a more alkaline composition. In fact they are characterised by plagioclase, k-feldspar and quartz xenocrysts in a groundmass of feldspatic microliths (plagioclase and sanidine) and micas (biotite and probably phlogopite). These dikes are probably referable to sub-crustal magmatism.

Skarns (*sk*)

They consist of metasomatic FeCa silicates (hedenbergite, ilvaite, epidote), sometimes containing Fe ores (pyrrotine, pyrite, magnetite) (Tanelli, 1977). They generally replace carbonatic rocks (e.g the Calcschists of the Acquadolce Unit at Torre di Rio, south of Rio Marina, and at Punta delle Cannelle, close to the Capo d'Arco Residence). The skarn rocks formed through metasomatic thermometamorphism produced by the La Serra-Porto Azzurro intrusion (6.0-5.4 Ma).

CATACLASITES (c_{1-5})

Five cataclastic horizons were distinguished in the field:

***c_1*- Zuccale cataclasite**. This level of cataclasite (Figs 3, 13 and 14) marks the tectonic superposition, by a low angle N-NE-plunging fault (Zuccale Detachment Fault), through which the whole tectonic pile (Units 2-9) was emplaced onto the Porto Azzurro Unit (Unit 1).

Fig. 13 - Foliated texture of the Zuccale cataclasite at Spiagge Nere, east of Porto Azzurro.

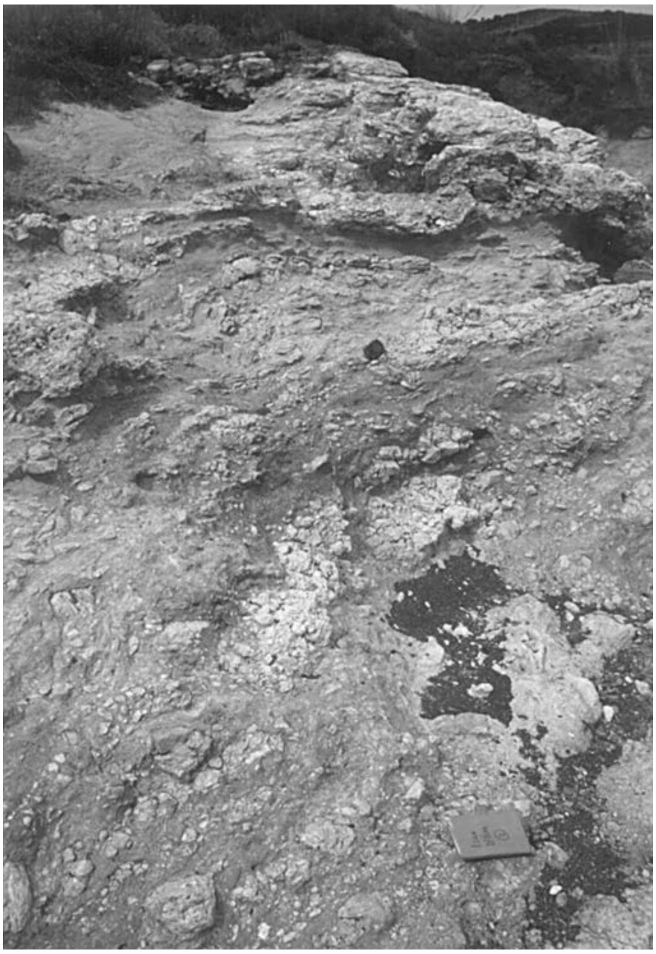

Fig. 14 - Cataclastic texture of the carbonatic "enclaves" of the Zuccale cataclasite at Spiagge Nere, east of Porto Azzurro.

Between Reale Beach and Terranera mine, on the hangingwall of this fault is exposed the Monticiano-Roccastrada Unit (Rio Marina Fm. and "Verrucano"), while in the footwall is exposed the Mt. Calamita Fm, injected by aplitic dikes. The cataclasite is an ochre-yellowish polymictic breccia about 10 m thick, it frequently shows a foliated texture, and is affected by pervasive Fe-oxide/hydroxide mineralisations (Fig. 13). The clasts, millimetric up to 15 cm, derive mostly from the Mt. Calamita Fm (micaschists, phyllites and more or less kaolinised aplite), and from the Monticiano Roccastrada Unit (graphitic phyllites, quartzites), but locally the cataclasite includes also marbles (Fig. 14), calcschist and rare chloritised serpentinite fragments, which likely belong to **AU**. The matrix is mainly carbonatic-phyllitic. Metric tectonic wedges of grey-greenish phyllites and metasiltstones, bedded grey-whitish to yellowish marbles and calcschists of **AU** are also included. It is noteworthy that the thermometamorphic imprint of the lithotypes that occur in the cataclasite predates the cataclastic event (for further details see Benvenuti and Pandeli 2001, in Benvenuti et al., 2001). Therefore, the cataclasite formed after the La Serra-Porto Azzurro intrusion and before the mineralising event.

In the westernmost localities (NE of La Crocetta Mine and on the eastern side of Mt. Fabbrello) the cataclasite consists of metamorphic (quartzites, phyllites and calcschists), ophiolitic and aplitic clasts in a chloritic-quartzitic matrix.

***c_2*- Valdana cataclasite**. ("Calcare Cavernoso" or "Vacuolar dolomitic limestone" Auctt.)

This level of cataclasite (Plate 1c) marks the tectonic contact between the Acquadolce and Ortano Units (Valdana Fault) and forms a more or less continuous and narrow outcrop which extends from Capo Arco Residence to north of the Ortano Valley. It also occurs in the Golfo Stella area. The best exposures are located at the base of the marble quarries in the Ortano Residence. The cataclasite is, at places, roughly stratified. It is a 10-15 m-thick, vacuolar and recrystallised carbonatic breccia, pale grey to yellowish in colour. The clasts (up to 50 cm in size) include mostly marble of **AU** and minor phyllitic lithotypes of **UO** (e.g. Porphyroids, Silver-grey phyllites). The latter are more abundant in the lower part of the level. The clasts are well cemented by fine- to coarse-grained sparite. The cataclasite locally hosts mineralisations (pyrite+pyrrhotite±chalc-pyrite of the Ortano mine), and north of Ortano it occurs as a hedenbergite+ilvaite skarn body. The lack of penetrative deformations suggest a "cold" nature for the cataclasitic event.

***c_3*- Capo Pero cataclasite**. It occurs along the coast, just south of Capo Pero, along a high-angle fault which puts into contact the Capo Pero Limestone with the Varicoloured Sericitic Schists of the hanging-wall. This breccia is made up of heterometric (max. 1 m in size) clasts which originated from both the above mentioned formations. In particular, the clasts mainly consist of green recrystallised limestones and minor phyllites, which are cemented by calcite±Fe-oxides/hydroxides. The thickness is about 9 m.

***c_4*-Ophiolitic cataclasite**. The only outcrop of this cataclasite occurs in the eastern part of the beach below the parking area of Capo Castello. It underlies the Palombini Shales of **ASU** and to the east it is in contact with the Varicoloured Sericitic Schists through a normal fault. It is an ophiolitic breccia which includes clasts of serpentinite, flaser gabbro and subordinate Palombini-like limestones in a foliated green serpentinitic-chloritic matrix. It is often crossed by abundant calcite veins. This level is here interpreted as the basal thrust breccia of **ASU**. The thickness is up to 7-8 m (however the base is not exposed).

c_5- **Colle Reciso cataclasite**. This level marks the contact of the Ophiolitic Unit (**VSU**) on the Paleogene Flysch (**EU**) Units (Colle Reciso Detachment Fault). It crops out only on the western side of Mt. Orello. It includes clasts and pluridecametric blocks of basalts, serpentinites, Colle Reciso Fm., Capo Bianco Aplites and San Martino Porphyries, in a shaly matrix which probably derives from the Colle Reciso Fm.

TECTONICS

INTRODUCTION

As mentioned before, the structure of central and eastern Elba Island consists of a pile of nine major tectonic units, pertaining to the Tuscan, and the Ligurian (comprising Ligurian-Piedmontese Units) Domains, characterised by a general top to the east vergence. From bottom to top the tectonic units are (Figs. 2, 24 and Tectonic scheme in the map):

1- Porto Azzurro Unit (**PU**); 2- Ortano Unit (**UO**); 3- Acquadolce Unit (**AU**); 4- Monticiano-Roccastrada Unit (**MU**); 5- Tuscan Nappe (**TN**); 6- Gràssera Unit (**GU**); 7- Ophiolitic Unit (**OU**) which consists of seven subunits (see below); 8- Paleogene Flysch Unit (**EU**); 9- Cretaceous Flysch Unit (**CU**). Units 1. 2, 4 and 5 pertain to the Tuscan Domain, the others ones to the Ligurian Domain (3 and 6 are Ligurian-Piedmontese Units).

The Figure 24 and the tectonic scheme in the map, emphasise that these units are separated by subhorizontal or gently dipping surfaces interpreted as thrusts and low angle normal faults (= detachments), and dissected by high angle transfer and normal faults. The tectonic schemes point out that the same succession of tectonic units occurs in the central and eastern Elba, in both sides of the N-S Valdana-Schiopparello alignment. All units underwent to mono- or polyphase folding and faulting both before and after their final emplacement. Many tectonic surfaces cannot be unequivocally attributed to a well defined deformation event and/or suffered movements under different tectonic regimes, thus they are grouped as “low angle surfaces of complex interpretation”.

The peculiarity of this tectonic pile is the repeated superposition of more or less metamorphic (**PU**, **UO**, **MU**, **AU**, **GU**) and non-metamorphic (**TN**, **OU**) units; this fact implies that the piling up is due not only to compressional thrusts but also to extensional detachment faults.

FOLDS

All the tectonic units of the Elba Island underwent polyphase folding. Moreover, in the four lowermost units (**PU**, **UO**, **AU** and **MU**) and in **GU**, the main folding events are syn-metamorphic. The correlation between the deformation events is complex because:

1- These events were not coeval in the different units (e.g. the first folding event in the Ligurian and Ligurian-Piedmontese Units is probably related to the Eocene tectonic phase, which marks the end of the “oceanic” sedimentation and predate the first deformations of the Tuscan continental margin. The successive collision probably occurred during Early Oligocene.

2- The stack of the Elba units is the result of a complex sequence of deformational events during which the tectonic units acquired their main deformation imprints at different structural levels, under different tectonic regimes and in different paleogeographic areas (e.g. the Ligurian-Piedmontese **AU** tectonically sandwiched between the Tuscan **UO** and **MU** (see later: Low-angle tectonic surfaces; see also Elter and Pandeli, 2001);

3- In some rocks, it is very difficult to distinguish the superimposed, substantially coaxial folding events.

A further tectonic complication in **PU** and in **UO**, is due to the presence of pre-Alpine schistosity relics which can be correlated to the Sudetian deformation event of the Variscan Orogeny (Pandeli and Puxeddu, 1990; Duranti et al., 1992; Elter and Pandeli, 2001).

Only the last, weak folding events which affected the whole tectonic pile are coeval.

If we consider only the deformations due to the Apenninic orogenesis, the succession of folding events can be summarised as follows:

The Ligurian events (Eocene-Oligocene?). They are due to the subduction of the Ligurian-Piedmontese Units under the European margin (Corso-Sardinian Massif), preceding the continental collision They produced the D_1 HP-LT event in **AU**, the ophiolitic detrital input in **EU**, and part of the oldest folds in **OU**, **CU** and **EU**.

The main Apenninic event (Late Oligocene/Early Miocene). During this event, progressive (ensialic) deformation and shearing affected the Tuscan Adriatic margin, and the Ligurian-Piedmontese Units were emplaced onto this margin: the D_1 syn-metamorphic (green-schists facies) folding in the deepest Tuscan **PU**, **UO**, **MU** (27 Ma on the Apuan Alps: Kligfield et al., 1986) and in the Ligurian-Piedmontese **AU** (19 Ma: Deino et al., 1992) were thus produced. The anchimetamorphic D_1 event in **GU** also took place. The main, non-metamorphic folding of the Ligurian Units (**OU**, **CU**, **EU**) and of the Tuscan Nappe probably occurred during the same time interval, but at a shallower structural level.

Refolding events (Middle/Late Miocene to Pliocene).

In the Elba stack, we can ascribe to these events:

a- the D_2 folding of the Tuscan Units and the D_3 of the Ligurian-Piedmontese **AU**. They are regionally connected to the exhumation of the deepest portions of the chain which Carmignani and Kligfield (1990) and Carmignani et al. (1995) referred to the beginning of post-orogenic extension of the overthickened orogenic pile. Instead, the Authors suggest an exhumation in a syn-orogenic frame (see Fazzuoli et al., 1994; Jolivet et al., 1998). In the Apuan Alps this event, according to Kligfield et al. (1986), occurred at 12 Ma.

b- The youngest weak folding of the whole tectonic pile, due to detachment tectonics and plastic deformations of the units caused by the Mio-/Pliocene magmatic intrusions. These latter folds are dissected by high angle normal faults filled with ~ 5.3 Ma hematite-rich ores.

As seen before, although fold axes and vergences generally have a constant trend, peculiar folding structures and deformations can be detected within each unit.

Porto Azzurro Unit (PU)

In the studied area, the thermometamorphic imprint in the Calamita Fm. often obliterated the previous tectono-metamorphic features. However, centimetric/decimetric, tight to isoclinal folding of the main continuous schistosity (related to the first Alpine tectono-metamorphic event) is locally recognisable, as well as younger open to close folds, metric to decametric in size. In particular centimetric D_1 isoclinal folds are rarely preserved because of the D_2 transposition. The D_2 folds show a N-S to NE-SW orientation of the axis and a west-low dipping axial surface (Fig. 15A); the D_3 folds are characterised by a widespread of the axial plunge (mainly in the SW and NW quadrants) (Fig. 15B) and a sub-vertical axial surface. A pervasive zonal to discrete crenulation cleavage is associated to F_2, while fracture cleavage is connected to D_3 folding. 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 Mt. Calamita Fm. in the Mt. Calamita Promontory). Finally, some later weak folds deformed the aplitic dikes 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 N65° dip direction in the Terranera area) (Fig. 15B), which displaces the Mt. Calamita Fm. and the included aplites, is consistent with the axial direction of these latest folds (A_3).

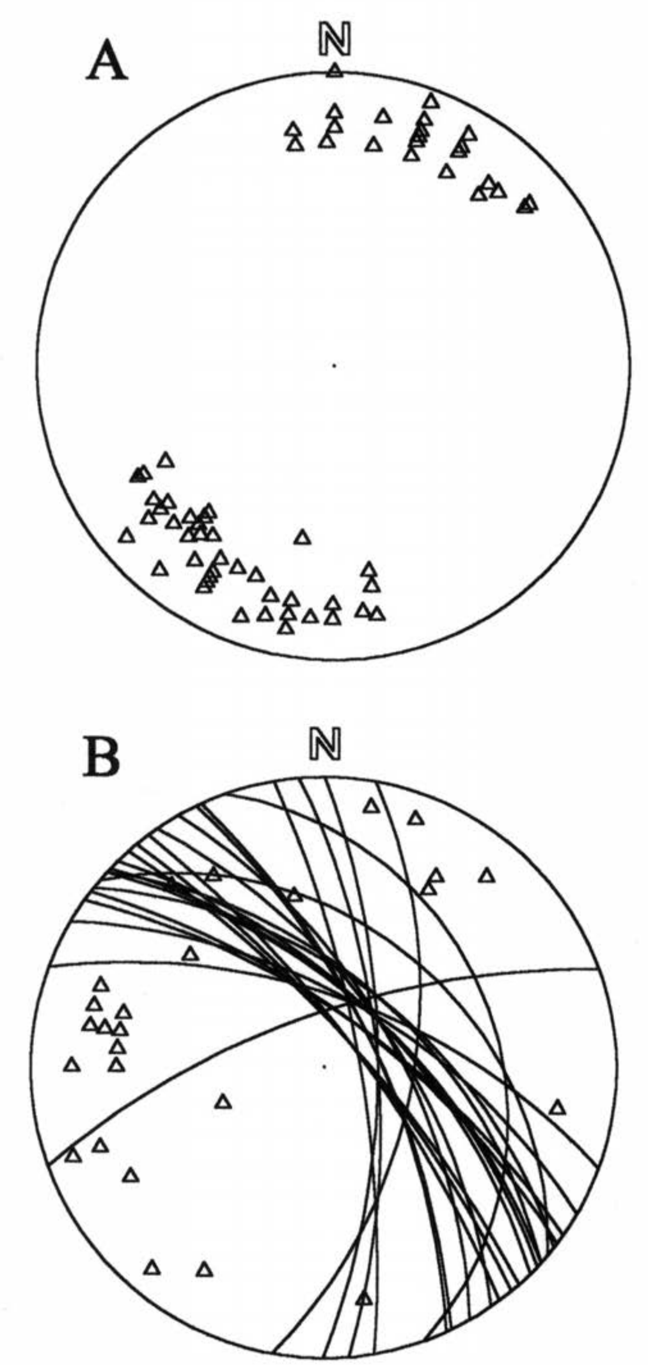

Fig. 15 - Equal area, lower hemisphere projections: A. A_2 axes (n = 63) in the Mt. Calamita Fm. (**PU**) of the Terranera area. B. Schmidt stereonet (lower hemisphere) of the A_3 axes (n = 26) and cyclographics of the fractures (n = 23) near Terranera.

Ortano Unit (UO)

Taking into account the proposed correlation between the Capo d'Arco Schists and the Silver-grey phyllites and quartzites, the structure of this Unit consists of an east-vergent hectometric synform anticline with the Porphyroids being at its core (cross-sections n. 4-6). At the mesoscale, the main continuous foliation (Ser/Mu+Qtz±Chl±Ab), which generally parallels the lithological contacts, is the axial plane schistosity of decimetric/decametric isoclinal, east-vergent flame-like F_1 (Plate 1b). Their axes and intersection/mineralogical lineations on the main schistosity, mainly trends N20° to N50° (Fig. 16). An earlier secondary foliation (Mu+Qtz±Chl), locally recognisable at the microscale within the microlithons, is referred to relics of the Hercynian foliation. The kinematic indicators associated to the main schistosity (σ-type porphyroclasts, shear folds, polycrystalline ribbon quartz and domino-like structures, etc.) point to a mainly "top to W/NW" sense of shear for the Capo d'Arco and Spiaggia del Lido areas, while a "top to N/NE" component is shown in the outcrops of the Ortano area.

The D_1 structures are deformed by metric/decametric, close to tight F_2 (Plate 7a) with rounded/sub-rounded hinges and axes oriented N350° to N70° (Fig. 16). Their spaced zonal crenulation cleavage (C) produces intersection lineations (strike N30° to N60°) on the main schistosity. A later, locally mineralised fracture cleavage, associated with gentle-open folds, trends about NS.

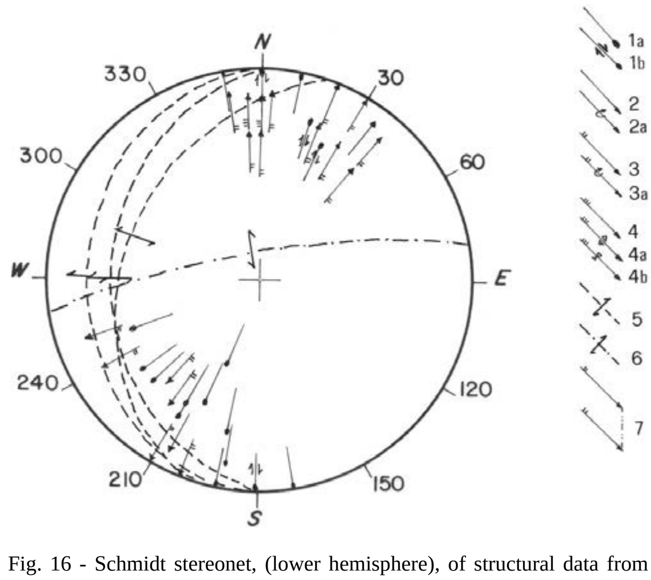

Fig. 16 - Schmidt stereonet, (lower hemisphere), of structural data from **UO** (Ortano Unit). 1a- mono- and poly-mineralogical lineation; 1b- mono- and poly-mineralogical lineation with component of shear; 2- axis related to Dp folds; 2a- axis related to Dp folds with facing; 3- axis related to Dc folds; 3a- axis related to Dc folds with facing; 4- axis of later folds; 4a- later antiform; 4b- later synform; 5- Sp plane with component of shear; 6- C plane with component of shear; 7- degree of axial dispersion on foliation plane (after Elter and Pandeli, 2001).

Acquadolce Unit (AU)

Folds are recognisable only in the Porticciolo Subunit (PSU). D_2 folds are the most common meso-structures. They are tight/isoclinal folds, centimetric to decametric in size, with rounded hinges and a recumbent/overturned attitude. Their axes trend N320° to N100° (Fig. 17). The associated sub-centimetric-spaced axial plane foliation (Plate 7b) forms a discrete crenulation cleavage, but it often becomes a continuous secondary foliation (Ser+Qtz±Chl±Cal±Ab). Sheath-type folds are also present.

D_2 deforms up to transposition a well defined continuous metamorphic layering (S_1 = Ser/Mu+Qtz±Chl±Ab±Cal), generally parallel to the lithologic boundaries, which locally can be identified only as a S_2 intrafolial relic. Rare centimetric/decimetric isoclinal folds are associated to S_1. Therefore, the main schistosity at the meso-scale is often a composite schistosity due to the parallel superposition of S_2 onto S_1 along the limb of D_2 folds.

The attitude of the mineralogical lineations on the main schistosity plane is similar to that of **UO** (the strike is mostly N350° to N50°), but the kinematic indicators point to a "top to SW" sense of shear in most of the eastern outcrops and a "top to SE" sense in those of the Capo Arco and Norsi areas.

Later deformation events produced open to close folds with thin zonal crenulations or a widely-spaced fracture cleavage/kinks, whose axes and intersection lineations on the main foliation trend mostly N20° to N70° and about NS or N60-70° respectively. In the calcschists of Torre di Rio area, S-C planes between the main schistosity and crenulations are visible and show a "top to NE" sense of shear.

Monticiano -Roccastrada Unit (MU)

A complex polyphase folding (cross-section n. 1) is well recognisable in the Paleozoic (Rio Marina Fm.) and in the Tuscan Mesozoic-Tertiary epimetamorphic succession of Capo Castello (Plate 2f) (Pandeli et al., 1995). On the contrary, the dominantly quartzitic "Verrucano" seems generally weakly affected by folding (cross-sections n. 3, 4, 6). Only in the pelitic-rich horizons it shows evident polyphase plastic deformations.

The continuous main foliation (Ser+Qtz±Chl±Cal) is generally parallel to bedding and associated to NE-vergent, centimetric/metric D_1 isoclinal folds (axes oriented mostly N320° to N10°; Fig. 18). The reverse limb of an hectometric, recumbent, NE vergent D_1 fold is well exposed at Capo Castello. The mineralogical lineations (Ser+Qtz±Chl) and the reduction spots that occur on the main foliation are oriented N320° to N360°. A "top to NE" component of shear, syn-kinematic to main foliation, was also distinguished.

The main foliation is deformed by decimetric/decametric open to tight D_2 folds with rounded/sub-rounded hinges, axes oriented N300° to N35° and generally steep to sub-vertical axial planes. A spaced zonal to discrete crenulation cleavage is associated to D_2 folds whose vergence is towards NE, but rare western-facing folds were also locally recognised. These folds are the best exposed structures in the Monticiano-Roccastrada Unit.

Later gentle/open folds with zonal crenulations or fracture cleavage, N-S trending axis and sub-horizontal or low-dipping axial planes are often evident in the field.

Tuscan Nappe (TN)

Two different structural settings characterise the Tuscan Nappe:

a- In the southern (La Parata-Porto Azzurro) and western (Valdana) portions of the study area **TN** comprises only the "Calcare Cavernoso", sandwiched between **MU** and **GU**; b- to the North (La Parata-Cavo area), on top of the "Calcare Cavernoso" the Triassic to Dogger formations also crop out (cross-sections n. 1, 2, 9).

The previous geologic setting strongly recalls the one that characterises the Southern Tuscany "Serie Toscana Ridotta" (= "Reduced Tuscan Series"), where "reduced" suc-

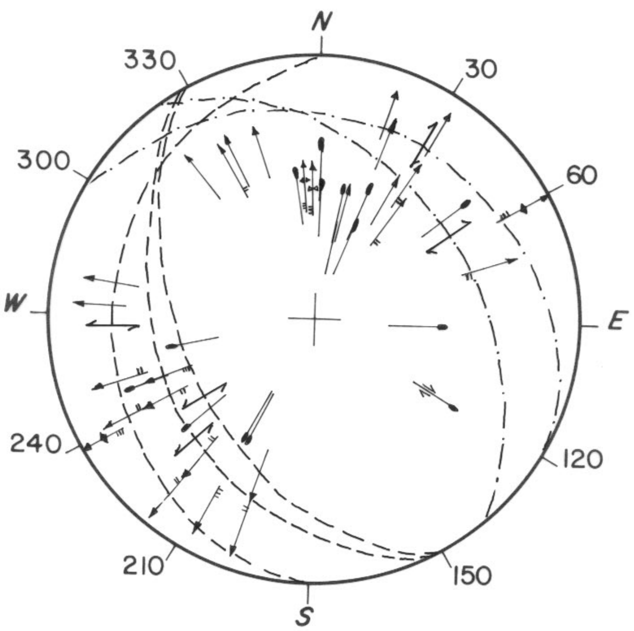

Fig 17 - Schmidt stereonet (lower hemisphere) of structural data from **AU** (Acquadolce Unit). Symbols as in Fig. 16 (after Elter and Pandeli, 2001).

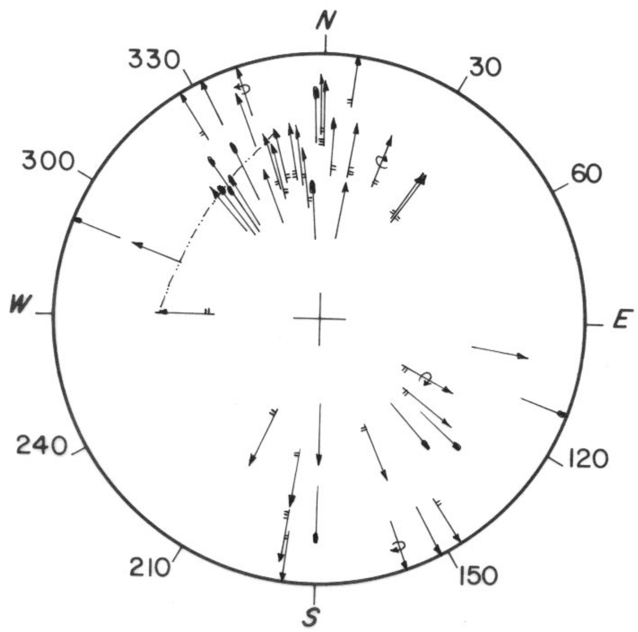

Fig. 18 - Schmidt stereonet (lower hemisphere) of structural data from **MU** (Monticiano-Roccastrada Unit). Symbols as in Fig. 16 (after Elter and Pandeli, 2001).

cessions, consisting only of the basal terms of the Tuscan Nappe and complete successions crop out close each other. This structure was recently attributed to low angle extensional faulting by Bertini et al. (1991) and Decandia et al. (1993).

The Triassic and Hettangian formations show only mild plastic deformations. In particular, the Pania di Corfino and the Mt. Cetona Fms. form a monocline gently dipping northwards (cross-section n. 9) (but southwestwards at Mt. Bicocco) and the "Calcare Massiccio" is affected only by brittle deformations. In the overlying well stratified Lower-Middle Jurassic formations, at least two fold associations are recognisable: a) decimetric, concentric tight folds, whose axes trend from N315° to N (locally E-W, at Punta delle Paffe). b) younger open, metric to decametric folds with N-S trending axes.

In some places (e.g. Valle Baccetti area) the Grotta Giusti Cherty Limestones and the overlying "Rosso Ammonitico" show different axial trends; the disharmonic folds are probably due to a "décollement" in between (cross-section n. 2).

Gràssera Unit (GU)

The pelitic lithotypes of the Cavo Fm. are characterised by a penetrative slaty cleavage, which deforms the bedding and the Qtz±Cc veins (Fig. 8). This planar anisotropy is associated to close to tight folds whose axes have a N280° to N40° strike (Fig. 19) and a frequent SE plunge of the axial plane. The mineralogical lineation (sericite and/or clay minerals) on the foliation plane is oriented about N-S. σ-like porphyroclasts (deformed Radiolarians) show a "top to SE" sense of shear.

The foliation is deformed by open to close F_2 whose axes plunge spread from N300° to N50° and have a sub-horizontal or a gentle dip of the axial plane. F_2 are characterised by a penetrative fracture cleavage and crenulations which produce on the foliation thin and closely spaced intersection lineation and rare mullions. Syn-D_2 boudinage of the more competent beds was also locally observed. Later asymmetric kinks (N320° to N5° strike) are also locally present.

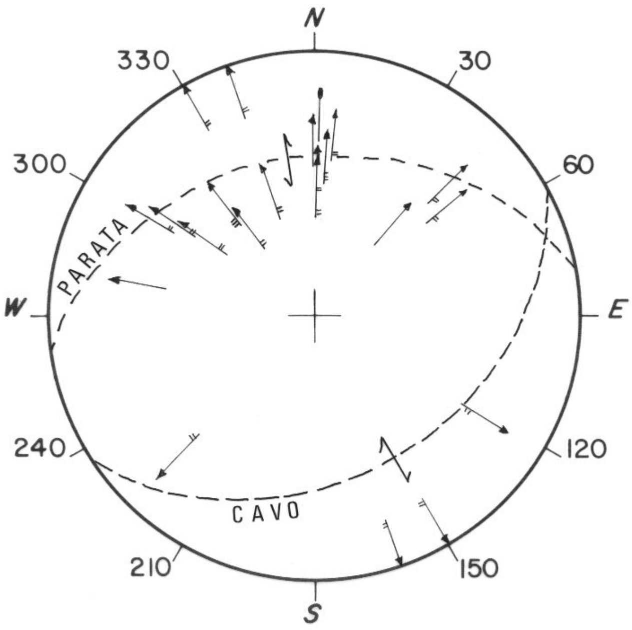

Fig. 19 - Schmidt stereonet (lower hemisphere) of structural data from **GU** (Gràssera Unit). Symbols as in Fig. 16 (after Elter and Pandeli, 2001).

Ophiolitic Unit (OU)

The Elba ophiolites, like all the ophiolites of the Northern Apennines, underwent oceanic Middle-Upper Jurassic metamorphism and extensional and/or transcurrent tectonic events. (For these general topics, see Abbate et al. (1985) Treves et al. (1995; 1996) and Corti (1998).

The different subunits of **OU** show different tectonic behaviours, and are discussed separately.

Acquaviva Subunit (**ASU**). As mentioned above, this subunit consists of thin slices of ophicalcites and/or serpentinites overlying or underlying, with not always clear relationships, Palombini Shales or thin levels of Mt. Alpe Cherts-Palombini Shales. The ophicalcite and the serpentinite slices show a very complex fracture net. In some places they show, near the low angle tectonic contacts at the base and at the top, shear zones or cataclastic/mylonitic levels, which generally develop parallel to these surfaces. The Palombini Shales are always strongly boudinated. We can hypothesise that the vertical repetition of the formations of the Subunit, could be due to east-vergent reverse and isoclinal folding (cross-sections 1-4) and/or to minor thrusts (cross-sections n. 1, 3, 6, 8).

Mt. Serra Subunit (**SSU**). This unit is affected by spectacular inclined and reverse folds, with hectometric wavelength, accompanied by minor folds (Fig. 20a): a succession of tree synclines and the intervening anticlines is very well exposed along the coast, from Cala dell'Inferno to il Pisciatoio beach (cross-sections n 1, 2). The anticline cropping out along the sea west of Mt. Grosso, can be followed landwards, all along the subunit, up to Rio Vignolo. South of Rio Vignolo other similar folds crop out and, even if a clear link with the preceding ones is lacking, they can be considered their south-western continuation (cross-section n. 3). The axes of all these folds trend ~N340° in the northern portion of the subunit, ~NS southwards; the axial planes are subvertical or plunge westwards with high angles.

Capo Vita Subunit (**CSU**). This Subunit is intensely folded: the folds show wavelengths up to tens metres; their axes trend NS and gently plunge northwards. Hectometric folds are only hypothesised (cross-section n. 1).

Sassi Turchini Subunit (**TSU**). No folds but only some shear zones dipping west, compatible with the general tectonic transport of the Subunit were observed. The thickness of **TSU**, consisting only of serpentinites (cross-sections n. 4-8) thins northwards, where it occurs in scattered slices a few metres thick, along the tectonic contact between **SSU** and **VSU**.

Volterraio Subunit (**VSU**).Within this subunit the deformation is not uniformly distributed.

The basalts seem to be deformed more or less conformably with the overlying Mt. Alpe Cherts.

The Mt. Alpe Cherts, east of Mt. Castello and north of Volterraio, are strongly folded showing belts of very close folds (with a wavelength of tens of metres) with very dipping axial planes plunging south-westward; on the contrary, west and north-west of Rio nell'Elba to Fosso dei Mangani basalts and Mt. Alpe Cherts form a monocline, deformed by minor gentle folds of wavelength up to hectometric (cross-sections n. 3, 4). All the succession cropping out southwards, shows a series of inclined or reverse folds, with a wavelength of hundreds of metres (cross-section n. 5). Fold axes generally trend from N340° to the north, to about NS, going southwards and plunge northwards of a few degrees (Fig 20b). Their axial planes dip west- to south-west, indicating a north- north-eastwards tectonic vergence.

Magazzini Subunit **(MSU).** This minor subunit (cross-section n. 5), which occurs located on top of VSU, is only characterised by a N340° trending anticline.

Bagnaia Subunit (**BSU**). This subunit shows the same style of folding described for **VSU**. However, the fold axes trend about N315°, indicating that during its emplacement onto the underlying subunits (**SSU**,**TSU** and **VSU**), **BSU** probably rotated anticlockwise of about 30°.

Flysch Units (EU and CU)

Within the study area it has been very difficult to precisely define the structure of the Flysch Units, due to the scarcity of continuous outcrops (except for those along the coast), and to the intricate networks of Miocene dikes (e.g. the Buraccio area). Generally, these units show an overall west-dipping monoclinalic attitude, complicated only by local minor folds (cross sections n. 5, 6).

Frequent boudinage of the carbonate beds, locally superimposed by weak folding, characterises **EU.** In **CU**, plastic structures are more evident. In particular, north of the Buraccio area, within **CU**, some decimetric to metric close to tight

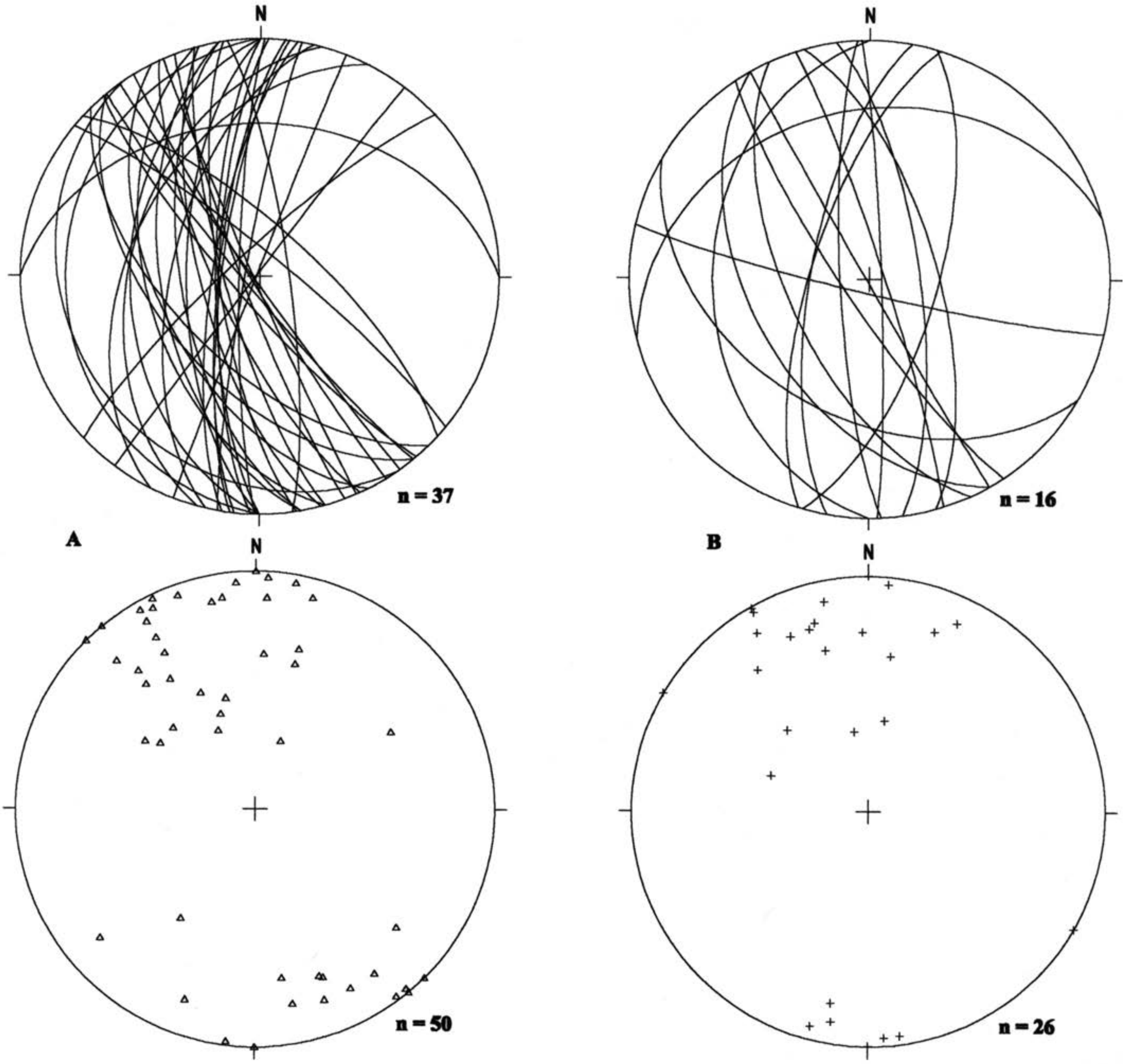

Fig. 20 - Schmidt stereonet (lower hemisphere) of fold axes (triangles and crosses) and axial planes (cyclographics), from **OU**. A- SSU (Mt. Serra Subunit); B- VSU (Volterraio Subunit).

folds with a NE-SW axis and a mainly NW low to middle angle-dipping axial surface were recognised. Symmetric and NNW-SSE to N-S oriented open folds with vertical axial surfaces are also present. The relationships between the previous fold groups are well exposed along the coast, between Capo di Fonza and Marina di Campo Gulf-La Foce (see Fig. 5 in Wunderlich, 1962), immediately west of the studied area. At this locality, the fissility of likely diagenetic origin (parallel to the bedding) is deformed into metric to decametric, tight to isoclinal folds. These overturned/recumbent folds and the related parasitic structures show east-vergences and a NE-SW axial orientations (Fig. 21). Decimetric to metric weak to open folds with a sub-vertical axial plane and an about N-S oriented axis, deform the previous structures (Fig. 21). It is worth noting that only the older fold system is clearly cut by Messinian aplitic intrusions, some of which seem to be locally deformed by the second folding event. This structural frame is in agreement to that described by previous authors (Wunderlich, 1962; 1963; Perrin, 1975).

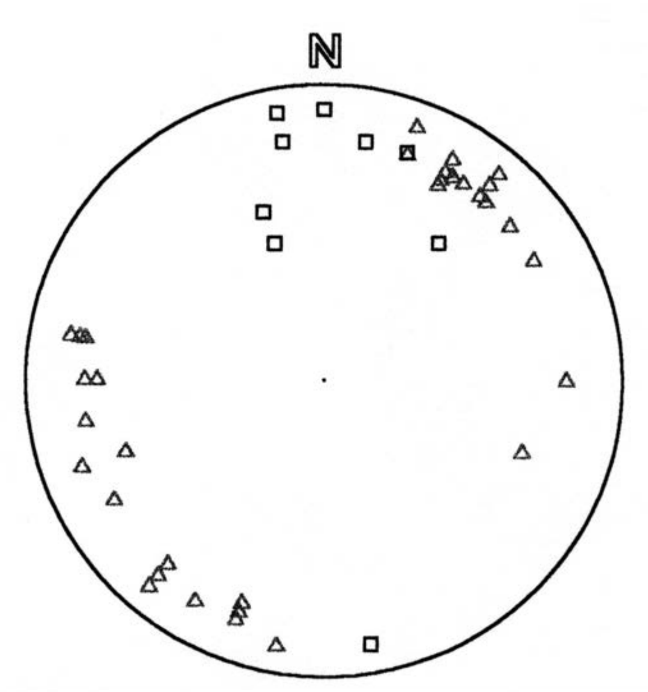

Fig. 21 - Schmidt stereonet (lower hemisphere) of structural data from the Cretaceous Flysch Unit (**CU**; A_1, triangles, n = 33; A_2, squares, n = 9).

FAULTS

Low-angle tectonic surfaces

Determining the age and the geodynamic mechanisms of the low angle tectonic surfaces (which in most cases occur covered by detrital cover) is a task that presents many difficulties. It is sometimes difficult to univocally decide if the tectonic surfaces are compressional thrusts or extensional low-angle faults, and if they have been reactivated during the same or different tectonic regimes.

The low angle tectonic surfaces within the study area occur both within the Ligurian and the Tuscan domains and their age possibly ranges from Eocene to Recent. Taking into account all the data collected in the study area and the general tectonic evolution of the Northern Apennine chain, the succession of thrust and detachment can be reconstructed as follows.

The Ligurian events (Late Cretaceous?/Eocene-Oligocene?). The Apenninic deformations began in the Ligurian domain during the Late Cretaceous-Eocene, when the end of the "oceanic" flysch sedimentation in the Internal Ligurids occurred. For the Elba Island, we can refer to the Eocenic compressional tectonic phase the thrusting of **CU** onto **EU** and, afterwards, of both **CU** and **EU** onto **OU**. In particular, if the Eocene Flysch is interpreted as a piggy-back deposit (see Stratigraphy: Colle Reciso Fm.), its westwards underthrusting must be Middle Eocene or younger, but older than Late Oligocene (see below and Fig. 31). This tectonic event was preceded by the **OU** deformation and, probably, by the piling up of its various subunits (which were deposited in a more western area).

The main Apenninic event (Late Oligocene-Early Miocene). After the Ligurian events, the deformations extended to the Tuscan Domain. After the end of the Oligocene, which is the age of the topmost formation (Macigno) of the Tuscan Succession in western Tuscany, a "squeezing" phase following the collision between Adria and Corsica caused the thrusting of the Ligurian-Piedmontese Units (**GU** and **AU**) and of the Ligurian Units (**OU**, **CU** and **EU**) onto the Tuscan units. The time relations between thrusting of the Ligurian-Piedmontese and Ligurian Units is still matter of debate (see Conclusions).

Extensional events (Late Miocene-Quaternary). After the main Apenninic event, only extensional gravitational detachments can be recognised. The recognition of the extensional events is based on: i- superposition of younger onto older terrains, ii- superposition of non-metamorphic onto metamorphic terrains and, iii- superposition of less on more metamorphic terrains. We surmise that the older detachments, along which we hypothesise that the Tuscan Units were discharged westwards (Fig. 32), would have been triggered by the uplift of the western Tuscany area (Mid Tuscan Ridge?) (Carmignani et al., 1994a; 1994b; 1995). This extensional phase is radiometrically dated to 12 Ma in the Alpi Apuane Mts. (Giglia and Radicati di Brozolo, 1970; Kliegfield et al., 1986; Carmignani and Kligfield, 1990). Further gravitational movements would have been caused by the uplift, of first the Mt. Capanne and, successively, of the La Serra-Porto Azzurro plutons (e.g., Trevisan, 1950, Pertusati et al., 1993; and others). For these detachments and for the contemporaneous high angle normal and transfer faults, some precious pinning points are provided by radiometric data of the magmatic bodies and by the geometrical relationships between the different tectonic structures.

Below we present a detailed discussion of, first the low angle tectonic contacts, and than the high angle (normal or transfer) faults.

The tectonic boundaries among the units

The vergence of the thrusting surfaces that occur between the units and/or subunits is interpreted as being either east or northeast, as commonly found in the whole Apennine chain. The detachment faults show variable trends of movements; however, the kinematic indicators are clearly exposed only for the Zuccale Fault (**ZDF**).

Four types of low-angle contacts we recognised (Fig.24):

a- *Thrusts*. The low angle tectonic surfaces separating **GU** from the underlying **TN** (La Parata Thrust Fault, **PTF**) and **CU** from the underlying **EU** (Madonna della Lacona Thrust Fault, **LTF**) are considered "*main thrusts*". The thrust contacts between subunits are considered "*secondary* *thrusts*". The age of all the thrust is pre-Late Miocene.

b- *Pre-intrusion detachment faults.* The low-angle tectonic surface, along which the metamorphic unit (**MU**) is overlain by the non metamorphic unit (**TN**) is interpreted as an old delamination of a probable Middle/Late Miocene age (Mt. Arco Detachment Fault, **ADF**).

c- *Syn-intrusion detachment faults.* The low-angle tectonic surfaces separating **CU** from the underlying **OU** (Casa Galletti Detachment Fault, **GDF**), and **OU** from **PU** (Mar dei Carpisi Detachment Fault, **MDF**), and **BSU** from **SSU**, **TSU** and **VSU** (Fosso dell'Acqua Detachment Fault, **FDF**) are considered detachment faults of uppermost Miocene age.

d- *Post-intrusion detachment faults.* The low-angle surfaces along which the whole tectonic pile overlies **PU** (Zuccale Detachment Fault, **ZDF**), **CSU** overlies **SSU** and **GU** (Casa Unginotti Detachment Fault, **UDF**), **VSU** overlies **EU** (Colle Reciso Detachment Fault, **RDF),** are considered the youngest delaminations of uppermost Miocene age.

e- *Low angle tectonic surfaces of complex interpretation.* The interpretation of some low-angle surfaces is very difficult because they are probably the result of the superposition of tectonic events occurred at different times and/or in different tectonic regimes. They are the Valdana Fault (**VCF**), along which **AU** overlies **UO**, the Mt. Fico Fault (**FCF**) along which **MU** overlies **AU,** and the San Felo Fault (**SCF**), along which the **OU** overlies **GU**

Minor, sub-horizontal shear planes often occur within the tectonic units. These structures, which we did not examine in detail, can be interpreted as the consequence of the main detachments and thrusts.

Main thrusts

i- La Parata Thrust Fault (PTF) (Gràssera Unit on Tuscan Nappe: **GU/TN**; cross-sections n. 1-6, 9). This thrust surface is well exposed along the Rio nell'Elba-Cavo road near La Parata (Cavo Fm. on "Calcare Cavernoso", Fig. 6), at Poggio Belvedere and west of Mt. Bicocco (Cavo Fm on "Rosso Ammonitico" or *Posidonia* Marlstones). Due to the lack of a cataclastic horizon, a local apparent stratigraphic conformity and crude lithologic convergence, former Authors (e.g. Barberi et al., 1969b; Boccaletti et al., 1977) considered GU as part of the Dogger *Posidonia* Marlstones or of the Cretaceous-Oligocene "Scisti Policromi". The evident, anchizonal imprint and the deformation features of **GU** with respect to the underlying **TN**, together with a local strong cleavage affecting the uppermost portion of **TN** (e.g. *Posidonia* Marlstones west of Mt. Bicocco), point to a tectonic nature for the **GU/TN** surface. Judging from the age of the top of **TN** at a regional scale, this tectonic surface is probably not older than the Aquitanian.

Within the study area, **GU** lies on different formations of the Tuscan Nappe: on the "Calcare Cavernoso", south of the La Parata (cross-sections n. 3-7, 9), and on the "Rosso Ammonitico" or the *Posidonia* Marlstones, in the Cavo area (cross-sections n. 1, 2). This structural setting could be attributed to a flat ("Calcare Cavernoso") - ramp (Pania di Corfino Fm.-"Calcare Massiccio"-Grotta Giusti Limestones) - flat ("Rosso Ammonitico" or *Posidonia* Marlstones) geometry of the thrust surface.

ii- Madonna della Lacona Thrust Fault (LTF) (Cretaceous Flysch Unit on Paleogene Flysch Unit: **CU**/**EU**; cross-sections n. 5, 6).

This surface, sub-horizontal or dipping very gently eastwards, crops out in the area north of Porto Azzurro (in the hangingwall of **ZDF**), and in central Elba west of Mt. Orello (west of **RDF**). The fault is in most places obliterated by the porphyritic and aplitic intrusions, accordingly, it predates the magmatic phases (8.5-7.9 Ma). Moreover, the presence of Middle Eocene foraminifers in the lower unit (**EU**) suggests a post- Middle/Late Eocene age for this thrust.

Secondary thrusts

Secondary thrusts subdivide the Acquadolce, the Ophiolitic and the Cretaceous Units into several subunits (Fig. 24).

Thrust in the Acquadolce Unit (AU)

In this unit, two subunits can be recognised: the Porticciolo (**PSU**) and the overlying Santa Filomena (**FSU**) Subunits, separated by a poorly exposed tectonic contact (cross-sections n. 2-6). The basal part of the **FSU** serpentinite is affected by pervasive spaced foliation parallel to the tectonic contact, probably due to shearing occurred between the two subunits. In the Mt. Fico area, veins of Fe-ores, linked to the Upper Miocene-Pliocene magmatism (5.3 Ma, according to Lippolt et al., 1995 and Laurenzi in Conticelli et al., 2001), cut through the tectonic surface, providing an upper chronological limit for this thrust movement.

Thrusts in the Ophiolitic Unit (OU)

Each subunit of **OU** is in contact with the underlying one through tectonic surfaces that we interpret as thrusts, except for the Bagnaia Subunit. In fact, the basal contact of the latter subunit cuts the thrusts between **VSU**/**TSU** and **TSU**/**SSU**, and can be considered as a detachment fault (see below). From bottom to top the recognised units and thrusts are:

i- The *Acquaviva Subunit* (**ASU)** is overthrust by **SSU** in the northern part of the eastern Elba (cross-sections n. 1-3), where it is exposed also in a tectonic window near Casa Novelli. It is overthrust by **TSU** in the southern part of the eastern Elba and in the central Elba, due to the progressive delamination of **SSU** south- and southwestwards, east of Mt. Orello (cross-sections n. 4-8). The contact **SSU/ASU** is well exposed only along the coast, in the southern side of Cala dei Mangani, where the Palombini Shales of **SSU** are overlain by the Calpionella Limestones of **VSU** (Plate 7g). Elsewhere the contact is badly exposed, and is recognisable in the field by the superposition of terms of two completely different successions (i.e. Basalts - Mt. Alpe Cherts - Nisportino Fm. - Calpionella Limestones of **SSU** on Serpentinites/Ophicalcites - Mt. Alpe Cherts - Palombini Shales of **ASU**. The contact **TSU/ASU**, is well-exposed along the road Rio Marina - Porto Azzurro (N of Fosso delle Maceratoie), where the serpentinites of **TSU** are in contact with the serpentinites of **ASU**. The contact is marked by a shear zone which is about ten metres thick. No age control is available.

ii- The *Mt. Serra Subunit* (**SSU)** is tectonically covered by **TSU** south of Rio nell'Elba (cross-sections n. 4, 5), and is exposed in a tectonic window north-west of Cima del Monte (see geological map), where it is also covered by **BSU** (see below). Northwards, it is covered by **VSU**, for the progressive delaminations of **TSU** (cross-sections n. 2, 3). The scattered and thin sheared slices of serpentinite cropping out along the contact possibly belong to the latter subunit. **SSU** is completely absent in central Elba (cross-sections n. 5, 6).

The contact **TSU/SSU**, generally badly exposed, juxtaposes different sedimentary terms of the underlying **SSU** and the serpentinites of **TSU,** strongly sheared near the contact. The contact **VSU/SSU** juxtaposes the sedimentary cover of the underlying **SSU** (mainly Calpionella Limestones) to the basalts and scattered slices of gabbros of the overlying **VSU**.

iii- The *Sassi Turchini Subunit* (**TSU)** is overlain by **VSU** (cross-sections n. 4-6), but this contact is never clearly exposed; in the tectonic window north-west of Cima del Monte (see geological mp), it is also covered by **BSU** (see below). The serpentinites of **TSU** are covered by gabbros, and only in a few localities by basalts of **VSU,** and they can be interpreted as the original basement of **VSU,** now tectonically decoupled by thrust movements, being the geometrical relationships similar to the original stratigraphic ones. Nature and age of this decoupling are however unknown.

The southernmost portion of this tectonic surface (south of the Cima del Monte Transfer Fault (**CTF**), has been successively reactivated, during the extensional regime, linked to the Casa Galletti Detachment Fault (**GDF**), which shows south-eastwards, movement (see below and Fig. 24)

iv- The *Volterraio Subunit* (**VSU)** is covered by two minor local subunits, the Magazzini Subunit (**MSU)** (cross-sections n. 4-5), and the Bagnaia Subunit (**BSU**; see below: Sin-intrusion detachment faults). The **MSU**/**VSU** thrust is marked by brecciated and intensely weathered basalts of **MSU** on Mt. Alpe Cherts and the Calpionella Limestones of **VSU**. Locally, along the contact, serpentinitic slices crop out.

Pre-intrusions detachment faults

Mt. Arco Detachment Fault (ADF) This tectonic surface separates the non-metamorphic rocks of **TN** from the underlying epimetamorphic rocks of **MU** (all cross-sections). It is recognisable only in very short segments at Mt. Arco, between Barbarossa and Terranera and north of the Norsi beach. Elsewere, **TN** and **MU** are separated by the Terranera high angle Normal Fault (**TNF**). At the regional scale, this detachment fault is well recognisable along the so-called Mid Tuscan Ridge (Apuan Alps - Mt. Pisano - Monticiano-Roccastrada Ridge - Mt. Leoni) and it is linked to the first extensional events, Serravallian-Tortonian in age, of the Apenninic chain (see Carmignani and Kligfield, 1990).

Sin-intrusion detachment faults

i- Casa Galletti Detachment Fault (GDF). It is exposed only north of Casa Galletti. This surface separates the basalts of **OU** from the overlying shear complex probably pertaining to **CU** (tectonic slices of serpentinites, gabbros, Palombini Shales and Calpionella Limestones). It ends towards north-east with an extensional lateral ramp (Casa Totano Transfer Fault, **TTF**, see below) which trends NW-SE, and that can also indicate a SE sense of sliding, along **GDF**.

ii- Mar dei Carpisi Detachment Fault (**MDF**). It crops out only along the western side of Mar dei Carpisi (cross-section n. 8), where **UO** overlies **PU**; immediately to the north it is cut by the Zuccale Fault (**ZDF**) (cross-sections n. 5, 6) This tectonic surface may be interpreted as the deeper branch of **GDF**.

iii- Fosso dell'Acqua Detachment Fault (**FDF**). This tectonic surface separates **BSU** from **VSU** to the north-east, and from the tectonic pile composed by **SSU-TSU-VSU**, which out in a tectonic window, to the south. The contact between **BSU** and **VSU** is characterised by a shear zone in which gabbro and serpentinite slices of **BSU** rest on the Mt. Alpe Cherts of **VSU.** Southwards, along and under the Volterraio road, the basalts and the Mt. Alpe Cherts of **BSU** rest on the basalts of **SSU**, the serpentinites of **TSU** and the gabbros and the basalts of **VSU**. This tectonic surface is marked by sheared slices of serpentinite, gabbro and basalt, and the formations of **BSU** are strongly laminated and pervasively folded. It is worth noting that the **FDF** cuts the thrust surfaces **TSU** on **SSU**, **VSU** on **TSU** and, probably, **MSU** on **VSU** (but the latter contact is covered by the Fosso dell'Acqua alluvial plain sediments). Evidently, its movement is younger that the previous thrust surfaces, and is probably linked to south-east trending detachments.

All the previous detachment surfaces may be interpreted as branches of the oldest detachments, related to the eastwards discharge caused by the uplift of the Mt. Capanne, the shallower **GDF** and **FDF**, and the deeper **MDF** (Fig. 33). (The gravitational emplacement of the central and eastern Elba nappe pile was previously suggested by Trevisan, 1950 and 1951, Barberi et al., 1969b, Pertusati et al., 1993, Daniel and Jolivet, 1995, Dini, 1997a and 1997b -which named the first detachment fault due to the Mt. Capanne uplift "Central Elba Fault", **CEF**- and Westerman et al. 1999; see below). To the same shifting episode can be possibly related the reactivation of the southern portion of the **VSU** on **TSU** thrust, and the Cima del Monte (**CTF**) and Casa Totano (**TTF**) Transfer Faults, which probably acted as extensional lateral ramps (see below). All these structures indicate a south-eastwards sliding movement preceding **ZDF**.

Post intrusions detachments

i- Zuccale Detachment Fault (**ZDF*).*** In central and eastern Elba the repetition of the tectonic pile which occurs in both sides of the N-S Valdana-Schiopparello alignment is the spectacular effect of a well documented detachment previously evidenced by Trevisan (1951, Fig. 17) and called "Zuccale Fault" by Keller and Pialli (1990) (cross-sections n. 3-6). **ZDF** is well exposed between Terranera Beach (Fig. 3) and Valdana, and on the eastern slope of Mt. Fabrello. On the hangingwall of this detachment fault are exposed all the units of the eastern Elba tectonic pile (Figs. 2, 24; cross-section n. 5), while **PU** constitutes the footwall. However, in the westernmost areas, near Fosso Valdana, **ZDF** rises at higher quotes and cuts the tectonic pile of central Elba, already structured before the granitoid intrusion. The latter suggestion is indicated by the fact that the thermometamorphic aureola is substantially preserved and continuous within the whole tectonic pile at least till the **ASU** in the Norsi area.

Dikes and magmatic bodies, intruding the footwall (La Serra-Porto Azzurro monzogranite and related dikes, 6.0-5.4 Ma, in **PU,** cross-sections n. 5, 6) and some of the hangingwall units (e.g. aplites in **UO**, cross-section n. 5, Portoferraio Porphyries and Capo Bianco Aplites, 8.5-7.8 Ma, in **EU** and **CU**, cross-sections 5, 6), are clearly cut by the Zuccale Fault. Therefore the Zuccale Fault post-dates these magmatic events.

In the type-outcrop of Terranera (Benvenuti et al., 2001) **ZDF** is marked by an up to ten metres-thick, foliated, polymictic cataclasite (see above: Zuccale cataclasite, c_1 in the map). The clasts of this cataclasite are often lined up along the foliation which appears to have been deformed by a later weak folding event. No syn-tectonic blastesis is associated to this foliation. The cataclastic horizon also includes metric to decametric tectonic slices of the metasiliciclastics and of the metacarbonatic-phyllitic successions of **AU**. These metacarbonates show a brittle behaviour, while the calcschist and phyllite levels show also boudinage, even at the sub-centimetric scale. The mylonitic nature of **ZDF** cataclastic horizon suggested by Pertusati et al. (1993), is in contrast with the previous observations. In fact our data point to a "cold" nature for the cataclastic horizon, which was originated after the intrusion of the La Serra-Porto Azzurro granitoid and the related dikes. The foliation of the breccia level seems to be the consequence of mechanical iso-orientation of the clasts, which possibly occurred in a fluid-rich environment. Several kinematic indicators (asymmetry of folds, intrafoliar "mantled" or faulted clasts, etc.) reveal a "top to NE" or a "top to SW" sense of shear. In the uppermost part of the Mt. Calamita Fm., in the Terranera area, some low-angle N250°-trending shear bands crosscut the ductile structures and also displace the aplitic dikes with a top to NE sense of movement. These brittle structures are sub-parallel, and probably they are linked to the overlying **ZDF**. While the north-westwards sense of tectonic movement is evident, local opposite sense of shear suggests a re-activation of this cataclastic horizon during the emplacement of the tectonic units. In any case, the separation of the eastern Elba tectonic pile from the central Elba one along an W/SW-E/NE trajectory seems reliable, as suggested also by the northeastwards dip of the fault surface, shown in the boreholes (cross-sections 4-6).

ZDF seems to show an east- to north-eastwards movement, connected to the uprise of the La Serra-Porto Azzurro intrusion, and is cut by the N-S-trending normal faults, along which 5.3 Ma mineralisations are hosted. Thus, its age seems to be well constrained: between 6 (La Serra-Porto Azzurro pluton older age) and 5.3 (mineralisations) Ma, that is the uppermost Messinian.

It is possible that a detachment surface, which could coincide with the eastern, sub-horizontal portion of **ZDF**, was linked to the Mt. Capanne uplift. Accordingly, **ZDF** underwent two sliding phases: i- the first (main) one caused by the uplift of the Mt. Capanne Pluton, but younger than movement of **CEF** (~6.7 Ma), and older of the intrusion of the La Serra-Porto Azzurro (6.0 Ma). This movement probably had an eastwards trajectory; ii- the second sliding phase, triggered by the uplift of the La Serra-Porto Azzurro stock, reactivated the eastern portion of the tectonic surface, causing a limited north-eastwards movement of the eastern part of the nappe pile. The previous interpretation could also explain the contradictory shear movements observed in the Zuccale Cataclasite, however, no field evidences are available.

Finally, **ZDF** has been affected by a weak folding event, which produced a mild undulation of the fault surface.

ii- Casa Unginotti Detachment Fault (**UDF**). The surface of this fault is not exposed, so we do not have kinematic indicators, but the geologic frame and the geometry of the contact, (cross-sections n. 1, 9) are consistent with a north - north-eastwards sliding movement. In fact, the strike and dip inferred by the intersection of the fault plane and the morphologic surface is about W/NW, NE 30.

On the hangingwall is exposed **CSU**, while **ASU**, is exposed on the footwall, to the west, and the underlying **GU**, to the east. This detachment fault, which caused a downwards movement of the upper portion of **SSU,** can be linked to the La Serra-Porto Azzurro stock uplift, as previously suggested for **ZDF**.

iii- Colle Reciso Detachment Fault (**RDF**). In the central Elba, on the western slope of Mt. Orello, the relationships between **OU** (**VSU**) and **EU** are inverted with respect to the eastern Elba: **EU** underlies **OU** (**VSU**) along the Colle Reciso Detachment Fault. This structure can be considered either as a backthrust or a detachment fault. In both cases, **RDF** has a westward movement which is opposite to that of **ZDF**. We prefer to consider this structure to be a detachment fault, for the lack of evident young compressive movements in the Elba Island (cross-sections n. 5, 6).

The fault surface is marked by a tectonic breccia (Colle Reciso Fault cataclasite, c_5) which includes clasts from the 8. 5-7.9 Ma old Capo Bianco Aplites. The latter observation suggests that **RDF** is younger than Late Miocene. Faulting may have occurred during or slightly before **ZDF** and might have triggered (as seen for **ZDF**) by the uplift of the La Serra-Porto Azzurro pluton.

Low-angle tectonic surfaces of complex interpretation

i- Valdana Fault (VCF). This low angle fault separates the Acquadolce Unit from the underlying Ortano Unit (**AU/UO**). Its surface is exposed on both the hangingwall (Ortano-Capo d'Arco area, Plate 1c) and on the footwall (Spiaggia del Lido-Norsi coast) of **ZDF** (cross-sections n. 4-6, 8). Because of the lack of penetrative foliations and of the overprint of skarn mineralisation, the age of the cataclasite related to this fault (Valdana cataclasite, c_2) is comprised between the timing of the ductile deformation of **AU** (19 Ma: Deino et al., 1992) and of the skarn formation, linked to the granitoid intrusion (6.0 Ma: Maineri et al., in prep.). This surface may have been active under different tectonic regimes: first, it acted as a thrust surface along which **AU** (previously affected by HP metamorphism) was emplaced onto the Tuscan Units and then it acquired the 19 Ma greenschist tectono-metamorphism. The occurrence of the "cold" Valdana Fault cataclasite (c_2) between **AU** and **UO** points to a re-activation of this tectonic surface at shallow levels, during an extensional event predating the thermometamorphism. The relationships between this surface and the skarn bodies are not completely clear, but the sharp basal contact of the skarns and the underlying **UO** suggests that the last movements of **VCF** occurred after the thermo-metasomatic events.

ii- Mt. Fico Fault (FCF). The tectonic contact between the Monticiano-Roccastrada Unit and the underlying Acquadolce Unit (**MU/AU)**, crops out between Rio Marina and Porto Azzurro, and in the Valdana area (cross-sections n. 2-6, 8). This low angle fault is well exposed in the Vigneria area, where the upper part of the serpentinite of **AU** is brecciated and includes metric tectonic slices and clasts of Rio Marina Fm. of **MU**. No kinematic indicators have been observed. The present superposition of the two Units is certainly younger than the greenschist metamorphism they underwent, given the evident foliations of the Rio Marina Fm. clasts, and the lack of penetrative foliation in the matrix of the tectonic breccia. Taking into account the overall tectonic evolution of the Tyrrhenian area, we suggest that this tectonic superposition could be the result of two tectonic events. First, the Ligurian-Piedmontese **AU** was thrust onto the Tuscan Units during or immediately after the tectono-metamorphic event. Successively, the early extensional events, possibly linked to the opening of the Corsica channel, produced west-vergent detachments within the tectonic stack, which caused the tectonic superposition of **MU** onto **AU**.

iii- San Felo Fault (**SCF**). This fault (well exposed along the Parata road and north-west of Cavo, all cross-sections) marks the superposition of the Ophiolitic Unit onto the Gràssera Unit (**OU/GU)**: everywhere the non-metamorphic Palombini Shales of **OU** lie on the anchimetamorphic varicoloured slates of the Cavo Fm. of **GU**. The anchimetamorphic nature of **GU** suggests that this Unit underwent tectonic burial (along a subduction zone?) and deformation before its emplacement onto **OU**. Therefore, the present superposition could be the product of a younger detachment.

High angle faults

In the studied area three high-angle fault systems were recognised. From the older to the younger they are: 1- NE-SW-trending normal faults; 2- NW-SE-trending transfer faults; 3- N-S-trending normal faults.

Systems 1- and 2- pre-date, and 3- post-dates, respectively, **ZDF**.

Transfer faults

Two main NW-SE trending structures cutting **VSU** can be interpreted as a pair of transfer faults:

i- Cima del Monte Transfer Fault (CTF). This left transfer fault (Fig. 24) constitutes the extensional lateral ramp of the tectonic surface which indents the **VSU/SSU** thrust, causing the southern portion of **VSU** to be advanced by 1.3 km south-eastwards with respect to the northern portion (see "Thrusts in the Ophiolitic Unit", iii-). The fault surface is not exposed. In its southern part, south of Cima del Monte, where the fault juxtaposes cherts and basalts, we measured a few tens of meso-faults which occur in close proximity to the main structure, but these minor fault-planes are smooth and show a very few striae (Fig. 22): thus, the sense of movement remains uncertain.

ii- Casa Totano Transfer Fault (**TTF**). This fault (Fig. 24), constitutes the extensional lateral ramp of the Casa Galletti Detachment Fault (**GDF**). It separates the flysch units (**CU** and **EU**) from the Ophiolitic Unit (**OU**). Because of the faulting, the first units advanced south-eastwards (probably for a few kilometres) with respect to **OU**. The fault surface is always covered, and no direction indicators were found.

As pointed out before (see "Sin-intrusion detachment faults"), this system of transfer faults and detachments, can be related to the first south-eastwards-directed gliding movements (**CEF**) due to the uplift of the Mt. Capanne pluton.

The previous two structures, cut the SW-NE-trending system of normal faults (see below).

High angle normal faults

As said above, an older and a younger system of normal faults can be recognised:

a- The ***older system*** includes four ENE-WSW trending normal faults (Fig. 24) located in the southern portion of **VSU** (south of **CTF**). These faults outline a WSW-ENE graben (Mt. Castello Graben, **MCG)** which shows an inverted morphology. This fault system occurred before the 5.8 Ma old shoshonitic dike (Conticelli et al., 2001) which intruded the gauge rocks of two of these faults: Mt. Castello, **MNF** (Figs. 23) and Acquacavalla **ANF** Faults. This fault system is cut by the transfer fault system (see above).

Other normal faults which show the same trend, occur in **OU**, and could be related to the same fault system. All the previous faults seem do not cross the basal contact of **OU** with the underlying **GU** (San Felo Fault: **SCF**).

Finally, in the Valdana zone a group of normal faults, which show a N-NE trend, cut the lower tectonic units (**UO** and **AU**) and are interrupted by **ZDF**, could pertain to this old system (Fig. 24, cross-section n 8).

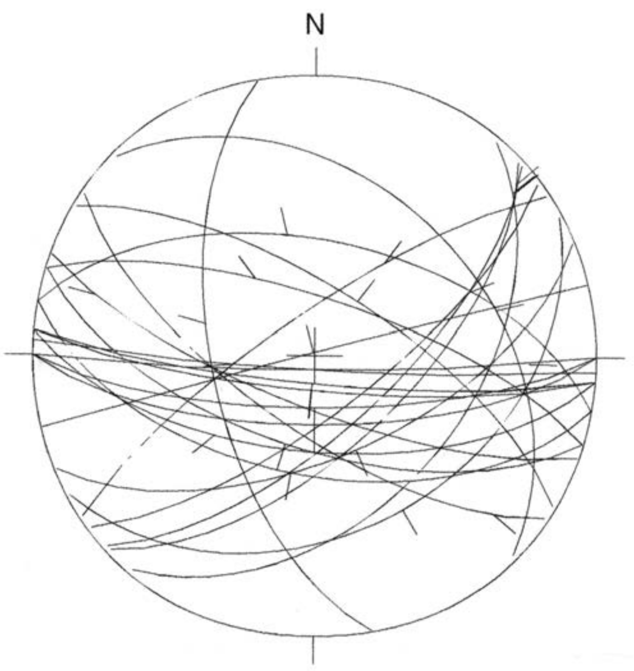

Fig. 22 - Schmidt stereonet (lower hemisphere) of the striae on minor fault surfaces (cyclographics) along the Cima del Monte Transfer Fault (**CTF**).

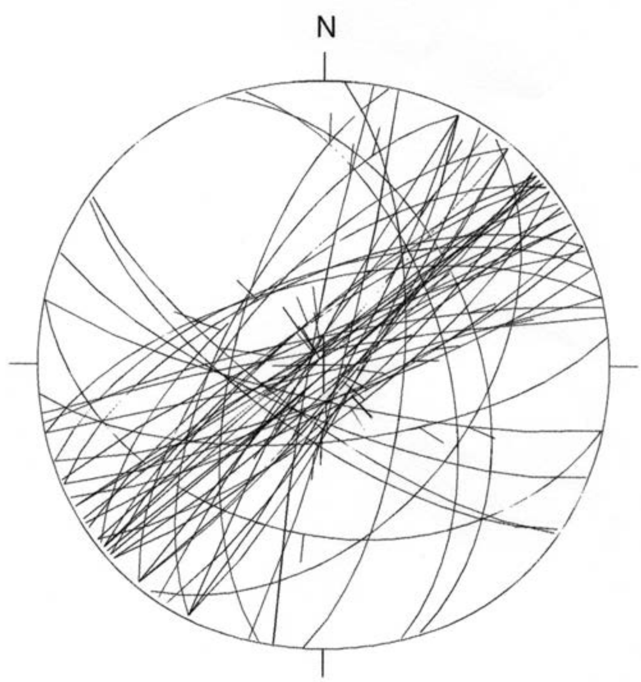

Fig 23 - Schmidt stereonet (lower hemisphere) of the striae on minor faults surfaces (cyclographics) along the Mt. Castello Normal Fault (**MNF**).

b- The ***younger system*** of high angle normal faults dissects both the whole tectonic pile and the Zuccale Fault itself. It shows a main N-S trend, which parallels the Piombino Channel. This fault system crosses all the previous tectonic structures, and possibly is responsible for the shape of the eastern coast of the Elba Island. Locally, along these younger faults, important hematite-rich ores occur (e.g. Terranera, Le Conche, Rio Marina-Valle Giove mines).

In eastern Elba this system includes three main faults (Fig. 24 and Tectonic scheme): the Terranera Fault (**TNF)** and the Santa Caterina Fault (**SNF**), which dip westwards (cross sections n. 3-5), and the Punta del Fiammingo Fault (**FNF**), which dip eastwards (cross section n. 2). **TNF** and **SNF** mark the western side of a horst culminating in the hills near the eastern coast of the Island; **FNF** marks the first step of the eastern side of the horst, which is at present buried in the Piombino Channel. In their northern and southern portions, **TNF** and **SNF** branch into a complex anastomosed system of faults: i- to the north they split up into a swarm of normal N/NE-S/SW trending faults, and they outline a system of grabens and horsts (Fosso del Giove-M.Calendozio and Mt. Gorgoli-Fosso Baccetti horsts, separating the Mt. Lecciolo-Cala del Telegrafo graben) which expose **TU** on the horsts and the overlying **GU** in the graben (cross-section n. 2). This swarm seems to end against an E-W-trending fault at Cavo (Cavo Fault, **CNF**), north of which only a N-S-trending fault exposed along the coast and west of Capo Castello (Cala dell'Alga Fault, **DNF,** cross-section n. 1) seems to mark their continuation. ii- to the south, they branch out in a complex network of minor NS- and EW-trending faults, all cutting **ZDF** (cross-section n. 6).

In central Elba this young fault system is characterised by a single westward dipping main fault (Mt. Orello Fault, **ONF**, Fig. 24, cross-sections n. 5, 6), which cuts the **OU** Subunits and lowers their western side, where the Flysch Units crop out. This fault probably continues northwards, where it is covered by Quaternary deposits and by the sea, and crops out again at Portoferraio (cross-section n. 7). West of this fault structure the Flysch Units are cut by some minor faults which do not show any clear trend. East of Mt. Orello, we suppose the existence of a buried NS-trending fault which, running along Fosso Valpiano, separates **OU** (to the east) from the Flysch Units (**EU**+**CU**) and cuts away **ZDF** which disappears north of Santo Stefano (cross-section n. 5).

THE TIMING OF THE TECTONIC AND MAGMATIC EVENTS

The tectonics of the Elba Island is the result of a complex sequence of events which affected both the Ligurian-Piedmontese, the Ligurian and the Tuscan Units. The most important constraints useful to reconstruct its tectonic evolution are:

1) The age of the magmatic events (aplites and porphyries, 8.5-7.2 Ma; Mt. Capanne monzogranite, 6.8 Ma on average; Mt. Castello shoshonite dike, 5.8 Ma; La Serra-Porto Azzurro monzogranite, 6.0-5.4 Ma) and their relationships with the deformational events.

2) The syn-/post-intrusion age of the low angle Zuccale Fault (**ZDF**) in eastern Elba which separates **PU** -already intruded by the aplites linked to the La Serra-Porto Azzurro monzogranite- from the overlying imbricate units (**UO** to **CU**);

Other pinning points are the following:

a- the thrusts between the Flysch Units (**CU** and **EU**), and most of their internal deformations predate the intrusion of the aplitic and porphyritic dikes and laccoliths (8.5-7.2 Ma) of the Mt. Capanne stock. These deformations are likely not older than Late Eocene (see the age of **EU**). During the acidic intrusions, the Flysch Units were on top or close to the Mt. Capanne pluton.

b- The main schistosity (related to the D_2 event) of the Acquadolce Unit is dated 19 Ma (Deino et al., 1992) thus excluding its possible genetic relationship with the Mt. Capanne intrusion, and indicating a Lower Miocene tectono-metamorphic event;

c- The structural features defined within the Elba metamorphic units stack suggest that their piling up occurred between the D_2 event of the Acquadolce Unit (19 Ma) and the La Serra-Porto Azzurro intrusion (5.1-5.4 Ma). Only a weak, later (syn-/post-Zuccale) folding affected the whole present tectonic stack including the Zuccale cataclasite;

d- In central Elba the tectonic superposition of the different structural units predates 1) and 2) (see above). In fact, in the Norsi-Spiaggia del Lido area the original thermometamorphic aureola of the La Serra-Porto Azzurro granitoid is continuous and well recognisable across the **PU** to **OU** (**ASU**) pile. Northwards, this assemblage is clearly cut by the Zuccale Detachment Fault;

e- The present tectonic superposition between the Flysch Units (**CU** and **EU**) and **OU** post-dates the intrusion of the dikes and porphyries (see point a) because the latter are cut by the thrust surface;

f- The sericitisation proces ("Eurite": 6.7 Ma in Maineri et al., in prep.), which affected the aplites and the porphyries of the basal portions of the Flysch Units, predates the la Serra-Porto Azzurro intrusion. Thus, this metasomatic event was produced by fluids deriving from the Mt. Capanne intrusion, and flowing along the basal detachment surface (**CEF**: Dini, 1997a,; 1997b) of the Flysch Units during their eastward gliding onto the units of central Elba (**EU/OU**);

g- The high-angle, NE-SW trending normal faults within **OU** predate its thrusting onto the underlying units. In fact, the shoshonitic dikes (5.8 Ma) intruded in this fault system probably do not cross the basal tectonic contact with **GU**;

h- The transfer faults produced only movements between the sub-units of the **OU** (e.g. the displacement of **VSU** with respect to the underlying sub-units);

i- The high-angle, N-S trending normal faults dissected the whole tectonic pile including the granitoid intrusions and the Zuccale cataclasite. The hematite-rich ores (e.g. Terranera, Rio Marina), about 5.3 Ma old (Lippolt et al. 1995, and Laurenzi in Conticelli et al., 2000), were emplaced through this fault system.

Taking into account the above pinning points, we the following tectonic and magmatic scenario for the evolution of the Elba Island.

PRE-MAGMATIC STAGES (> 8 Ma)

The oldest deformational event recognisable in the Elba Island affected the Tuscan Basement, as suggested by the pre-Alpine schistosity relics found within Paleozoic rocks (**PU** and **UO**) and which are regionally related to the Sudetic tectono-metamorphic event of the Hercynian Orogeny (Pandeli et al., 1994).

In the Ligurian Units, besides the oceanic tectonism and metamorphism of the ophiolites (e.g. ductile and brittle deformations; ophicalcites), the oldest compressional events are recorded by the folds and the thrusts that occur within **OU**. In the Flysch Units, the **CU** folds are younger than Campanian and their thrusting onto **EU** is not older than the Middle Eocene. The ophiolitic breccias in **EU** can be related to deformations of Eocene age. The relics of schistosity within the main foliation (S_2: 19 Ma, Deino et al., 1992) of

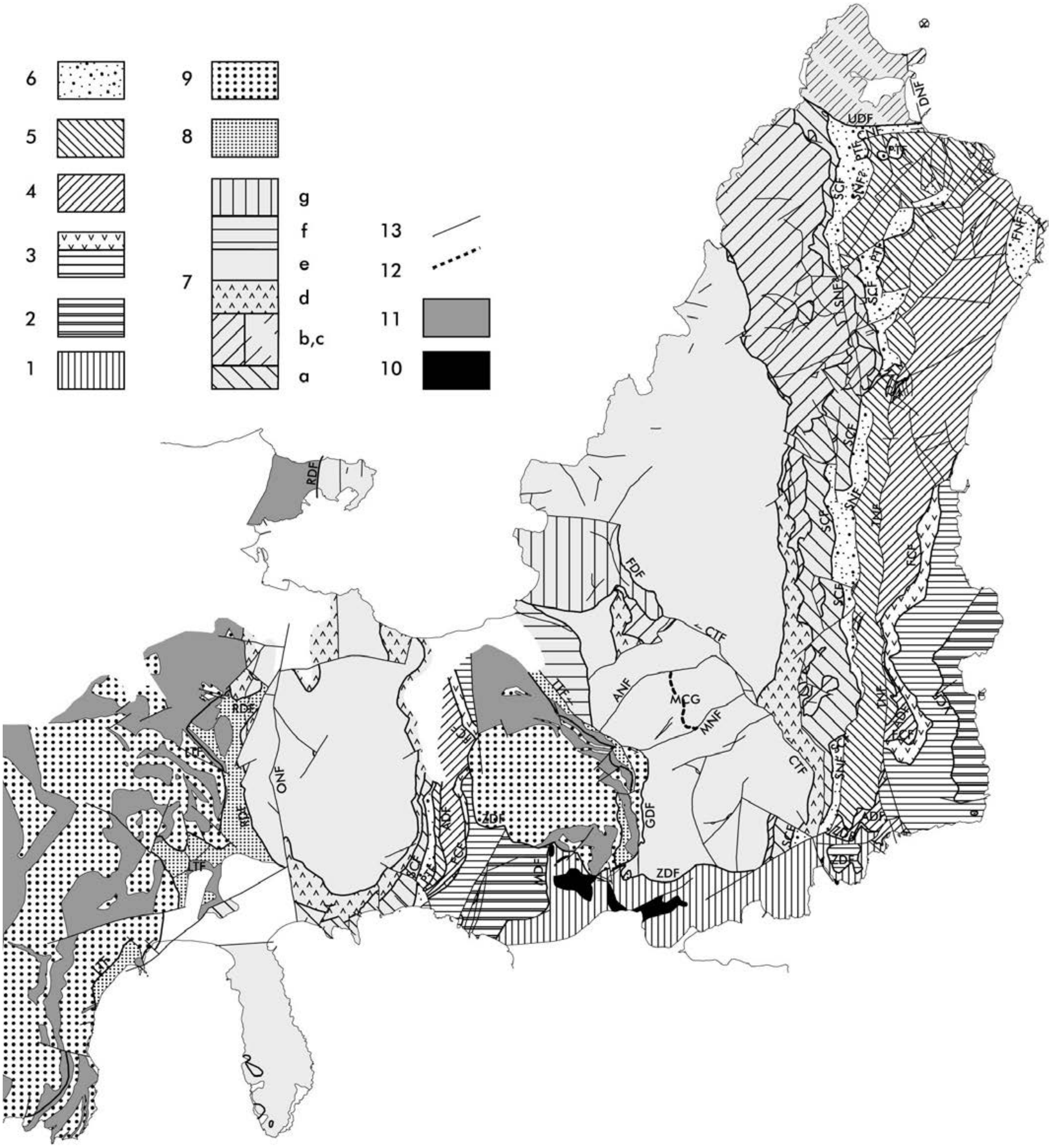

Fig. 24 - Structural map of central and eastern Elba Island. 1- **PU** -Porto Azzurro Unit (Tuscan Domain); 2- **UO** - Ortano U. (TD); 3- **AU** - Acquadolce Unit (a- **PSU** - Porticciolo Subunit; b- **FSU** - Santa Filomena S.) (Ligurian-Piedmontese Unit); 4- **MU** - Monticiano-Roccastrada U. (T.D.); 5- **TN** - Tuscan Nappe (T.D.); 6- **GU** - Gràssera U. (P.D.); 7- **OU** - Ophiolitic U. (a- **ASU** - Acquaviva S.; b- **SSU** - Monte Serra S.; c- **CSU** - Capo Vita S.; d- **TSU** - Sassi Turchini S.; e- **VSU** - Volterraio S.; f- **MSU** - Magazzini S. g- **BSU** - Bagnaia S.) (Ligurian Domain); 8- **EU** - Paleogene Flysch U. (L.D.); 9- **CU** - Cretaceous Flysch U. (L.D.), 10- La Serra - Porto Azzurro monzogranite; 11- Neogene aplites and porphyries; 12- Mt. Castello shoshonitic dike; 13- Faults.

LTF- Madonna della Lacona Thrust Fault **CU**/**EU**; **PTF**- La Parata Thrust Fault **GU**/**TN**; **ADF**- Mt. Arco Detachment Fault **TN**/**MU**; **GDF**- Casa Galletti Detachment Fault **EU**/**UO**; **ZDF**- Zuccale Detachment Fault All Units/**PU**; **UDF**- Casa Unginotti Detachment Fault **CSS**/**SSU** and **GU**; **RDF**- Colle Reciso Detachment Fault **VSU**/**EU**; **FDF**- Fosso dell'Acqua Detachment Fault **BSU**/**SSU**,**TSU** and **VSU**; **VCF**- Valdana Complex Fault **AU**/**UO**; **FCT**- Mt. Fico Complex Fault **MU**/**AU**; **SCF**- St. Felo Complex Fault **OU**/**GU**; **CTF**- Cima del Monte Transfer Fault; **TTF**- Casa Totano Transfer Fault; **MNF**- Monte Castello Normal Fault; **ANF**- Acquacavalla Creek Normal Fault; **TNF**- Terranera Normal Fault; **SNF**- St. Caterina Normal Fault; **ONF**; Mt. Orello Normal Fault; **CNF**- Cavo Normal Fault; **DNF**- Cala dell'Alga Normal Fault; **FNF**- Punta del Fiammingo Normal Fault; **MCG**- Mt. Castello graben.

the Ligurian-Piedmontese **AU** can be the product of a HP-LT metamorphic deformation which occurred during the Eocene events.

The onset of the collisional phase probably coincided with the above mentioned Middle-Late Eocene deformational events, when the piling up of the Ligurian Units and sub-Units was already completed. The deformational events in the Ligurian and Ligurian-Piedmontese units continued through part of the Early Miocene (Deino et al., 1992), and in part overlapped those occurring within the Tuscan Domain.

The shortening of the Tuscan Domain occurred during Late Oligocene-Late Miocene. According to some authors (Boccaletti et al., 1980, Carmignani and Kligfield, 1990) the main compressional orogenic event, dated at 27 Ma in the Apuan Alps (Kligfield et al., 1986) produced the ensialic shortening of the Tuscan Domain on top of which were already thrust the sub-Ligurian, Ligurian and Ligurian-Piedmontese Units. In the Elba stack this event is recorded by the east-facing isoclinal, syn-metamorphic folding which affected the metamorphic Tuscan Units (**PU**, **OU** and **MU**). The greenschist re-equilibration of the Ligurian-Piedmontese **AU** (D_2: 19 Ma) can be related to the same event which also produced the folding of the Tuscan Nappe and the D_2 deformation of the Gràssera Unit.

The refolding event of 10-12 Ma that Kligfield et al. (1986) recognised in the Apuan Alps has been interpreted by Carmignani and Kligfield (1990) as the result of the “stretching” of the tectonic pile by ductile extension and low-angle normal faults due to isostatic re-equilibration. A similar Adriatic-vergent refolding of the Tuscan Units (**PU**, **UO**, **MU**), and also of the Ligurian-Piedmontese **AU**, was also recognised in the Elba Island (e.g. Keller and Pialli, 1990; Elter and Pandeli, 2001), but we prefer to relate it to the latest pulse of the Apenninic shortening (see Fazzuoli et al., 1994; Jolivet et al, 1998).

The development of a sedimentary basin east of the Corsica Island and west of the Elba Island during the Burdigalian-Langhian (Bartole et al., 1991) and the intrusion of the Sisco lamproites in eastern Corsica (13.5-15 Ma in Serri et al., 1993), mark the beginning of the extension of the innermost part of the Apennine chain. It is likely that during Middle/Late Miocene the same extension regime affected the Elba nappe pile, mostly by detachment faults. This event modified the structure of the tectonic pile causing the intercalation of **AU** within the Tuscan Units (**UO** and **MU**), the emplacement of **TN** onto **MU** and the superposition of **OU** on top of **GU**. Thus, the main tectonic structure of central Elba (see the pile **PU**→**OU** in the Norsi-Spiaggia del Lido-Valdana area) was built. Following extensional stages occurred during late Tortonian-Quaternary time (see below).

SYN-MAGMATIC STAGE (8.2÷5.4 Ma)

In western Elba, the anatectic magmatic activity began during late Tortonian, while in eastern Elba it began at the boundary Messinian/Pliocene. The uplift of hot asthenosphere and the increase of the extension rate produced thinning and fracturing of the continental crust, and caused the genesis and the uplift of anatectic melts.

In chronological succession, the magmatic events of western Elba include: a) intrusion of aplitic and porphyritic dikes and laccoliths in the **OU** around Mt. Capanne and **CU**+**EU** (8.5÷7.2 Ma); b) intrusion of the Mt. Capanne granodioritic stock (6.8 Ma on average) and thermometamorphism of the surrounding **OU**; c) intrusion of the basic Orano dikes within the semi-plastic or just semi-brittle Mt. Capanne stock (6.8 Ma).

During the emplacement and the uplift of the Mt. Capanne monzogranite, part of its sedimentary cover (the Flysch Units **CU**+**EU**) was detached and slid towards central Elba (Trevisan, 1951). During this movement the circulation of metasomatic fluids within the basal detachment fault (**CEF** = Central Elba Fault of Dini, 1997a; 1997b) lead to the sericitisation of the overlying aplitic and porphyritic dikes (6.7-6.8 Ma) (Maineri et al, in prep.).

The successive intrusion event is recorded by the 5.8 Ma Mt. Castello shoshonitic dykes which intrude NE-SW trending high-angle, syn-/?pre-magmatic normal faults of **OU** in central and eastern Elba (**MCG**). The latter are the oldest high angle fault system recognisable in the Elba Island, and it is likely that the NW-SE transfer fault system which cuts them was connected to the uprise of the Mt. Capanne stock: in fact it constitutes the extensional lateral ramp system of **CTF** and **TTF**. During that time the eastern stack (except for the Flysch Units) was contiguous with that of the Norsi-Mt. Orello area.

About 6.0-5.4 Ma age, the La Serra-Porto Azzurro granitoid and its aplitic dyke swarm formed within the eastern Elba tectonic stack, causing a thermometamorphic overprint in the lower units (**PU**, **UO**, **AU** and **MU**), and local Fe-rich skarn bodies within **PU** (e.g. Mt. Calamita mines) and **AU** (e.g. Punta Cannelle, Ortano-Porticciolo and Santa Filomena-Torre di Rio skarns).

During or immediately later, the Zuccale Detachment Fault (**ZDF**) enucleated at the top of the La Serra-Porto Azzurro intrusion (as **CEF** at the top of the Mt. Capanne pluton) and allowed the east/north-east-vergent detachment of the easternmost part of the **UO**→**CU**+**EU** tectonic stack with respect to the underlying **PU**. Also the Colle Reciso Detachment Fault (**CDF**), which caused the superposition of **OU** onto the Flysch Units (**CU**+**EU**) toward the west, occurred in the same time. It probably induced a 20°-40° anticlockwise rotation of the Ophiolitic Unit cropping out west of Mt. Orello. Furthermore, another shallower detachment, likely linked with **ZDF**, is the Casa Ugonotti Detachment Fault (**UDF**) which is located nearby Cavo.

At the end of these events the present geometry of the Elba tectonic pile was finally completed, and was later affected by a final weak folding event.

POST-MAGMATIC STAGE (< 5.4 Ma)

The last tectonic event is recorded by the N-S trending normal faults which are well recognisable in central and eastern Elba, and in the Northern Tyrrhenian Sea (Tricardi and Zitellini, 1987).

This continuous system of high angle fault dissected the tectonic stack as a whole and locally originates horst structures (e.g. the Rio Marina - Mt. Calendozio Horst). The age of the hematite-rich ores (4-5.3 Ma), hosted within these structures, suggest that a short time interval occurred between the intrusion of the La Serra-Porto Azzurro monzogranite, the activation of the late detachments (e.g. the Zuccale Fault), and the final N-S-trending faulting. These observations are in agreement with the correspondent structures in the Northern Tyrrhenian Basin of Late Miocene-Early Pliocene age (Zitellini et al., 1986).

THE ELBA ISLAND AND THE GEODINAMIC EVOLUTION OF CORSICA-NORTHERN APENNINE OROGENIC SYSTEM.

Geodynamic framework

1) The convergence of Africa+Adria/Europe+Iberia began during Late Cretaceous (e.g.: Sestini et al, 1970; Abbate et al., 1980), and was probably oblique with respect to the continental margins (Abbate et al, 1986; Bortolotti et al 1990), i.e. it occurred in a transpressive regime (Marroni and Treves, 1998). The convergence of the previous continental masses resulted from multiple geodynamic factors: i- the opening of the North Atlantic Ocean, ii- the anticlockwise rotation of Africa and Adria, iii- the collision and the soldering of Adria with the Moesia-Rhodope Eurasian indenter (that started at the end of Jurassic), iv- the opening of the Mesogea and of the Bay of Biscay basins, v- the anticlockwise rotation of Iberia (see Abbate et al 1986, with references). These complex interactions caused south-north - southeast-northwest convergence, characterised also by meridian movements between the Ligurian and Tuscan Domains.

2) The subduction zone developed in the Western Tethys, was located near the Corsica-Sardinia continental margin, and had a westwards dip. Thus, the oceanic lithosphere merged below this continental margin, leaving to the west an extended trapped crust. The inspiring models are those of Treves (1984), Principi and Treves (1984), Abbate et al. (1986), Bortolotti et al., (1990), Keller and Coward (1996), Lahondère and Guerrot (1997), Jolivet et al. (1998), all with references. The previous interpretation is not shared by all scholars of the Northern Apennines-Corsica orogenic system. An alternative model (for the Northern Apennines, see Boccaletti et al., 1971; Boccaletti and Guazzone, 1974; Boccaletti et al. 1980; Hoogerduijn Strating and Van Wamel, 1989; Marroni and Pandolfi, 1996; for the Alpine Corsica see Warburton, 1986; Gibbons et al., 1986; Fournier et al. 1991; Malavielle et al., 1998) suggests that at first (Paleocene-Eocene), an eastwards dipping subduction zone formed near Corsica, thus causing a westwards vergence of the orogenic chain. Then (Oligocene?), an inversion of the subduction took place, with the new subduction plane plunging westwards, and all the tectonic units involved in the Alpine accretionary wedge acquired this new superimposed, Apenninic vergence. Recently, the occurrence of a real subduction was put into question by a transpression model (Marroni and Treves, 1998).

3) The orogenic phases which affected the Corsica-Elba Island-Tuscan Apennine system, are divided in two main periods (Figs. 25 and 26)

i- a pre-Burdigalian period, characterised by compressive events. Four main paleogeographic and paleogeodynamic domains are considered. From west to east they are: a) Corsica-Sardinia (Europe) continental margin (**CCM**); b) Western Ligurian trapped ocean crust basin (**TCB**); c) Eastern Ligurian ocean basin (**ELD**), in which trench (**Tr**) and accretionary wedge (**AW**), located at the boundary with the trapped crust, prograde eastwards; d) Tuscan (**TD**)-Umbrian (**UD**) (Adria) continental margin.

ii- a post-Burdigalian period when dominantly extensional tectonics then prograded eastwards.

4- The paleogeography for the Cretaceous time is based on the model proposed by Gardin et al. (1994; Fig. 27).

5- The geodynamic model for the Tertiary extensional events is in agreement with Coli et al. (1991) (Fig. 28), and partially to Carmignani et al. (1995), Bartole et al. (1991), Bartole (1995); Boccaletti et al. (1997).

6- The origin and the geodynamic implications of the Neogene-Quaternary magmatic activity are in agreement with the models of Peccerillo (1985); Beccaluva et al. (1991), Coli et al. (1991), Serri et al. (1991; 1993), Conticelli and Peccerillo (1992), Peccerillo (1993) and Innocenti et al. (1992).

Late Cretaceous-Early Paleocene (Fig. 29)

Corsica-Sardinia (Europe) continental margin (CCM). The production of siliciclastics from the Corsica continental margin begins during the Late Cretaceous (Principi and Treves 1984; Gardin et al. 1994 , Fig 27). These deposits, mainly turbiditic, formed large submarine fans on the oceanic trapped crust (see below), and on the thinned easternmost Corsica margin (Tralonca Flysch of the Santa Lucia Domain; Durand Delga, 1984, with references).

Western Ligurian trapped oceanic crust basin (TCB) Starting from Cenomanian, this basin was filled by turbiditic sediments, (Gare de Novella Sandstones, Gardin et al., 1994), and deposition continued and culminated during Campanian-?Maastrichtian/?Paleocene (Balagne Calcareous Flysch; Macinaggio Flysch; Elba Flysch) (Fig. 29).

Accretionary wedge (AW). During this period, an embryonal accretionary wedge composed of ocean crust slices pertaining to the Vara Supergroup formed (Abbate and Sagri, 1970). Some of the slices underwent HP-LT metamorphism (Ligurian-Piedmontese Units: e.g. “Schistes Lustrés”). Probably, the westernmost (internal) slices included the ophiolitic units of Elba Island, while the eastern (external) ones included the eastern units of the Vara Supergroup located in the Northern Apennines (eastern Liguria and Southern Tuscany).

Eastern Ligurian oceanic basin (ELD). The more external units of the accretionary wedge were delivering ophiolitic olistoliths and olistostromes into the embryonal trench, located immediately to the east of the trapped crust. The trench was filled by the westernmost Helminthoid flysches of Southern Tuscany (Monteverdi Marittimo Flysch pp.; Montaione Flysch). Instead, the easternmost Helminthoid flysches (Monteverdi Marittimo Flysch pp. and San Donato Flysch) covered an eastern portion of the Ligurian oceanic basin. More eastwards, near the Adria margin, the Sillano-St. Fiora Formations, including thick lenses of Pietraforte sandstones, deposited. The latter were turbidite deposits originated from the Austroalpine Domain (Fig. 29) which, travelling through the E-W trending Lombard Basin (Lombard Flysch), located on the western margin of the Adria passive margin, reached the Ligurian Basin. A narrow domain, located close to the western Tuscan (Adria) continental margin, or on its westernmost edge, hosted the basal formations of the Paleocene-Eocene Canetolo (Subligurian) succession.

Tuscan continental margin (TD). East of the Tethys Ocean, pelagic sedimentation continued on the Adria continental margin (clays, marls and calcareous turbidites of the “Scisti Policromi”).

Geodynamic remarks. The existence of a subduction zone during this period is matter of debate. The only evidence for a subduction zone is recorded by rare eclogitic rocks occurring in the Castagniccia-Cape Corse area (Corsica), dated at 90 Ma (Cervione, Castagniccia) by Maluski (1977, Ar^{39}/Ar^{40} on glaucofane), and at 83.8±4.9 Ma (Volpajola-Farinole Unit) by Lahondère and Guerrot (1998, Sa/Nd on noodles of jadeite; see also Lahondère, 1996 with references). Later on, only Middle-Late Eocene, HP-LT metamorphic rocks have been found (see later).

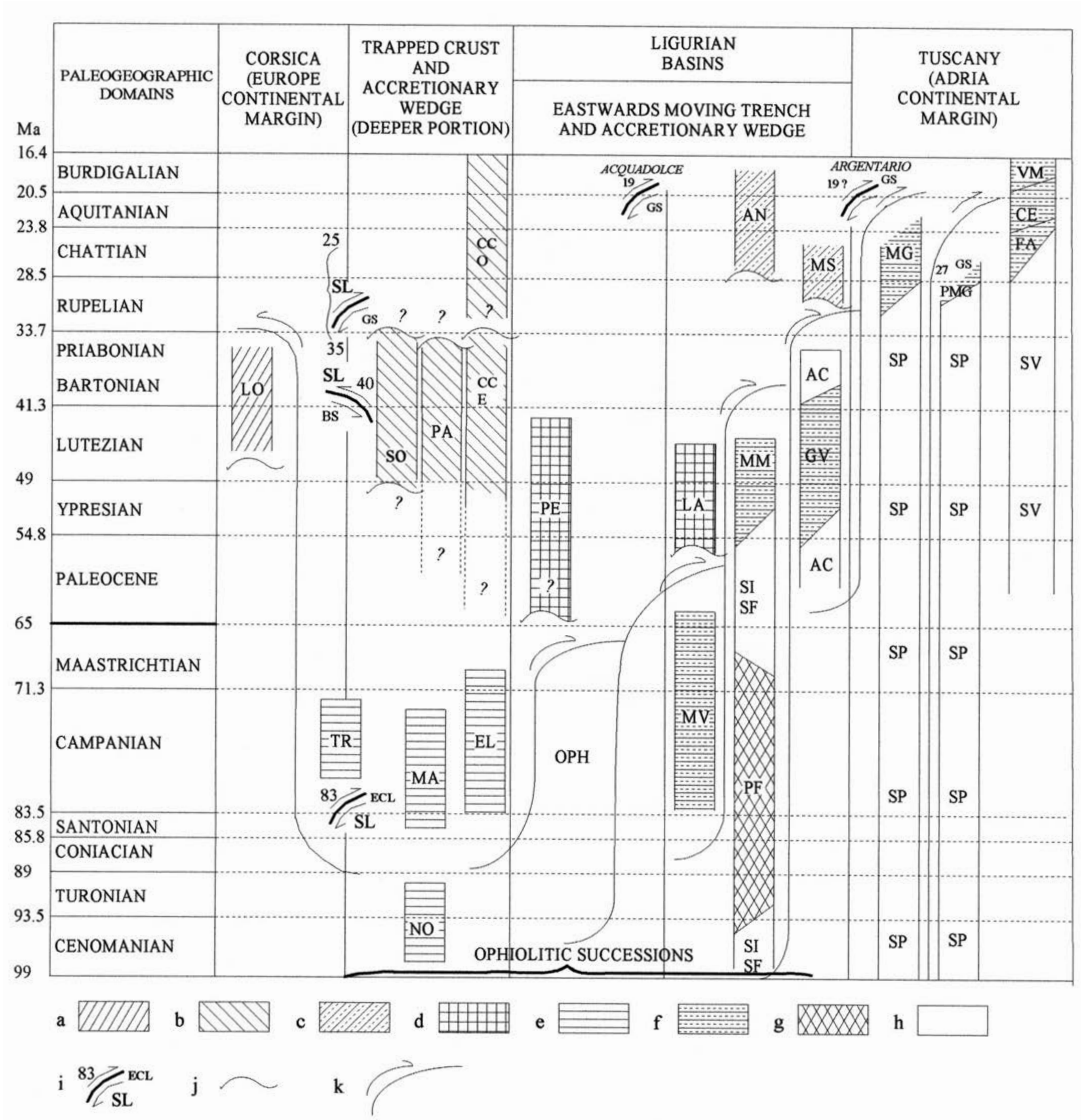

Fig. 25 - Late Cretaceous-Burdigalian events of the Corsica-Elba-Northern Apennines orogenic system. a- Corsica neoautochthon; b- Eocene deposits of the trapped crust and of the easternmost Corsica continental margin; c- Oligocene-Lower Miocene piggy-back deposits; d- Eocene piggy-back deposits; e- Cretaceous deposits of the trapped crust and of the easternmost Corsica continental margin; f- trench and abyssal plain turbidites; g- Cretaceous passive margin turbidites fed from the Insubria continental margin; h- hemipelagic basinal plain deposits; i- deformational and metamorphic events, with their radiometric ages and metamorphic facies: ECL- eclogites, BS- blueschists, GR- greenschists; J- unconformities or iatuses of sedimentation; K- phases of nappe piling. LO- Lozari Sandstones; SL- "Schistes Lustrés"; SO- Solaro Fm.; PA- Palasca Sandstones; CCO- Oligocene deposits of the Corsica Channel; CCE- Eocene deposits of the Corsica Channel; TR- Tralonca Flysch; NO- Gare de Novella Sandstones; MA- Balagne Calcareous Flysch and Macinaggio Sandstones; EL- Elba Cretaceous Flysch; PE- Paleocene-Eocene Elba Flysch; LA- Lanciaia Fm.; OPH- Vara Supergroup ophiolites; MV- Monteverdi Marittimo Flysch; MM- Monte Morello Fm.; SI- Sillano Fm.; SF- Santa Fiora Fm.; PF- "Pietraforte"; AC- Canétolo "Argille e Calcari"; GV- Groppo del Vescovo Fm.; AN- Antognola Fm.; MS- Monte Senario Fm.; MG- "Macigno"; PMG- "Pseudomacigno"; SP- "Scisti Policromi"; VM- Vicchio Marlstones; CE- Monte Cervarola Sandstones; FA- Monte Falterona Sandstones; SV- "Scisti Varicolori".

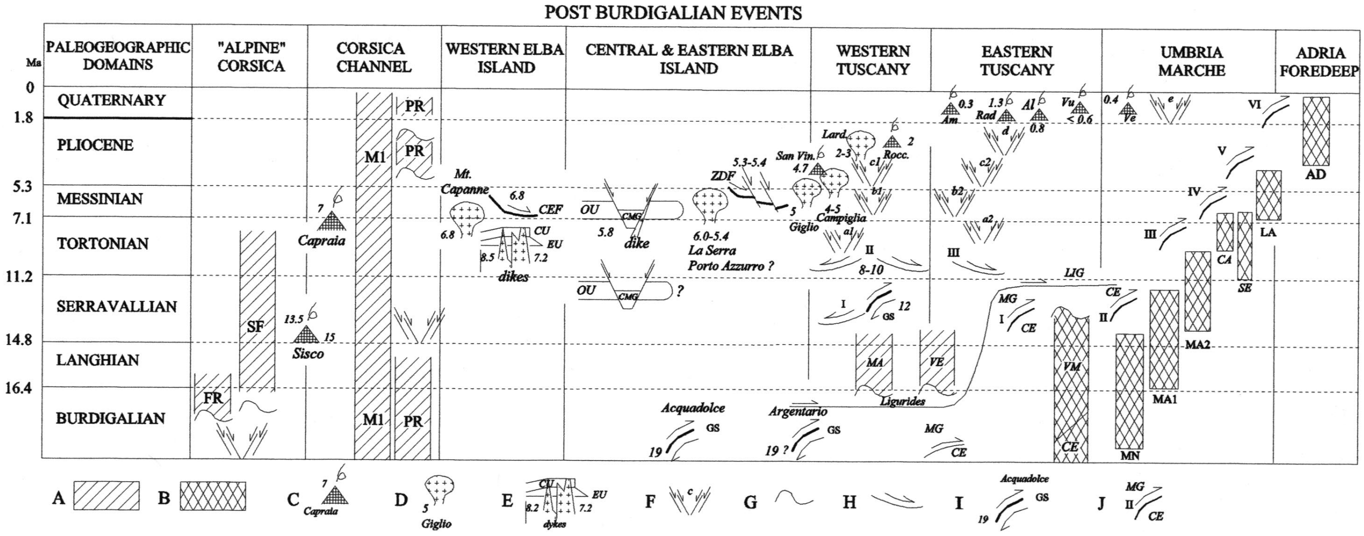

Fig. 26 - Post-Burdigalian events of the Corsica-Elba-Northern Apennines orogenic system. A- Miocene piggy-back deposits; B- foredeep deposits; C- effusive magmatic events; D- granitoid bodies, with their radiometric ages; E- dikes, with their radiometric ages; F- high-angle normal faults and extensional basins: Western Tuscany (a1- upper Tortonian-Messinian lacustrine lignitiferous basins; b1- Messinian evaporitic basins; c1- Lower-Middle Pliocene basins), Eastern Tuscany (a2- lacustrine Baccinello Basin, Tortonian-Early Messinian phase; b2- lacustrine Baccinello Basin, late Messinian phase; c2- Lower-Middle Pliocene Siena-Radicofani Basin; d- Villafranchian Valdarno Superiore Basin), Umbria (e- Quaternary Gubbio Basin); G- unconformities or hiatuses of sedimentation; H- low-angle detachment faults (I-III); I- compressional events and radiometric ages of the metamorphic signature, if present: GS- greenschists; L- main thrusts (I-VI).
FR- Francardo Basin deposits; SF- Saint Florent Basin deposits; M1- Martina 1 borehole; PR- Pianosa I. Ridge deposits; CEF- central Elba Detachment Fault; CU- Cretaceous Elba Flysch Unit; EU- Paleocene-Eocene Elba Flysch Unit; OU- Ophiolitic Unit; CMG- Cima del Monte graben; ZDF- Zuccale Detachment Fault; MA- Manciano Sandstones; VE- La Verna Fm.; MG- "Macigno"; CE- Monte Cervarola Sandstones; VM- Vicchio Marlstones; MN- Monte Nero Sandstones (the more internal portion of the Marnoso-arenacea); MA1- Internal "Marnoso-arenacea"; MA2- External "Marnoso-arenacea"; CA- Camerino Basin deposits; SE- Serraspinosa Basin deposits; LA- Laga Fm.; AD- Adriatic Basin deposits.
S. Vin- San Vincenzo; Lard.- Larderello; Rocc.- Roccastrada; Am.- Mt. Amiata; Rad.- Radicofani; Al.- Torre Alfina; Vu. Monti Vulsini; Ve- San Venanzo.

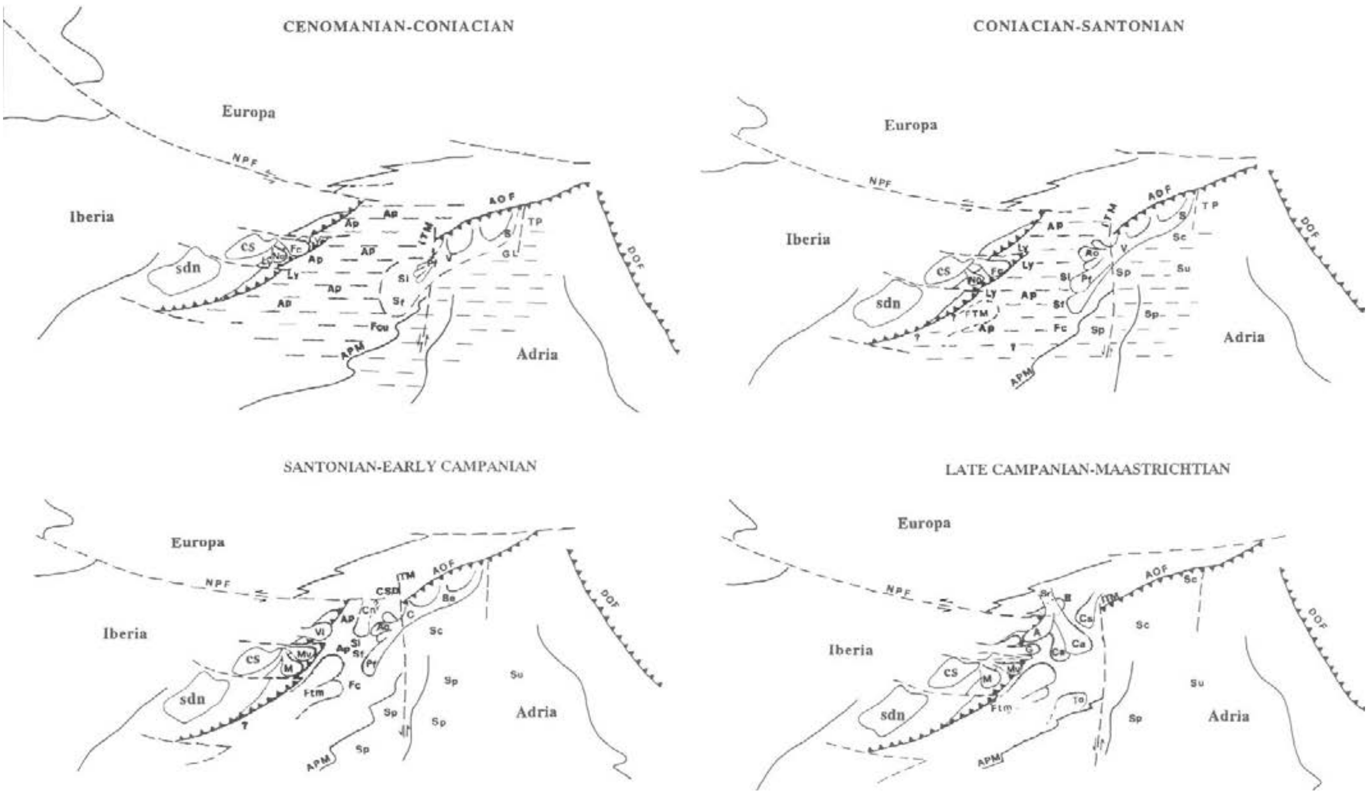

Fig 27 - The Late Cretaceous evolution of the turbidite sedimentation of the Ligurian Domain (after Gardin et al., 1994). cs- Corsica; sdn- Sardinia; NPF-North Pyrenees Fault; AOF- Alpine orogenic front; ITM- Insubric transcurrent margin (Paleo-Canavese Line?); APM- Adria passive margin; GL- Giudicarie line; TP- Trento plateau; DOF- Dinaric orogenic front; Ly- "Lydiennes"; No- Novella Sandstones; Fc- Balagne calcareous flysch; Ap- Palombini Shales; Si-Sillano Fm.; Sf- Santa Fiora Fm.; Fcu- Fosso Cupo Fm.; Pf- "Pietraforte"; V- Varesotto Flysch, S- Sarnico Flysch; Ftm- Helminthoid Flysch of Southern Tuscany (Monteverdi Marittimo Fm. Auctt.); Ao- Ostia (Scabbiazza) Sandstones; Sp- "Scisti Policromi" (Tuscany "Scaglia"); Sc- Lombardia "Scaglia"; Su- Umbria "Scaglia"; M- Macinaggio and Elba flysches; Mv- Mt. Venere Flysch; Vl- Val Lavagna Shales; Cn- Casanova Sandstones; CSD- Salti del Diavolo Conglomerates; C- Coldrerio Flysch; Be- Bergamo Flysch; G- Mt. Gottero Sandstones; A- Mt. Antola Flysch; Sr- San Remo Flysch; B- Bordighera Sandstones; Ca- Mt. Caio Flysch. Cs- Mt. Cassio Flysch; To- Tolfa Fm.

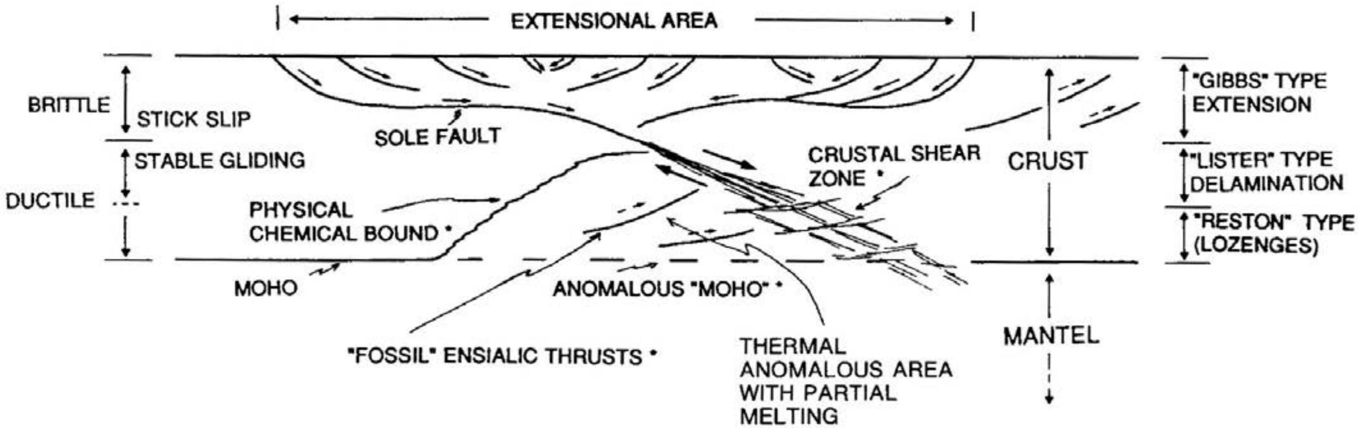

Fig. 28 - Delamination model proposed by Coli el al. (1991a).

The siliciclastic input (Fig. 29) coming from the uplifted Corsica Massif during Campanian, is consistent with the hypothesis of a subduction zone located beneath the Corsica margin. However, the lack of a coeval magmatic arc could not support the previous hypothesis. In order to justifie the presence of a westward dipping subduction during this period, Abbate et al. (1980) and Abbate and Sagri (1982), were obliged to suppose that the subduction surface jumped more than once before stabilising. Treves (1984) and Principi and Treves (1984) hypothesised an extremely low rate for the convergence. Alternatively, Marroni and Treves (1998) proposed that the Upper Cretaceous-Lower Tertiary movement of the Iberia Plate relative to Adria Plate was prevalently transcurrent, thus without the formation of an active subduction zone.

Even though the problem is still matter of debate, we support the model of Treves (1984) and Principi and Treves (1984), which envisages a single subduction zone, plunging westwards, under a wide trapped crust and the Corsica continental block. Given the lack of arc magmatism, the subducted oceanic slab could not have been (at least until Oligocene) longer than about one hundred kilometres. Only a very slow convergence rate (about 0.25 cm/year) or/and pauses of the subduction processes can help explaining the latter model. The convergence rate could have been low because of the oblique convergence (Bortolotti et al., 1990, with bibl.), caused by a combination of the northwards movement of Adria (solidary with the Western Tethys ocean basin) and the eastward movement of Iberia (with an anticlockwise rotation component). An oblique subduction could also help to explain a decrease of the dip of the subduction surface, along the E-W transect Corsica-Elba-Southern Tuscany we deal with, and defer the beginning of the arc magmatism. In the inner part of the embryonal ac-

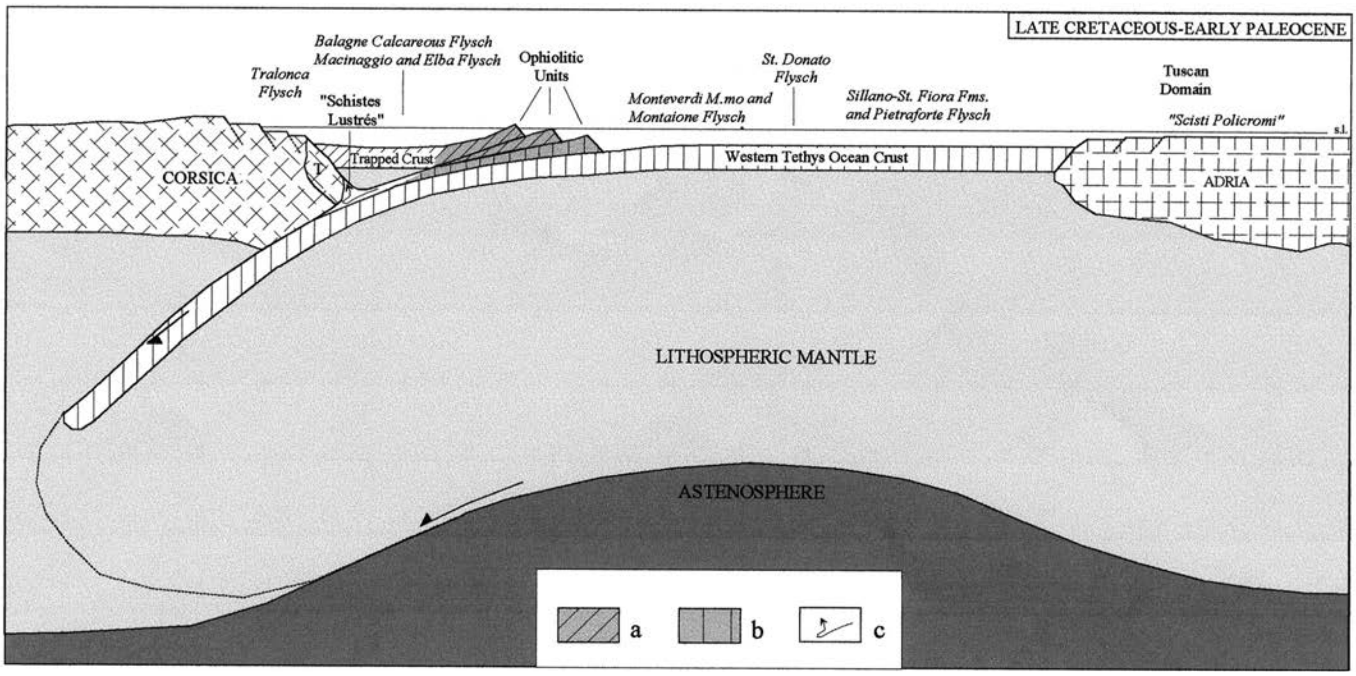

Fig. 29 - Schematic cross-section of the orogenic system Corsica-Northern Apennines during Late Cretaceous-Early Paleocene times.T- Tenda Massif; a- Upper portion of the accretionary wedge (**AW**) formed by trapper crust material; b- Lower portion of **AW** formed by ocean crust; c- Upwards flow of the deepest portions of AW. For explanation, see text.
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.

cretionary wedge (below the trapped crust and at the contact with the Corsica continental crust) and along the subducting ocean crust, high pressure parageneses (up to eclogites) could have formed both in the oceanic and, possibly, in the continental margin units (e.g., Tenda Massif, Corsica) (Fig. 29).

Late Paleocene-Early Eocene (Fig 30)

Corsica (European) continental margin (CCM). At the end of this period, on the portion of the passive (submerged) continental margin close to **TCB**, the deposition of siliciclastic sediments began (Lozari and Solaro Fms.). The western border of the Corsica Massif began to subside, due to eastwards progradation of the Ebro Basin.

Western Ligurian trapped oceanic crust basin (TCB). On the western border of **TBC**, the Palasca Sandstones were deposited, and also eastwards (the future location of the Pianosa Ridge and the Corsica Channel: Martina I borehole, Ministero dell'Industria data, AGIP 1975), the deposition of siliciclastic sediments began (see Lazzarotto et al., 1995).

Accretionary wedge (AW). In its more internal portion, **AW** was formed by the ophiolitic tectonic slices of the Vara Supergroup. During Early to Late Paleocene the Monteverdi Marittimo Helminthoid Unit underthrust westwards the already deformed ophiolitic slices. Successively, from Late Paleocene/Early Eocene to Middle Eocene, piggy back basins formed on these deformed units and were filled by the Lanciaia Fm. (including ophiolitic olistoliths and olistostromes) and the Paleogene Elba Flysch.

Eastern Ligurian Domain (ELD) and Trench (Tr). From the Early Paleocene to the Early Eocene in **Tr** only the more internal portion of the Sillano Fm. (with some rare ophiolitic and carbonatic olistoliths and olistostromes) deposited. In the eastern portion of the ocean (**ELD**), not yet involved in the subduction, was depositing the more external portion of the Sillano Fm. From the Early/Middle Eocene, **Tr** migrated eastwards collecting sediments of the Monte Morello (Helminthoid) Fm. and its ophiolitic and carbonatic olistoliths and olistostromes. During this time, east of the Sillano and Mt. Morello Fms. sedimentation area, the Canetolo succession also deposited ("Argille e Calcari" Fm.), probably on both **ELD** and **TD.**

Tuscan (TD) and Umbrian (UD) Domains. In the Tuscan Domain the sedimentation of pelagites continued, ("Scisti Policromi" to the west, and the "Scisti Varicolori" to the east). In the Umbrian pelagic Domain, the calcareous-marly sedimentation of the "Scaglia Rossa" took place.

Geodynamic remarks. After subduction, the oceanic slab reached the upper limit of the asthenosphere and the overhanging European lithospheric mantle begins to be anomalised by fluids upwelling from the subducting oceanic crust. From the deepest portion of the accretionary prism, HP-LT metamorphic rocks (mostly deep sea oceanic sediments with some ophiolitic masses and offscraped slices of the European basement) began to move upwards and underwent further ductile deformations (Principi and Treves, 1984; Jolivet et al., 1998; Bortolotti et al., 2001b).

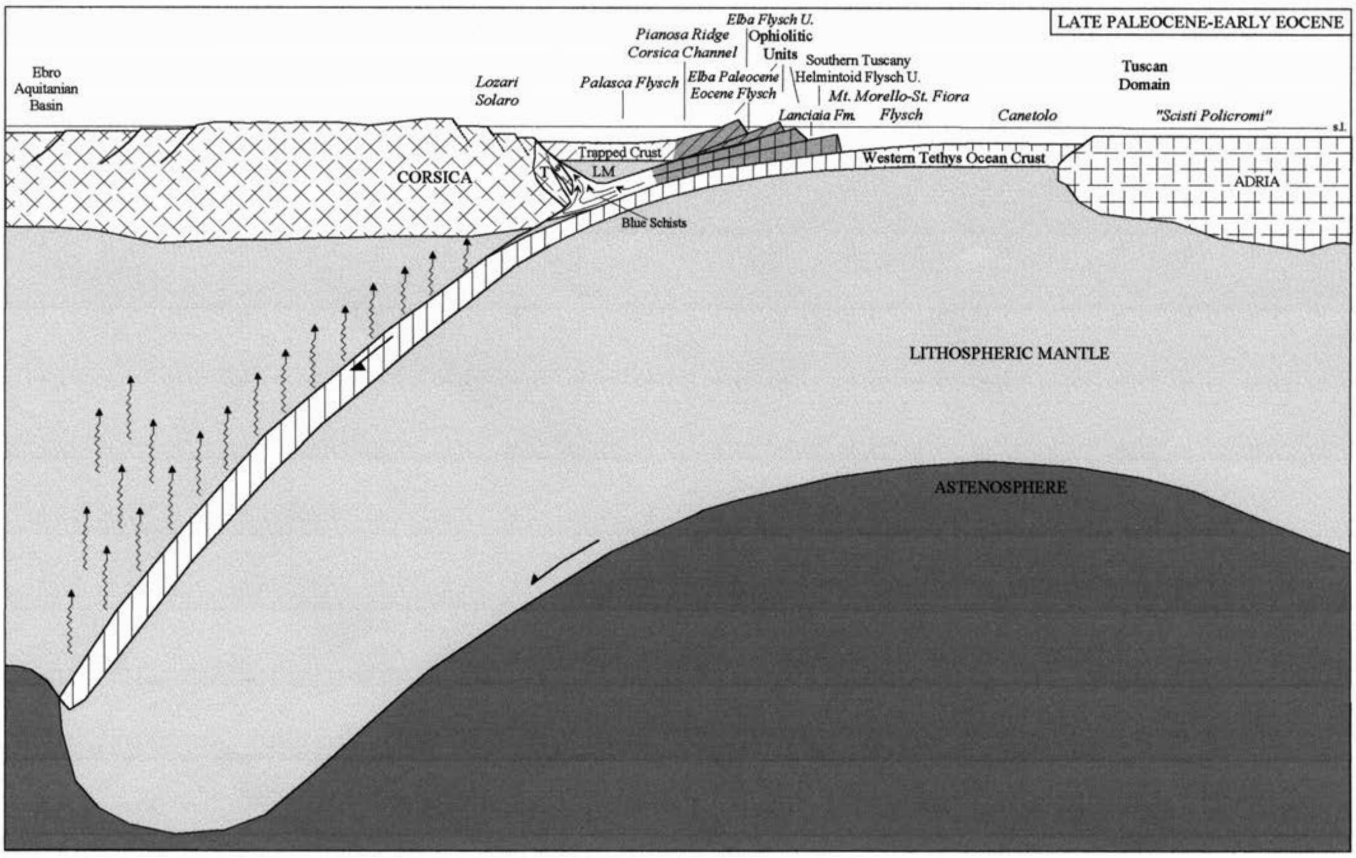

Fig. 30 - Schematic cross-section of the orogenic system Corsica-Northern Apennines during Late Paleocene-Early Eocene times. T- Tenda Massif; S- Serra di Pigno slice; Zigzag arrows- Path of the hydrating fluids rising from the subducting slab. For the other symbols see Fig. 29. For explanation, see text.

Late Eocene/Oligocene-Early Miocene (Fig. 31)

Corsica Continental margin (CCM). Since the end of the Eocene the eastern margin of the Corsica Massif became part of the active orogenic Northern Apennines system, together with the western continental margin of Adria (Tuscany). During this period, a continent-continent collision progressively occurred. Consequently, the Ligurian oceanic basement was completely underthrust below the accretionary wedge and, afterwards, below the Corsica continental margin; **TD** was then included in **AW**.

The eastern Corsica margin was overthrust by the Ligurian nappes (the old trapped crust), by the “Schistes Lustrés” slices, and by the Corsica continental margin slabs (eg. Tenda Massif, Serra di Pigno). The latter were passively exhumed by the upward flow of the “Schistes Lustrés”. This west vergent backthrusting formed the “Alpine Corsica” orogenic belt .

Accretionary Wedge (AW). During Late Eocene, the “Schistes Lustrés” and the outernmost part of the Corsica continental margin suffered an Alpine-vergent HP-LT (Blueschist facies) tectonometamorphism testified by radiometric data (Volpajola-Farinole Unit: 40 Ma, Ar^{39}/Ar^{40} on phengites in eclogites, Lahondère, 1996; “Schistes Lustrés of Castagniccia, Cervione: 40 Ma, Ar^{39}/Ar^{40}, on phengites, Maluski, 1977; metaophiolites of Inzecca Zone: 43.7±2 Ma, zircon fission tracks on plagiogranites, Carpena et al, 1979; eastern border of Tenda Massif: 40.8±2 Ma, apatite fission tracks on orthogneiss and 39±2 Ma apatite fission tracks on granodiorites, Carpena et al., 1979). From the latemost Eocene to Early Miocene, the Ligurian accretionary wedge was underthrust by the western margin of the Tuscan continental crust. The Tuscan lithosphere was probably cut into imbricate slices which formed embryonal ensialic underthrusting units (Boccaletti et al., 1980). The westernmost of these slices probably corresponds to the Elba - Punta Bianca basement; below which the Apuan Alps (including the kyanite-bearing Massa Unit) - Monticiano-Roccastrada metamorphic ridge was already underthrust. Part of the sedimentary cover of **TD** (Tuscan Nappe) was detached from its basement and then accreted at the base of the Ligurian thrust pile, probably along a very low angle thrust crosscutting the older ones (Fig. 31). In the deepest part of **AW**, the “Schistes Lustrés” comprising their eastern portion (the “Calcschists with ophiolites” of Principi, 1994) were firstly squeezed upwards and eastwards (like a toothpaste) and underwent ductile deformations (greenschist metamorphic facies; Maluski, 1977;

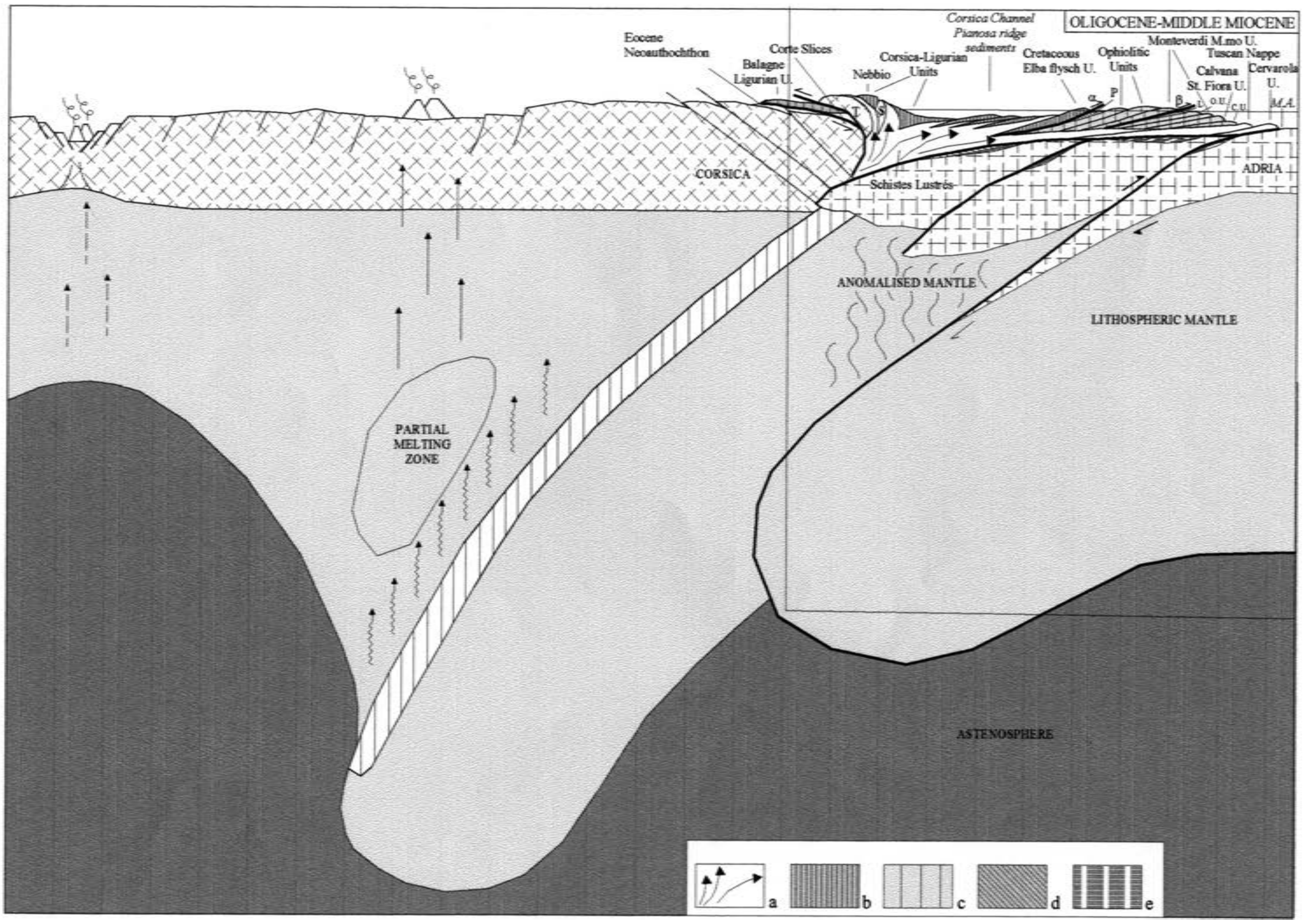

Fig. 31 - Schematic section of the orogenic system Corsica-Northern Apennines during Oligocene-Early Miocene times.
a- “Schistes Lustrés” and Calcschists with ophiolites (ductile metamorphic rocks of the deep portion of AW: AU and GU in central and eastern Elba) and their exhumation (upwards and eastwards) trajectories; b- Corsica Ligurides and Internal Ligurides; c- External Ligurides and epi-Ligurides; d- metamorphic Tuscan Unit; e- metamorphic Umbrian Unit. T- Tenda Massif; S- Serra di Pigno slice; P- Paleogene Elba flysch Unit; L- Lanciaia Fm.; O.U.- Ophiolitic Unit; C.U.- Canétolo Complex. α- Cretaceous Elba Flysch onto Paleogene Elba Flysch; β- Monteverdi Marittimo Unit (internal portion) onto the Lanciaia Fm. 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: The area outlined is shown in Fig 32. For explanation, see text.

Jourdan, 1988); successively, they suffered only brittle thrust movements (see Figs 32 and 33). During their exhumation, the “Schistes Lustrés” pierced the trapped crust and were carried, in part onto the eastern margin of Corsica (Balagne, St. Florent, Macinaggio and Pineto-Nebbio) and in part (the “Calcschists with ophiolites”) onto the western margin of Tuscany. In fact, during the Early Miocene (19 Ma, Deino et al., 1992), some buried slices of this ductile metamorphic rock unit were pushed eastwards between the Ligurian tectonic pile and the Tuscan basement (Gràssera Unit in Elba I., between **TN** and **OU**), and between different Tuscan Units (Acquadolce Unit in Elba I., between **UO** and **MU**). During the same time the “Calcschists with ophiolites” were probably emplaced in Southern Tuscany (Argentario Promontory, Roselle close Grosseto) onto the Mesozoic Tuscan succession and basement, constituting the easternmost spurs of the Ligurian-Piedmontese units.

Furthermore, during the same period, the old Ligurian accretionary wedge underwent new tectonic deformations linked to the activation of out of sequence thrusts. For example, the Cretaceous Flysch Unit was thrust onto the sediments of the piggy back basin formed at its front (**CU** onto **EU** in Elba I.; Podere Taucci Fm. onto Lanciaia Fm. in the Larderello area, Bertini et al., 2000).

In the new piggy back basins that formed on **AU**, marls and sands were depositing: they are the siliciclastic rocks in the Pianosa Ridge area (Martina I borehole, Ministero dell’Industria data, AGIP 1975), the Ranzano-Antognola succession, the Petrignacola and Aveto Fms. in Emilia, and the Mt. Senario Fm. in Tuscany.

Tuscan (TD) and Umbrian (UD) Domains and Trench (**Tr**). The trench was ensialic (= foredeep) and, up to the beginning of Miocene, was infilled by the Macigno sandstones. During Early Miocene, most of **TD** underthrust beneath the accretionary wedge and the depocenter of the trench migrated slightly eastwards, where it started collecting the pelitic-arenaceous Mt. Cervarola Sandstones. Eastwards, in **UD**, the pelagic marly sedimentation continued (“Bisciaro” Fm.) up to Burdigalian, when the siliclastic turbidite sedimentation began (Mt. Nero Sandstones) because of the eastwards shift of the foredeep depocenter due to the underthrust of most of the Mt. Cervarola basin. At the top of the easternmost portion of the Mt. Cervarola basin (not yet underthrust), a slope marly-siliceous sedimentation took place (Vicchio Marlstones pp.).

Geodynamic remarks. During this time interval, the oceanic subduction was replaced by ensialic subduction. At the onset, this process produced two main thrust surfaces plunging westwards within the Tuscan Domain. While this system of imbricate slabs cut the continental crust, at greater dept, the crust and the lithospheric mantle were decoupled, and the latter was moving independently beneath the continental margin of Corsica. Only at the end of this period, the subduction surface probably jumped eastwards (as also suggested by the eastward migration of the magmatism) and was followed by the underthrusting of the Umbrian lithosphere below the Tuscan one.

When the head of the subducted oceanic slab reached the asthenosphere, a calcalkaline magmatic activity started on the western side of the Corsica Massif. Westwards, the asthenospheric uplift caused the opening of the Ligurian-Balearic back arc basin.

Burdigalian pp.-early Messinian (Figs. 32)

Corsica-Sardinia (Europe) continental margin (CCM). At the end of the Burdigalian, the continental margin of Corsica and the overlying “Alpine Corsica” nappes underwent extensional tectonics recorded by the marine ingression followed by the deposition of the clastic sediments of Francardo (Ferrandini and Laye-Pilot, 1992), St. Florent (Ferrandini et al., 1996) and Aleria plain (Orzag-Sperberg, 1978, with references; Ferrandini et al., 1996, with references).

Corsica channel (CC). During the Burdigalian, an extensional basin, filled by clastic sediments, formed in the internal side of the Oligocene-Early Miocene accretionary wedge (Martina 1 borehole, Marina del Marchese Fm. in the Pianosa ridge). At the beginning of the Serravallian, the first magmatic event registered in the Tyrrhenian area occurred near Sisco, on the eastern coast of Corsica, and at the Tortonian-Messinian boundary, the volcanic activity reached the Capraia Island.

Elba Island (EI). During this period, the first extensive detachment faults caused the sliding of the tectonic pre-Burdigalian stack **MU** - **TN** - **GU** - **OU** - **CU** - **EU** onto **AU**. (see later). The lack of Miocene sediments in the Elba Island suggests that the compressional events probably caused the emersion of the Island. During Late Miocene (Tortonian) the Island was affected by a phase of block tectonics, during which the first system of high angle normal faults (NE-SW trending **MCG**) and the Corsica Channel basin were formed.

Tuscan (TD) and Umbrian(UD) Domains and Trench (Tr). During the Burdigalian-Serravallian times, the Mt. Cervarola basin was completely underthust below the Tuscan Nappe the huge siliciclastic sedimentation in the Umbrian foredeep continued more to the east. (i.e. Marnoso Arenacea). The shifting of the Apenninic foredeep within the Umbria-Marche Domain can be related to further phases of the underthrusting of the Umbria-Marche lithosphere. On **AW,** platform to slope, marly-bioclastic deposits occurred in piggy back basins (e.g. Vicchio Marlstones pp., Bismantova Fm., Manciano Sandstones and St. Marino Fm.

Geodynamic remarks. For the Middle-Late Miocene period, we hypothesise a progressive deepening and back-retreating (eastwards) of the subduction surface, as shown in Fig 32. During stage A- occurred the more internal Tyrrhenian magmatic phase (Sisco); successively (stages B and C) the subcontinental mantle below the Tyrrhenian Sea and Tuscany (Adria continental margin) underwent a strong anomalisation, and a second magmatic phase, both mantellic (Capraia) and anatectic (Elba) took place. Contemporaneously, the asthenospheric mantle rose, and a phase of extensional tectonics began in the internal zones of the Apenninic chain, between Corsica and Southern Tuscany. The mantle uplift, together with the isostatic uplift of the imbricate slices of Adria (Boccaletti et al., 1980) triggered a crustal delamination process (and its conjugate high angle normal faults), which master fault developed in the eastern portion of the Corsica Massif. The detachment surface reached the Moho discontinuity under the Adria continental margin. According to the previous hypothesis, the North Tyrrhenian magmatism, characterised by a supra-subduction signature (Peccerillo et al., 1988; Coli et al., 1991a; 1991b; Innocenti et al., 1992; Serri et al., 1993; Peccerillo et al., 2000), could be the product of ensialic subduction.

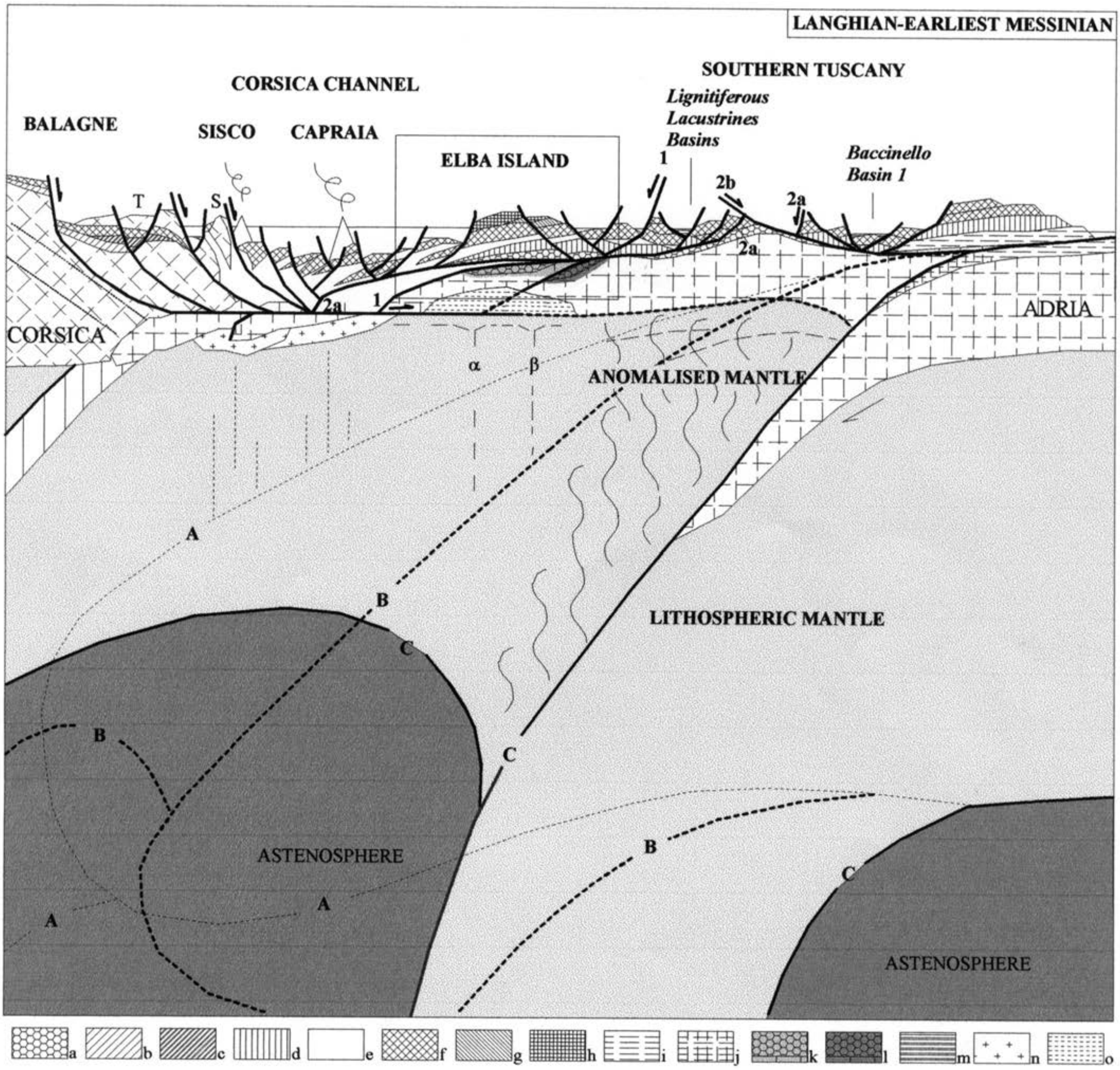

Fig 32 - Schematic section of the orogenic system Corsica-Elba-Northern Apennines during Langhian-earliest Messinian times.
a- Tuscany metamorphic units; b- Corsica Middle Eocene neoautochthon; c- Corte slices; d- Tuscan Nappe; e- “Schistes Lustrés” and Calcschists with ophiolites; f- Ligurides; g- Elba Paleogene Flysch Unit; h- Elba Cretaceous Flysch Unit; i- non metamorphic Cervarola and Umbria Units; j- metamorphic Umbria Unit; k- external Tuscan metamorphic basement (Porto Azzurro Unit -PU- in the Elba Island); l- internal Tuscan metamorphic basement (Ortano Unit -UO- in the Elba Island); m- Neogene lacustrine deposits; n- underplating magmatic bodies; n- anatectic zone beneath Elba Island. 1 and 2a- 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 Mt. 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 33.

Latest Miocene (6.8-5.3 Ma) (Figs. 33 A, B, C)

During Messinian, the anatectic melting produced the Mt. Capanne granitoid pluton. This magmatic body (~6.8 Ma) pierced through the Apennine accretionary wedge, deforming and metamorphosing the host rocks. The uplift of the Mt. Capanne induced both westwards and eastwards discharges of the nappe pile, along detachment faults (Fig. 33A). On the western side of Mt. Capanne the ophiolitic metamorphic aureola was displaced westwards along a detachment surface located in the Chiessi-Punta Polveraia and, probably, also in the Fetovaia-Pomonte areas. On the eastern side, a symmetrical detachment surface has been recognised and described as Central Elba Fault (**CEF**) by Dini (1997a; 1997b). The circulation of the fluids along this detachment surface allowed metasomatic k-enrichment (euritisation) of the porphyries and aplitic dikes in both **CU** and **EU** units, occurring on the hangingwall (Maineri et al., 1999; 2000). Later detachments probably caused a further eastwards sliding of the

Ligurian units.

Successively (6-5.5 Ma, Fig. 33B), the anatectic process shifted eastwards, and produced the uplift and emplacement of the La Serra Porto Azzurro granitoid, whose thermometamorphism affected the lower and middle part (till **MU**) of the eastern Elba tectonic pile, but in the Valdana-Golfo Stella area it reached the base of **OU** (**ASU** in Norsi Beach). Contemporaneously, a shoshonitic dike (μ, 5.8 Ma) intruded **OU**. Like the uplift of the Mt. Capanne, also the La Serra-Porto Azzurro pluton uplift produced extensional detachments, both westwards (**RDF**) and north-eastwards (**ZDF** and **UDF**), thus producing the last horizontal movements recorded in the Elba I. At about 5.4-5.3 Ma, near the Miocene-Pliocene limit (Fig. 33C), a new phase of block tectonics produced an horst-and-graben, N-S-trending structure, which normal faults were the conduits for the mineralising fluids that produced the famous Elba hematite ore deposits. Likely, this tectonic phase caused also the opening of the Piombino Channel.

Pliocene and Quaternary (< 5.3 Ma)

During this time, the Elba I. underwent prevalently movements of uplift, as suggested by the absence of marine sediments. Locally, eolian sands and alluvial deposits occur. Erosion affected the whole tectonic pile, thus giving to the Island its present morphologic profile, sketched in Fig. 33C.

Acknowledgements

Research founded by C.N.R., Centro di Studio di Geologia dell'Appennino e delle Catene Perimediterranee, Florence, (Publ. n. 348), and M.P.I. 40% and 60% (Responsibles Valerio Bortolotti and Gianfranco Principi).

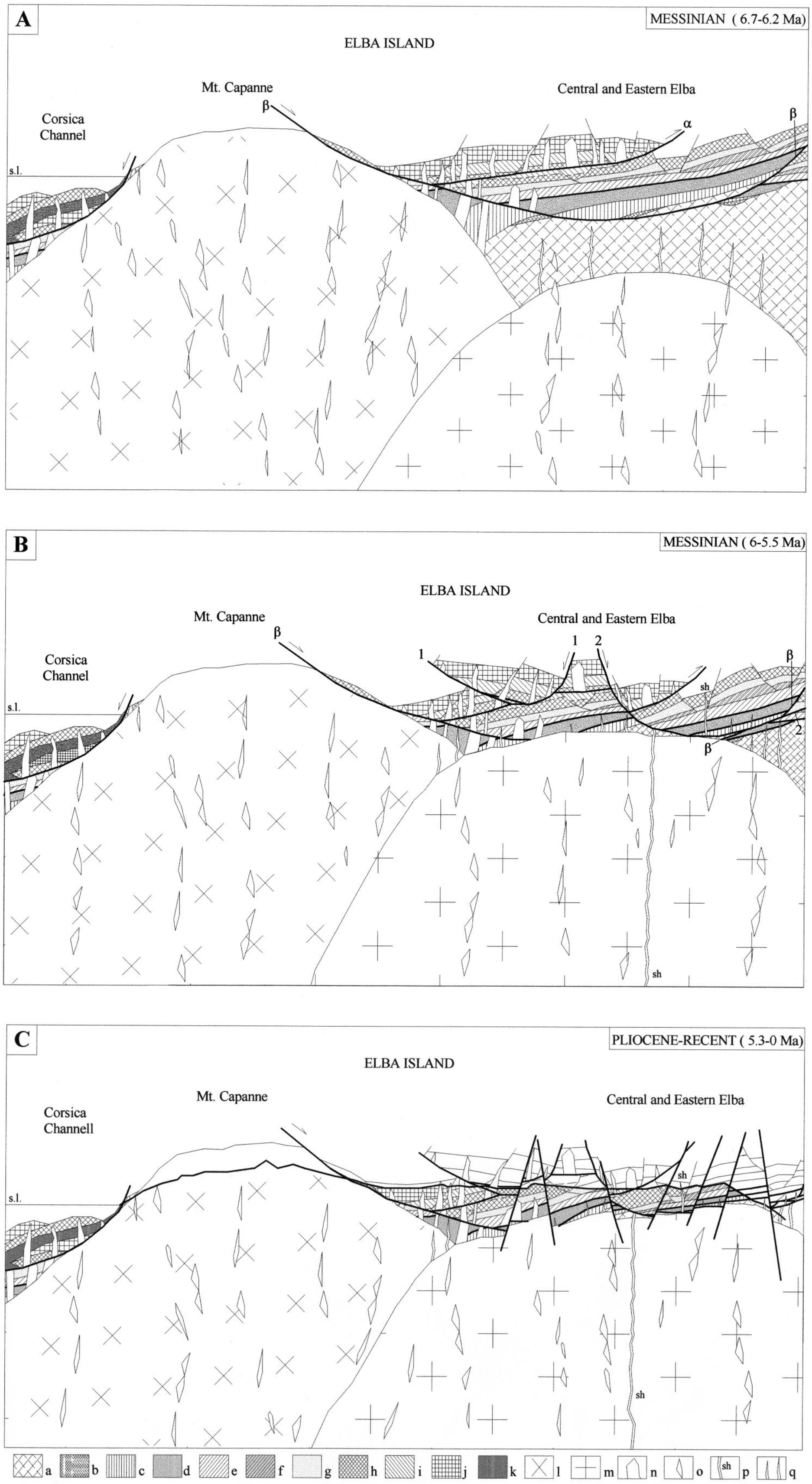

Fig. 33 - Schematic sections of the Elba Island from 6. 7 to 0 Ma (uppermost Messinian to Present)
A- Early Messinian (6.7-6.2 Ma). Early Messinian final uplift of the Mt. Capanne pluton and the quasi-contemporaneous development of detachment faults producing westwards and eastwards (α- **CEF 1** and β- **CEF 2**) delamination of the tectonic pile;
B- Messinian (6-5.5). Final uplift of the La Serra - Porto Azzurro pluton and development of **ZDF** - Zuccale (α) and **RDF** - Colle Reciso (β) divergent delaminations;
C- Late Messinian high angle normal faulting and the contemporaneous formation of the ore mineralisations. The heavy line represents the present W-E Mt. Capanne-Mt. Arco topographic section.

REFERENCES

Aiello E., Bruni P. and Sagri M., 1977. Depositi canalizzati nei flysch cretacei dell'Isola d'Elba. Boll. Soc. Geol. It., 96: 297-329.

Aiello I.W., 1997. Le rocce silicee biogeniche pelagiche della Tetide Occidentale (Giurassico). Tesi dott., Univ. Firenze, 210 pp.

Aloisi P., 1910. Rocce granitiche negli scisti della parte orientale dell'Isola d'Elba. Atti Soc. Tosc. Sci. Nat., Mem., 26: 3-30.

Aloisi P., 1912. Rocce dioritiche del Monte Capanne (Elba). Atti Soc. Tosc. Sci. Nat., Mem., 28: 200-208.

Aloisi P.,1919-20. Il Monte Capanne. Ed. Nistri, Pisa, 303 pp.

Babbini A., 1996. Geologia delle Liguridi dell'Elba centrale tra la Piana di S. Giovanni (Portoferraio) e M. Capo Stella, ad ovest dell'allineamento Poggio Corsetti - Bucine. Unpubl. Thesis, Univ. Florence, 92 pp.

Barberi F., Brandi G.P., Giglia G., Innocenti F., Marinelli G., Raggi G., Ricci C.A., Squarci P., Taffi L. and Trevisan L., 1969a. Isola d'Elba, Foglio 126. Carta Geol. d'It. Serv. Geol. d'It., E.I.R.A., Firenze.

Barberi F., Dallan L., Franzini M., Giglia G., Innocenti F., Marinelli G., Raggi R., Ricci C.A., Squarci P., Taffi L. and Trevisan L., 1967a. Carta geologica dell'Isola d'Elba alla scala 1:25.000. E.I.R.A., Firenze, 1967

Barberi F., Dallan L., Franzini M., Giglia G., Innocenti F., Marinelli G., Raggi R., Squarci P., Taffi L. and Trevisan L., 1969b. Note illustrative della Carta Geologica d'Italia alla scala 1:100.000. Foglio 126 (Isola d'Elba). Serv. Geol. d'It., 32 pp.

Barberi and F. and Innocenti F., 1965. Le rocce cornubianitico-calcaree dell'anello termometamorfico del Monte Capanne (Isola d'Elba). Atti Soc. Tosc. Sci. Nat., Mem., Ser. A, 72: 306-398.

Barberi F. and Innocenti F., 1966. I fenomeni di metamorfismo termico nelle rocce peridotitico-serpentinose dell'aureola del Monte Capanne (Isola d'Elba). Period. Mineral., 25: 735-768.

Barberi F., Innocenti F. and Ricci C.I., 1967b. Il complesso scistoso di Capo Calamita (Isola d'Elba). Atti Soc. Tosc. Sci. Nat., Mem, Ser. A, 74: 579-617.

Barrett T.J., 1982. Stratigraphy and sedimentology of Jurassic bedded cherts overlying ophiolites in the North Apennines, Italy. Sedimentology, 29: 353-373.

Bartole R., 1995. The North Tyrrhenian-Northern Apennines postcollisional system: constraints for a geodynamic model. Terra Nova, 7: 7-30.

Bartole R:, Torelli L., Mattei G., Peis B. and Brancolini G., 1991. Assetto stratigrafico-strutturale del Tirreno Settentrionale: stato dell'arte. St. Geol. Camerti, Vol Spec. 1991/1: 115-140.z

Baumgartner P.O., 1984. A Middle Jurassic-Early Cretaceous low-latitude radiolarian zonation based on Unitary Associations and age of Tethyan radiolarites. Ecl. Geol. Helv., 77 (3): 729-837.

Baumgartner P.O., Bartolini A., Carter E.S. et al., 1995. Middle Jurassic to Early Cretaceous Radiolarian biochronology of Tethys based on Unitary Associations. In: P.O. Baumgartner et al. (Eds.), Middle Jurassic to Lower Cretaceous Radiolaria of Tethys: occurrences, systematics, biochronology. Mém. Géol (Lausanne), 23: 1013-1048.

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

Bellincioni D., 1958. Rapporti tra "Argille scagliose" ofiolitifere, Flysch e calcare nummulitico nell'Elba centrale. Boll. Soc. Geol. It., 77 (2): 112-132.

Beneo E., 1948. Guida schematica alla geologia dell'Isola d'Elba. Atti Congr. Miner. It, 1948, p. 3-21.

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

Beneo E. and Trevisan L., 1943. I lineamenti tettonici dell'Isola d'Elba. Boll. R. Uff. Geol d'It., 68 (1945), Nota I, p. 1-18.

Benvenuti M., Bortolotti V., Fazzuoli M., Pandeli E. and Principi G., 2001. Pre-meeting transect Corsica-Elba Island-Southern Tuscany Guidebook. 2 - Elba Island. B - Eastern Elba. Ofioliti 26 (2a), this volume.

Bertini G., Cameli G.M., Costantini A., Decandia F.A., Di Filippo M., Dini I., Elter F.M., Lazzarotto A., Liotta D., Pandeli E., Sandrelli F. and Toro B., 1991. Struttura geologica fra i Monti di Campiglia e Rapolano Terme (Toscana meridionale): stato attuale delle conoscenze e problematiche. Studi Geol. Camerti, Vol. Spec. 1991/1: 155-178.

Bigazzi G., Bonadonna F.P., Ferrara G. and Innocenti F., 1973. Fission track ages of zircons and apatites fron Northern Apennines ophiolites. Forschr. Mineral., 50: 51-53.

Boccaletti M, Bonazzi U., Coli M., Decandia F., Elter P., Puccinelli A., Raggi G., Verani M. and Zanzucchi G., 1977. Problemi stratigrafico-strutturali dell'Elba centro-orientale. Prog. Final. Geod. Sottoprog. Mod. Struttur., Gruppo Appennino Sett., 15 pp.

Boccaletti, M., Coli, M., Decandia, F.A., Giannini, E. and Lazzarotto, A., 1980. Evoluzione dell'Appennino Settentrionale secondo un nuovo modello strutturale, Mem. Soc. Geol. It., 21: 359-373.

Boccaletti M., Elter P. and Guazzone G., 1971. Plate tectonics model for the development of the Western Alps and the Northern Apennines. Nature, 234: 108-111.

Boccaletti M., Gianelli G. and Sani F., 1997. Tectonic regime, granite emplacement and crustal structure in the inner zone of the Northern Apennines (Tuscany, Italy): A new hypothesis. Tectonophysics, 270: 127-143.

Boccaletti M. and Manetti P., 1972. Caratteri sedimentologici del Calcare Massiccio della Toscana a sud dell'Arno. Boll. Soc. Geol. It., 91: 559-582.

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

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

Bodechtel J, 1964a. Stratigraphie und Tektonik der Schuppenzone Elbas. Geol. Rundsch., 53: 25-41.

Bodechtel J., 1964b. Die Hämatit-Magnetit-Paragenese in den Eisenerzen der Toskana und der Insel Elba und ihre genetische Deutung. Fortschr. Mineral., 41: 168-169.

Bodechtel J., 1965. Zur Genese der Eisenerze der Toskana und der Insel Elba. Neues Jahrb. Min. Abhandl., 103: 147-162.

Bonatti S. and Marinelli G., 1953. Appunti di litologia elbana. Boll. Soc. Geol. It., 70: 473-489.

Borsi S. and Ferrara G., 1971. Studio con il metodo K/Ar dei rapporti cronologici tra le rocce costituenti il complesso intrusivo dell'Isola d'Elba. Rend. S.I.M.P., 27: 323.

Bortolotti V., Cellai D., Chiari M., Vaggelli G. e I.M. Villa, 1995. $^{40}Ar/^{39}Ar$ dating of Apenninic ophiolites: 3. Plagiogranites from Sasso di Castro, Northern Tuscany, Italy. Ofioliti, 20: 55-65.

Bortolotti V., Cellai D., Martin S., Principi G., Tartarotti P. and Vaggelli G., 1994a. Ultramafic rocks from the Eastern Elba Island ophiolites (Tyrrhenian Sea, Italy). Mem. Soc. Geol. It., 48 (1): 195-202.

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

Bortolotti V., Martin S., Principi G:, Tartarotti P. and Vaggelli G., 1991. Le sequenze ofiolitiche dell'Elba orientale: aspetti geologici e petrografici. Atti Ticinensi Sci. Terra., 34: 71-74.

Bortolotti V., Pandeli E. and Principi G., 2001a. The geology of the Elba Island: an historical introduction. Ofioliti, 26 (2a), this issue.

Bortolotti V., Principi G. and Treves B., 2001b. Ophiolites, Ligurides and the tectonic evolution from spreading to convergence og a Mesozoic Western Tethys segment. In: P. Martini and G.B. Vai (Eds.), Anatomy of an orogen: The Apennines and adjacent Mediterranean basins. Kluwer Acad. Publ., Dordrecht, in press.

Bouillin J.P., 1983. Exemples de déformations locales liées à la mise en place de granitoïdes alpins dans des conditions distensives: l'Ile d'Elbe (Italie) et le Cap Bougaroun (Algérie). Rev. Géol. Dyn. Géogr. Phys., 24: 101-116.

Bouillin J.P., Poupeau G. and Sabil N., 1994. Etude thermochronologique de la dénudation du pluton du Monte Capanne (Ile d'Elbe, Italie) per les traces de fission. Bull. Soc. Géol. France, 165: 19-25.

Cadisch J., 1929. Zur Geologie der Insel Elba. Verhandl. Natur. Gesell. Basel, 40: 52-61.

Capponi G., Giammarino S. and Mazzanti R., 1990. Geologia e morfologia dell'Isola di Gorgona. In: Mazzanti R. (Ed.), La Scienza della Terra nei comuni di Livorno e di Collesalvetti. Quad. Mus. Stor. Nat. Livorno, 11 (Suppl. 2): 115-137.

Carmignani L., Decandia F.A., Disperati L., Fantozzi P.L., Lazzarotto A., Liotta D. and Oggiano G., 1995. Relationships between the Tertiary structural evolution of the Sardinia-Corsica-Provençal Domain and the Northern Apennines. Terra Nova, 7: 128-137.

Carmignani L., Decandia F.A., Fantozzi P.L., Lazzarotto A., Liotta D. and Meccheri M., 1994a. Tertiary extensional tectonics in Tuscany (Northern Apennines, Italy. Tectonophysics, 238: 295-315.

Carmignani L., Fantozzi P.L., Giglia G., Kligfield R. and Meccheri M., 1994b. Tectonic inversion from compression to extension: the case of the Metamorphic Complex and Tuscan Nappe in the Apuane Alps (Northern Apennines, Italy). Mem. Soc. Geol. It., 48: 23-29.

Carmignani L. and Kliegfield R., 1990. The transition from compression to extension in mountain belts: evidence from the Northern Apennines Core Complex. Tectonics, 9: 1275-1303.

Ciarapica G. and Passeri L., 1982. Panoramica della geologia delle Alpi Apuane alla luce delle più recenti ricerche. Mem. Soc. Geol. It., 24: 193-208.

Cobianchi M. and Villa G., 1992. Biostratigrafia del Calcare a Calpionelle e delle Argille a Palombini nella sezione di Statale (Val Graveglia, Appennino Ligure). Atti Ticinensi Sci, Terra, 35: 199-211.

Cocchi I., 1871. Descrizione geologica dell'Isola d'Elba. In: Barbera G. (Ed.), Mem. per servire alla descrizione della Carta Geol. d'It. R. Com. Geol., Roma, 1: 141-298.

Coli M., Nicolich R., Principi G. and Treves B., 1991a. Crustal delamination of the Northern Apennines thrust belt. Boll. Soc. Geol. It., 110: 501-510.

Coli M., Peccerillo A. and Principi G., 1991b. Evoluzione geodinamica recente dell'Appennino Settentrionale e attività magmatica Tosco-Laziale: vincoli e problemi. Studi Geol. Camerti, Vol. Spec., 1991/1: 403-412.

Collet L.W., 1938. La Corse, Elbe et l'Apennin, du point de vue tectonique. Bull. Soc. Géol. France, 8: 737-753.

Conticelli S., Bortolotti V., Principi G., Laurenzi M.A., D'Antonio M. and Vaggelli G., 2001. Petrology, mineralogy and geochemistry of a mafic dyke from monte Castello, Elba Island, Italy. Ofioliti, 26 (2a), this issue.

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

Cortesogno L., Galbiati B., Principi G. and Venturelli G., 1978. Le brecce ofiolitiche della Liguria orientale: nuovi dati e discussione sui modelli paleogeografici. Ofioliti, 3: 99-160.

Corti S., 1995. Le Liguridi dell'Elba centrale tra Portoferraio e Spiaggia del Lido, ad est dell'allineamento Poggio Corsetti - Bucine. Unpubl. Thesis, Univ. Florence, 150 pp.

Corti S., 1998. Messa a punto di metodi analitici per la determinazione dei paleostress giurassici in sequenze oceaniche: Tetide occidentale e Albanidi. Tesi Dott., Univ. Florence, 77 pp.

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

Daniel J.M. and Jolivet L., 1995. Detachment faults and pluton emplacement: Elba Island (Tyrrhenian Sea). Bull. Soc. Géol. France, 166: 341-354.

Debenedetti A., 1951. Osservazioni sui giacimenti di pirite dell'Elba. L'Industria Min., 2: 445-450.

Debenedetti A., 1953. Osservazioni geologiche sulle zone minerarie dell'Isola d'Elba. Boll. Serv. Geol. d'It., 74: 53-85.

Decandia F.A., Lazzarotto A. and Liotta D., 1993. La "serie ridotta" nel quadro dell'evoluzione della Toscana meridionale. Mem. Soc. Geol. It., 49: 181-191.

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

Deino A., Keller J.V.A., Minelli G. and Pialli G., 1992. Datazioni $^{40}Ar/^{39}Ar$ del metamorfismo dell'Unità di Ortano-Rio Marina (Isola d'Elba): risultati preliminari. Studi Geol. Camerti, Vol. Spec. 1992/2: 187-192.

Deschamps Y., 1980. Contibution à l'étude des gisements de Pyrite-Hématite de Rio Marina (Ile d'Elbe, Italie). Approche pétrographique, géochimique et structurale. Thèse Doct. 3ᵉ cycle spécial. Univ. Claude Bernard, Lyon, 492 pp.

Deschamps Y., Dagallier G., Macaudier J, Marignac C., Maine B. and Saupé F., 1983. Le gisement de Pyrite-Hématite de Valle Giove (Rio Marina, Ile d'Elbe, Italie). Contribution à la connaissance des gisements de Toscane- I. Partie 1. Schweiz. Min. Petr. Mitt., 63: 149-165.

De Stefani C., 1914. Fossili paleozoici dell'Isola d'Elba. Rend. R. Acc. Lincei, 23: 906-913.

De Wijkerslooth P., 1934. Bau und Entwicklung des Apennins besonders der Gebirge Toscanas. Geol. Inst. Amsterdam, 426 pp.

Dimanche F., 971. Les minerais de magnetite et les skarns du Ginevro (Ile d'Elbe -Italie). Mineral. Dep., 6: 356-379.

Dini A., !997a. The porphyritic rocks ("rocce porfiriche") of the Island of Elba: geology, geochronology and geochemistry. Plinius, 17: 130-136.

Dini A., !997b. REE-Y-Th-U-rich accessory minerals in granitoid rocks of Tuscan Magmatic Province (Italy): preliminary data on the porphyritic rocks of the Island of Elba. Plinius, 18: 101-102.

Dini A. and Tonarini C., 1997. Evoluzione tettono-magmatica dell'Isola d'Elba centro-occidentale: Nuovi dati geologici e geocronologici nelle rocce porfiriche. Conv. Naz. Prog. CROP, Trieste, giugno 1997. Riass., 2 pp.

Dini A., Tonarini S., Innocenti F., Rocchi S. and Westerman D.S., !996. Le "rocce porfiriche" dell'Isola d'Elba: geologia, geocronologia e geochimica. Plinius, 16: 111-112.

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

Dini C., 1995. Le unità tettoniche Toscanidi dell'Isola d'Elba orientale. Geologia dell'area compresa tha Rio Marina, Rio nell'Elba e Porto Azzurro. Unpubl. Thesis, Univ. Florence, 139 pp.

Durand Delga M., 1984. Principaux trats de la Corse alpine et corrélations avec les Alpes ligures. Mem. Soc. Geol. It., 28: 285-329.

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

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

Elter F.M. and Pandeli E., 2001. Structural evolution of anchi-/epimetamorphic units of central and eastern Elba (Ortano, Acquadolce, Monticiano-Roccastrada and Gràssera Units). Ofioliti, 26 (2a), this volume.

Fazzuoli M., Fois E. and Turi A., 1988. Stratigrafia e sedimentologia dei "Calcari e marne a Rhaetavicula contorta" Auctt. (Norico-Retico) della Toscana nordoccidentale. Nuova suddivisione formazionale. Riv. It. Paleont. Strat., 94: 561-618.

Fazzuoli M., Pandeli E. and Sani F., 1994. Considerations on the sedimentary and structural evolution of the Tuscan Domain since Early Liassic to Tortonian. Mem. Soc. Geol. It., 48: 31-50.

Fazzuoli M. and Sguazzoni G., 1986. Jurassic and Cretaceous isopic zones in the Tuscan Domain. Mem. Soc. Geol. It., 31 (1988): 59-84.

Ferrandini M., Ferrandini J., Loye-Pilot M.D., Butterlin J., Cravatte J. and Janin M.C., 1996. Le Miocène du bassin de Saint-Florent (Corse): modalités de la trasgression du Burdigalien supérieur et mise in évidence du Serravallien. Geobios, 1: 125-137.

Ferrandini J. and Loye-Pilot M.D., 1992. Tectonique en distension et décrochement au Burdigalien-Tortonien en Corse: l'exemple du bassin de Francardo-Ponte Leccia (Corse Centrale). Géol. Alpine, Sér. Spéc., Rés. Colloques, 1: 30-31.

Ferrara G., Hirt B., Marinelli G. and Tongiorgi E., 1961. I primi risultati della determinazione con il metodo Rubidio-Stronzio dell'età di alcuni minerali dell'Isola d'Elba. Boll. Soc. Geol. It., 80 (2): 145-150.

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

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

Fournier M., Jolivet L., Goffé B., and Dubois R., 1991. The Alpine Corsica metamorphic core complex. Tectonics, 10: 1173-1186.

Giglia G. and Radicati di Brozolo R., 1970. K/Ar age of metamorphism in the Apuane Alps (Northern Tuscany). Boll. Soc. Geol. It., 89: 485-497.

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

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

Jolivet L., Faccena C., Goffé B., Mattei M., Rossetti F., Brunet F., Storti F., Funicello R., Cadet J.P., D'Agostino N. and Parra T., 1998. Midcrustal shear zones in postorogenic extension: example from the Northern Tyrrenian Sea. J. Geophys. Res., 103: 123-160.

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

KahlerF and Kahler G., 1969. Einige südeuropäische Vorkommen von Fusuliniden. Mitt. Geol. Ges., 61: 49-60.

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

Kligfield R., Hunziker J., Dallmeyer R.D. and Schamel S., 1986. Dating of deformation phases using K-Ar and $^{40}Ar/^{39}Ar$ techniques: Results from Northern Apennines. J. Struct. Geol., 8: 781-798.

Lahondère D. and Guerrot C., 1997. Datation Sm-Nd du métamorphism éclogitique en Corse Alpine: un argument pour l'existence au Crétacé supérieur d'une zone de subduction active localisée sous le bloc corse-sarde. Géol. France, 3: 3-11.

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

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

Lotti B., 1884. Carta geologica dell'Isola d'Elba alla scala 1:25.000. R. Uff. Geol. d'It.

Lotti B., 1886. Descrizione geologica dell'Isola d'Elba. Mem. Descriz. Carta Geol. d'It., 2, 254 pp.

Lotti B., 1887: I giacimenti ferriferi del Banato e quelli dell'Elba. Boll. R. Com. Geol., 8: 197-202.

Lotti B., 1901: Sui depositi ferriferi dell'Elba e della regione litoranea tosco-romana. Rassegna Min., 15: 3-6.

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

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

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

Manasse E., 1912. Ricerche petrografiche e mineralogiche sul Monte Arco. Atti Soc. Tosc. Sci. Nat., Mem., 28: 118-199.

Marinelli G., 1955. Le rocce porfiriche dell'Isola d'Elba. Atti Soc. Tosc. Sci. Nat., Mem., Ser. A, 62: 269-417.

Marinelli G., 1959a. Le intrusioni terziarie dell'Isola d'Elba. Atti Soc. Tosc. Sci. Nat., Mem., Ser A, 66: 50-223.

Marinelli G., 1959b. I minerali di bismuto del cantiere Falcacci a Rio Marina (Isola d'Elba). Atti Soc. Tosc. Sci. Nat., Ser A, 66: 337-352.

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

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

Marroni M. and Pandolfi L., 1996. The deformation history of an accreted ophiolite sequence: the Internal Liguride units (Northern Apennines, Italy). Geodin. Acta, 9 (1): 13-29.

Orlandi P. and Pezzotta F., 1997. Minerali dell'Isola d'Elba, i minerali dei giacimenti metalliferi dell'Elba orientale e delle pegmatiti del M. Capanne. Ed. Novecento Grafico, Bergamo, 245 pp

Orlandi P., Pasero M. and Perchiazzi N., 1990. Nb-Ta oxides from Elba Island pegmatites. Atti Soc. Tosc. Sci. Nat., Mem., Ser. A, 97: 161-173.

Orszag-Sperber F., 1978. Le Néogène de la Corse et ses relations avec la géodynamique de la Méditerranée occidentale. Thèse Doctorat-ès-Sciences et Travaux Labor. Géol. Struct. Appliquée d'Orsay, 328 pp., (inédit).

Orszag-Sperber F. and Pilot M.D., 1976. Grands traits du Néogène de Corse. Bull. Soc. Géol. France, Sér.7, 18: 1183-1187.

Pandeli E., Bortolotti V. and Principi G., 1995. La successione toscana epimetamorfica di Capo Castello (Cavo, Isola d'Elba nord-orientale). Atti Tic. Sci. Terra, 38: 171-191.

Pandeli E., Gianelli G., Puxeddu M. and Elter F.M., 1994. The Paleozoic basement of the Northern Apennines: stratigraphy, tectono-metamorphic evolution and Alpine hydrothermal processes. Mem. Soc. Geol. It., 48: 627-654.

Pandeli E. and Puxeddu M., 1990. Paleozoic age for the Tuscan upper metamorphic sequences of Elba and its implications for the geology of the Northern Apennines (Italy). Ecl. Geol. Helv., 83 (1): 123-142.

Pandeli E., Puxeddu M. and Ruggieri G., 2001. Tthe metasiliciclastic-carbonate sequence of the Acquadolce Unit(eastern Elba Island): new petrographic data and paleogeographic interpretation. Ofioliti, 26 (2a), this volume.

Parea G.C., 1964. Età e provenienza dei clastici del Flysch arenaceo dell'Isola d'Elba. Atti Accad. Naz. Lincei, Rend. Cl. Sci. Fis. Mat. Nat., 36: 651-657.

Peccerillo A., 1985. Roman Comagmatic Province (Central Italy): Evidence for subduction related magma genesis. Geology, 1: 103-106.

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

Peccerillo A. and Manetti P., 1985. The potassium alkaline magmatism of Central Southern Italy: a review of the data relevant to petrogenesis and geodynamic significance. Trans. Geol. Soc. S. Africa, 88: 379-394.

Peccerillo A., Poli G. and Donati C., 2001. The Plio-Quaternary magmatism of southern Tuscany and northern Latium: compositional characteristics, genesis and geodynamic significance. Ofioliti 26 (2a), this volume.

Peccerillo A., Poli G. and Serri G., 1988. Petrogenesis of orenditic and kamafugitic rocks from Central Italy. Canad. Mineral., 26: 45-65.

Penta F.. 1952. Memoria sul ferro in Italia. VI: Giacimenti dell'Isola d'Elba. In: Blondel F. et Marvier L. (Eds.), Symposium sur les gisements de fer du monde. 19th Congrès Géol. Intern., Alger, p. 247-347.

Perrin M., 1969. Contribution à l'étude de la Nappe ophiolitifère dans l'Elbe orientale. Atti Soc. Tosc. Sci. Nat., Mem., Ser: A, 76: 45-87.

Perrin M., 1975. L'Ile d'Elbe et la limite Alpes-Apennin: données sur la structure géologique et l'évolution tectogénétique de l'Elbe alpine et de l'Elbe apennine. Boll. Soc. Geol. It., 94: 1929-1955.

Perrin M. and Neumann M., 1970. Présence, au NE de l'Ile d'Elbe d'une série de type "scisti policromi" à faune maestrichtienne. C.R. Acad. Sci., Sér. D, 270: 2260-2263.

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

Pezzotta F., 1993. Osservazioni strutturali, petrografiche e classificative sui filoni aplitico-pegmatitici litiniferi del settore occidentale del M.te Capanne (Isola d'Elba). Plinius, 10: 208-209.

Pezzotta F., 1994. Helvite of a Mt. Capanne pluton pegmatite (Elba Island, Italy): chemical, X-ray diffraction data and description of the occurrence. Rend. Fis. Accad. Lincei, 5: 355-362.

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

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

Principi G., 1994. Stratigraphy and evolution of the Northern Apennine accretionary wedge with particular regard to the ophiolitic sequences: a review. Boll. Geof. Teor. Appl., 36: 243-269.

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

Pullé G., 1921. Le miniere dell'Elba. In: Stella (Ed.), Le miniere di ferro dell'Italia. Ed. Lattes, Torino.

Puxeddu M., Saupé F., Dechomets R., Gianelli G. and Moine B., 1984. Geochemistry and stratigraphic correlations. Application to the investigation of geothermal and mineral resources of Tuscany, Italy (Contribution to the knowledge of ore deposits of Tuscany, II). Chem. Geol., 43: 77-113.

Raggi G., Squarci P. and Taffi L., 1965. Considerazioni stratigrafico-tettoniche sul flysch dell'Isola d'Elba. Boll. Soc. Geol. It., 84 (6): 1-14.

Raggi G., Squarci P., Taffi L. and Trevisan L., 1966. Nuovi contributi alla tettonica dell'Elba sud-orientale. Atti Soc. Tosc. Sci Nat., Ser. A, 73: 3-15.

Rampone E., Hofmann A.W. and Raczek I., 1998. Isotopic contrasts within the internal Liguride ophiolite (N. Italy): the lack of a genetic mantle-crust link. Earth Planet. Sci. Lett., 163: 175-189.

Rau A. and Tongiorgi M., 1974. Geologia dei Monti Pisani a sud-est della Valle del Guappero. Mem. Soc. Geol. It., 12: 227-408.

Reutter K.J. and Spohn A., 1982. The position of the West-Elba ophiolites within the tectonic framework of the Apennines. Ofioliti, 7: 467-478.

Richter M., 1962. Bemerkungen zur Geologie der Insel Elba. N. J. Geol. Paläont. Mon., p. 495-505.

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

Serri G., 1980. Chemistry and petrology of gabbroic complexes from the Northern Apennine ophiolites. In: A. Panayiotou (Ed.), Ophiolites. Proceed. Intern. Ophiolite Symp., Cyprus 1979. Geol. Survey Cyprus, p. 296-313.

Serri G., Innocenti F. and Manetti P., 1993. Geochemical and petrological evidence of the subduction of delaminated Adriatic continental lithosphere in the genesis of the Neogene-Quaternary magmatism of central Italy. Tectonophysics, 223: 117-147.

Serri G., Innocenti F., Manetti P., Tonarini S. and Ferrara G., 1991. Il magmatismo neogenico-quaternario dell'area Tosco-Laziale-Umbra: implicazioni sui modelli di evoluzione geodinamica dell'Appennino Settentrionale. Studi Geol. Camerti, Vol. Spec. 1991/1: 429-463.

Signorini R., 1963. La Formazione di Murlo a sud di Siena. Boll. Serv. Geol. d'It., 84: 65-81.

Soffel H., 1981, Palaeomagnetism of a Jurassic ophiolite series in east Elba (Italy). J. Geophys., 49: 1-10.

Staub R., 1933. Zur tektonischen Analyse des Apennins. Vierteljahr. Naturfor. Gesell., 78:127-151.

Stefani M. and Trombetta G.L., 1989. Le successioni retiche della Toscana orientale e dell'Umbria: cicli sedimentari asimmetrici in un bacino dominato dalle tempeste. Boll. Soc. Geol. It., 108: 591-606.

Stella A., 1933. Nuovi studi sui giacimenti ferriferi dell'Isola d'Elba. Boll. Soc. Geol. It., 52: 367-373.

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

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

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

Tartarotti P. and Vaggelli G., 1994. Melt impregnation in mantle peridotites and cumulates from the Elba Island ophiolites, Italy. Mem. Sci. Geol., 47: 201-215.

Termier P., 1909. Sur les nappes de l'Ile d'Elbe. C. R. Acad. Sci. Paris, 148: 1648.

Termier P., 1910. Sur la tectonique de l'Ile d'Elbe. Bull. Soc. Géol. France, 4 sér., 10: 134-160.

Treves B. and Harper G.D., 1994. Exposure of serpentinites on the ocean floor: sequence of faulting and hydrofracturing in the Northern Apennine ophicalcites. Ofioliti, 19: 435-462.

Treves B., Hickmott D. and Vaggelli G., 1995. Texture and microchemical data of oceanic hydrothermal calcite veins, Northern Apennine ophicalcites. Ofioliti, 20: 111-122.

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

Trevisan L., 1951. La 55a Riunione Estiva della Società Geologica Italiana. Isola d'Elba, Settembre 1951. Boll. Soc. Geol. It., 70 (1953): 435-472.

Tricardi F. and Zitellini N., 1987. The rifting of the Tyrrhenian Basin. Geo-Marine Lett., 7: 1-6.

Vai G.B., 1978. Tentative correlation of Paleozoic rocks, Italian peninsula and islands. Oesterr. Akad., Erdw. Kom., 3: 313-329.

Westermann D.S., Dini A., Innocenti F., Rocchi S. and Tonarini S., in prep. The evolution of a nested Christmas-tree Laccolith complex: an example from Elba Island, Italy.

Wunderlich H.G., 1962. Stromungsmarken und Faltenachsen im Flysch von Elba. N. Jb. Geol. Paläont. Mh., p. 230-244.

Wunderlich H.G., 1963. Faltenbau, Stratigraphie und fazielle Entwicklung Ostelbas. N. Jb. Geol. Paläont. Mh., p. 161-181.

Zia R., 1955. Calcari a Calpionelle della Toscana. Boll. Soc. Geol. It., 74 (2): 81-92.

Zitellini N., Tricardi F., Marani M. and Fabbri A., 1986. Neogene tectonics of the Northern Tyrrhenian Sea. Giorn. Geol., 48: 25-40.

Received, October 12, 2000
Accepted, December 29, 2000

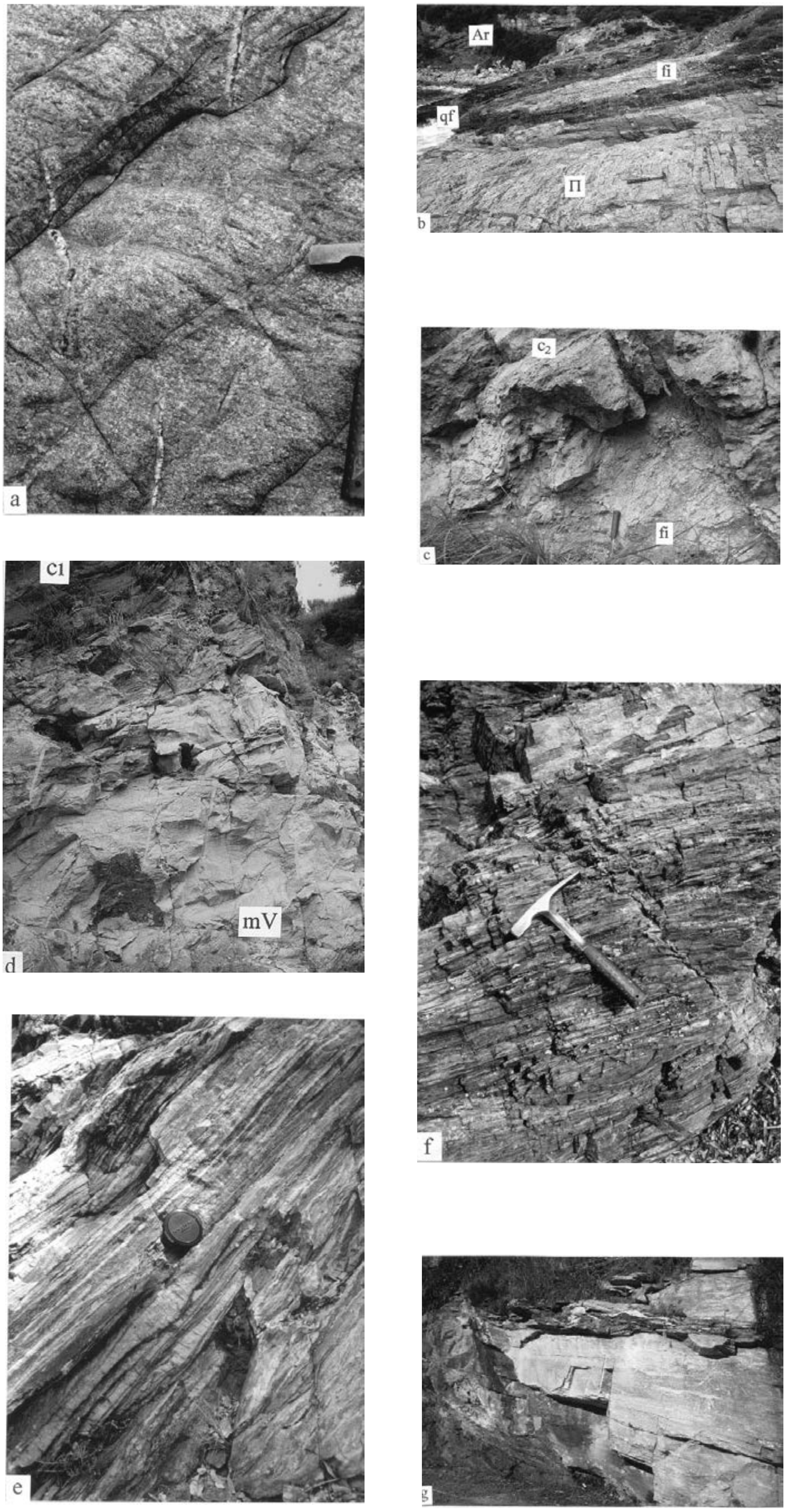

Plate 1 - a) Augen texture of the Porphyroids (UO), cut by post-tectonic hydrothermal veins of quartz+chlorite. b) Alpine D_1 isoclinal fold marked by a decimetric-thick horizon of Blackish quartzites and phyllites (qf) at the top of Porphyroids (Π). Silver-grey phyllites and quartzites (fi) are at the core of the fold. In the background, the Capo d'Arco Schists (Ar), are upthrown by a normal fault. c) The Valdana cataclasite (c_2) onto the Silver-grey phyllites and quartzites (fi) of the Ortano Unit (entrance of the Ortano Residence). d) The Valdana Marbles (mV) grading upward into Calcschists (ci) (entrance of the Ortano Residence). e) The Calcschists with siliceous bands and nodules (entrance of the Ortano Residence). f) The Phyllites and metasiltstones of Acquadolce Unit (eastern coast of Golfo Stella). g) The Calcschist intercalations within the Phyllites and metasiltstones, close to Torre di Rio (south of Rio Marina).

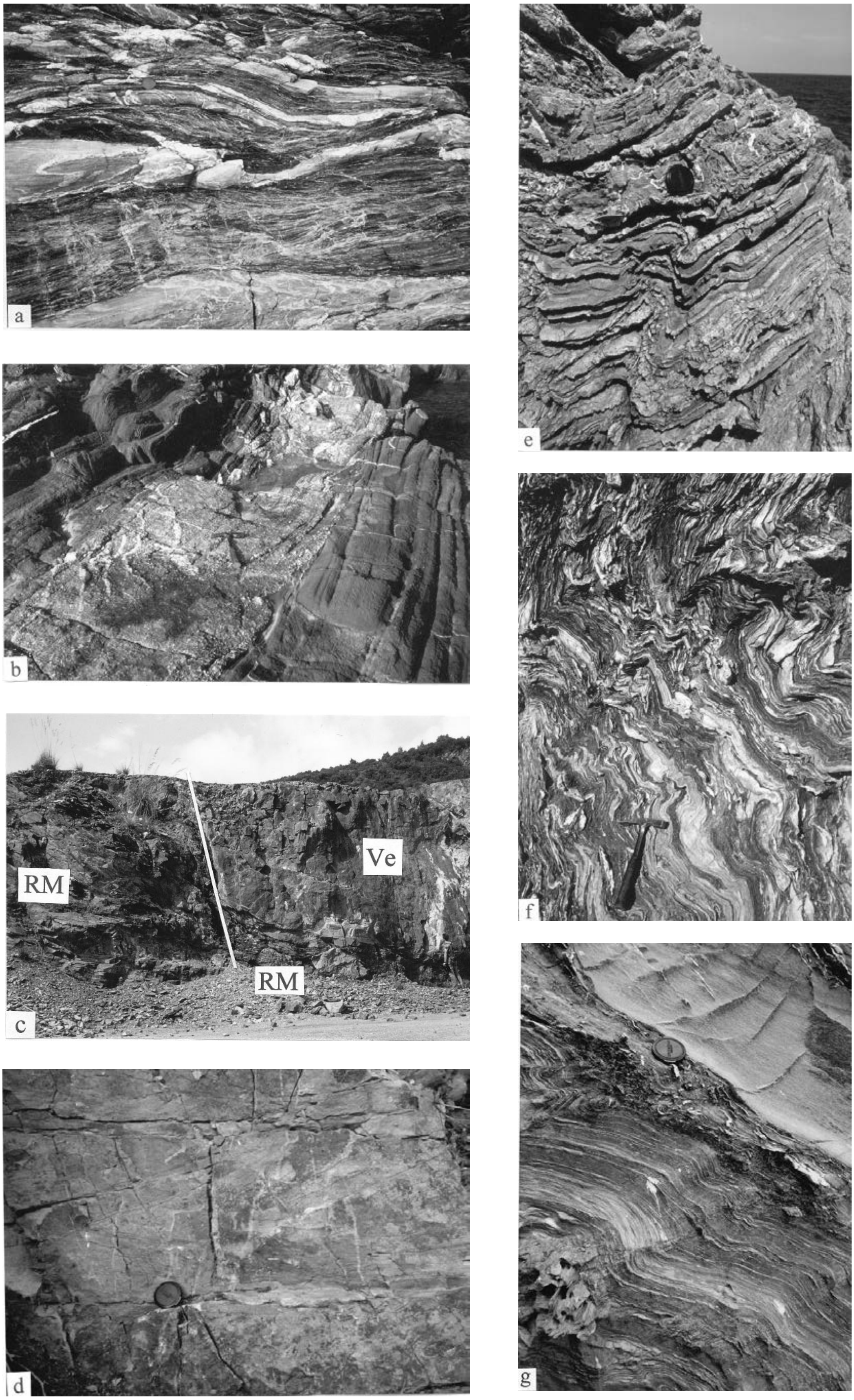

Plate 2 - a) Blackish phyllites and calcareous phyllites with grey marble and calcschist intercalations at Porticciolo (AU Phyllites and metasiltstones, (north of Capo Ortano). b) Quartzitic metaconglomerates within the metasandstones and graphite-rich metapelites of Rio Marina Fm. in the Vigneria area (north of Rio Marina). c) Contact of the basal anagenite bed of the Verruca Fm. (Ve) with the underlying Rio Marina Fm. (RM) in the Valle Giove mine (northwest of Rio Marina). The contact is dissected by a younger high angle normal fault. d) Cross bedding in the Green Quartzites Member of the Mt. Serra Quartzites (southern flank of Mt. Sàssera, north of Rio Marina). e) “Maiolica”-type Limestones at Capo Castello (north of Cavo). f) Polydeformed Varicoloured Sericitic Schists of Capo Castello area (north of Cavo). g) Alternating metasandstones, metasiltstones and black phyllites of the Pseudomacigno in the Topi Island (north of Cavo).

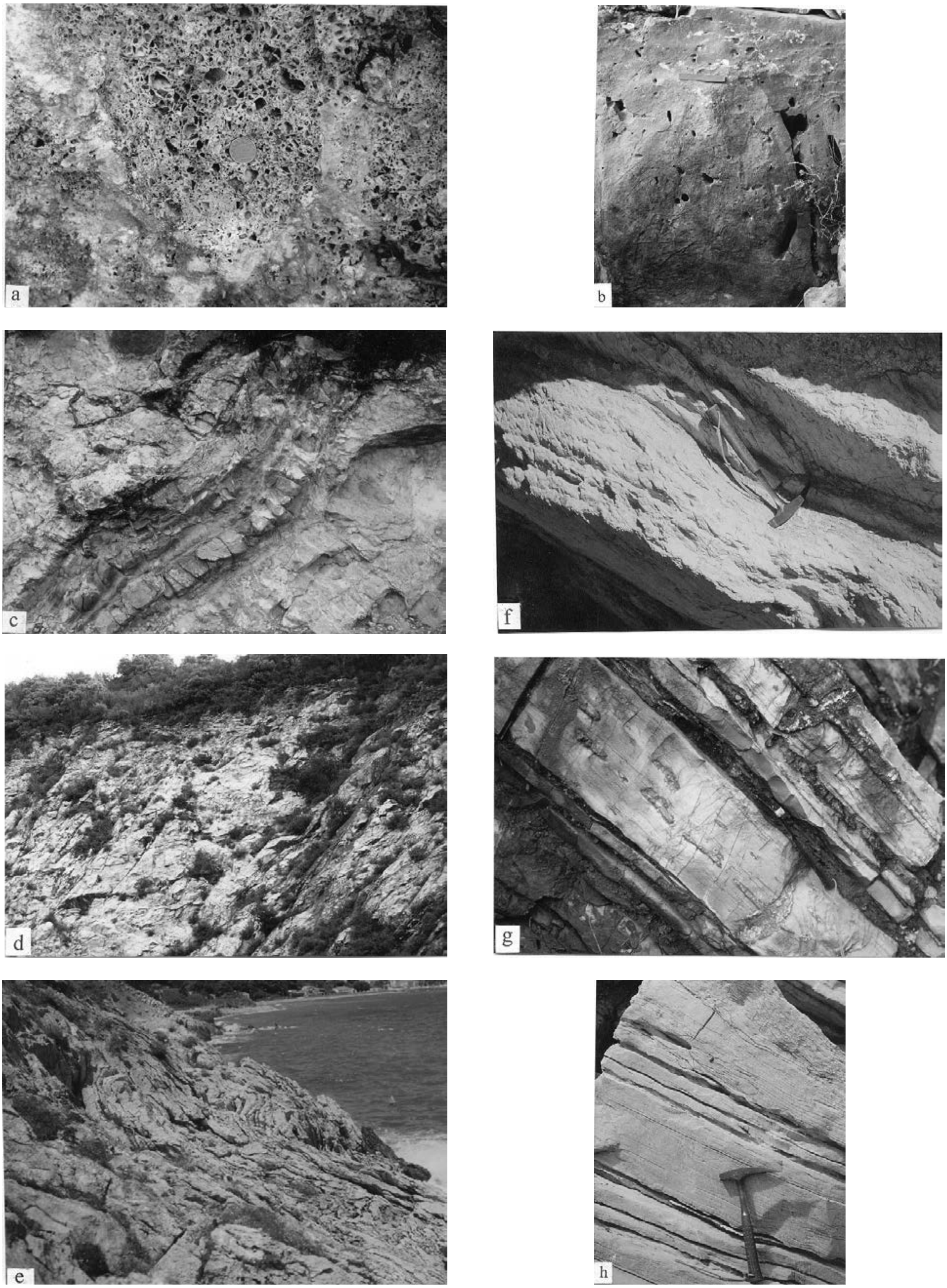

Plate 3 - a) Brecciated limestones with irregular mm- to cm-sized vacuoles, “Calcare Cavernoso”, near the Rio Marina cemetery. b) Thick-bedded dolomite-rock, Pania di Corfino Fm., south of Mt. Bicocco. c) Alternating marlstones (dm- to m-thick beds) and thinner calcilutites beds, Mt. Cetona Fm., on the road Rio Marina - Cavo. d) Strongly fractured massive calcilutites and calcarenites, “Calcare Massiccio”, in the Cavo Quarry. At its top, the tectonised contact with the overlying thin bedded Grotta Giusti Limestones. e) Well bedded cherty calcilutites and calcarenites, Grotta Giusti Limestones, along the coast, north of Mt. Le Paffe. The fold axes plunge northwestwards. f) Nodular calcilutite beds, intersected by abundant styloliths, alternating with thin marlstones, “Rosso Ammonitico” at Cala del Telegrafo. g) Cherty calcilutites, separated by styloliths or mm- to cm-thick shales and marlstones, Limano Cherty Limestones, on the road Rio Marina - Cavo. h- Pale brown, marly, calcilutitic beds, with parallel lamination; the uppermost amalgamated beds consist of a slump at the base and a debris-flow at the top, *Posidonia* Marlstones, on the road Rio Marina-Cavo.

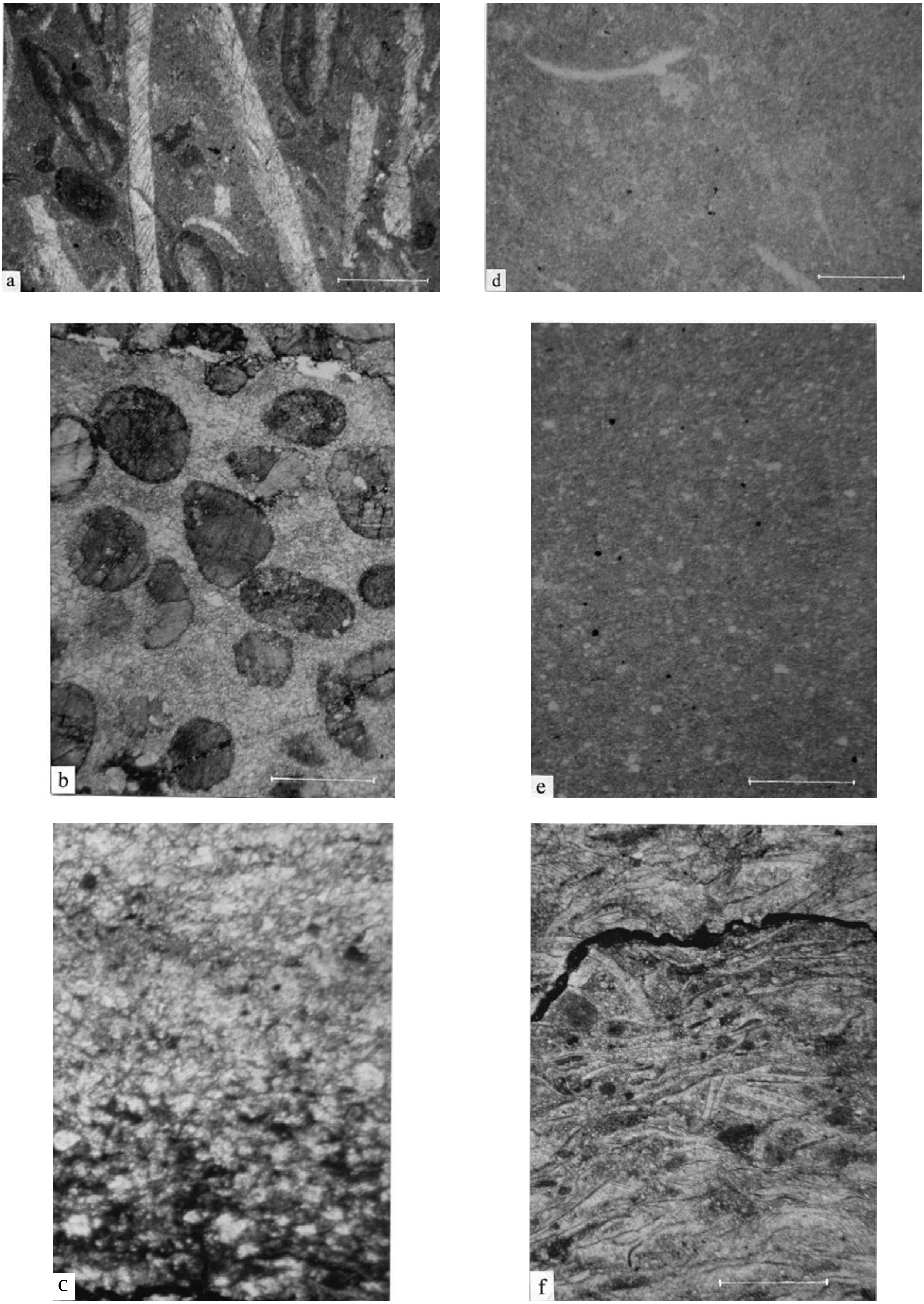

Plate 4 - a) Storm deposit consisting of bioclastic floatstones with pelecypods, gastropods and planktonic foraminifers, Mt. Cetona Fm. b) Recrystallised oolitic and intraclastic grainstone; ooids are completely dolomitised. “Calcare Massiccio” c) Microsparitic mudstone/wackestone, with abundant silt-sized detrital quartz and rare bioclasts (radiolarians). Grotta Giusti Limestones. d) Recrystallised mudstone and bioclastic wackestone with pelecypods, crinoids and radiolarians, of “Rosso Ammonitico”. e) Recrystallised mudstone, with abundant silt-sized quartz grains and Fe-oxide crystals, of Limano Cherty Limestones. f) Bioclastic packstone-floatstone, with filaments and crinoids, cut by a Fe-oxide stained stylolith. *Posidonia* Marlstones. White line = 1 mm.

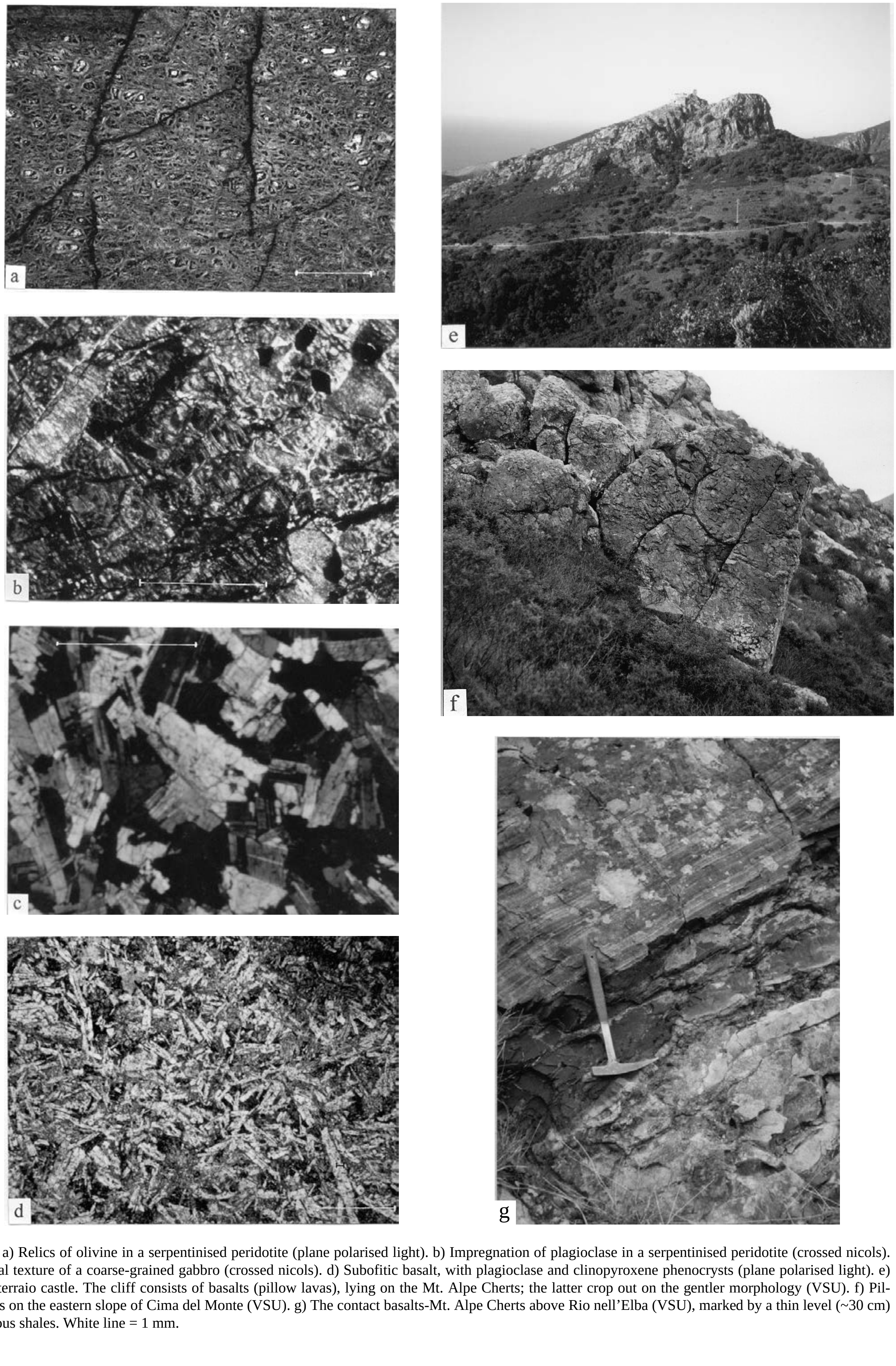

Plate 5 - a) Relics of olivine in a serpentinised peridotite (plane polarised light). b) Impregnation of plagioclase in a serpentinised peridotite (crossed nicols). c) Typical texture of a coarse-grained gabbro (crossed nicols). d) Subofitic basalt, with plagioclase and clinopyroxene phenocrysts (plane polarised light). e) The Volterraio castle. The cliff consists of basalts (pillow lavas), lying on the Mt. Alpe Cherts; the latter crop out on the gentler morphology (VSU). f) Pillow-lavas on the eastern slope of Cima del Monte (VSU). g) The contact basalts-Mt. Alpe Cherts above Rio nell'Elba (VSU), marked by a thin level (~30 cm) of siliceous shales. White line = 1 mm.

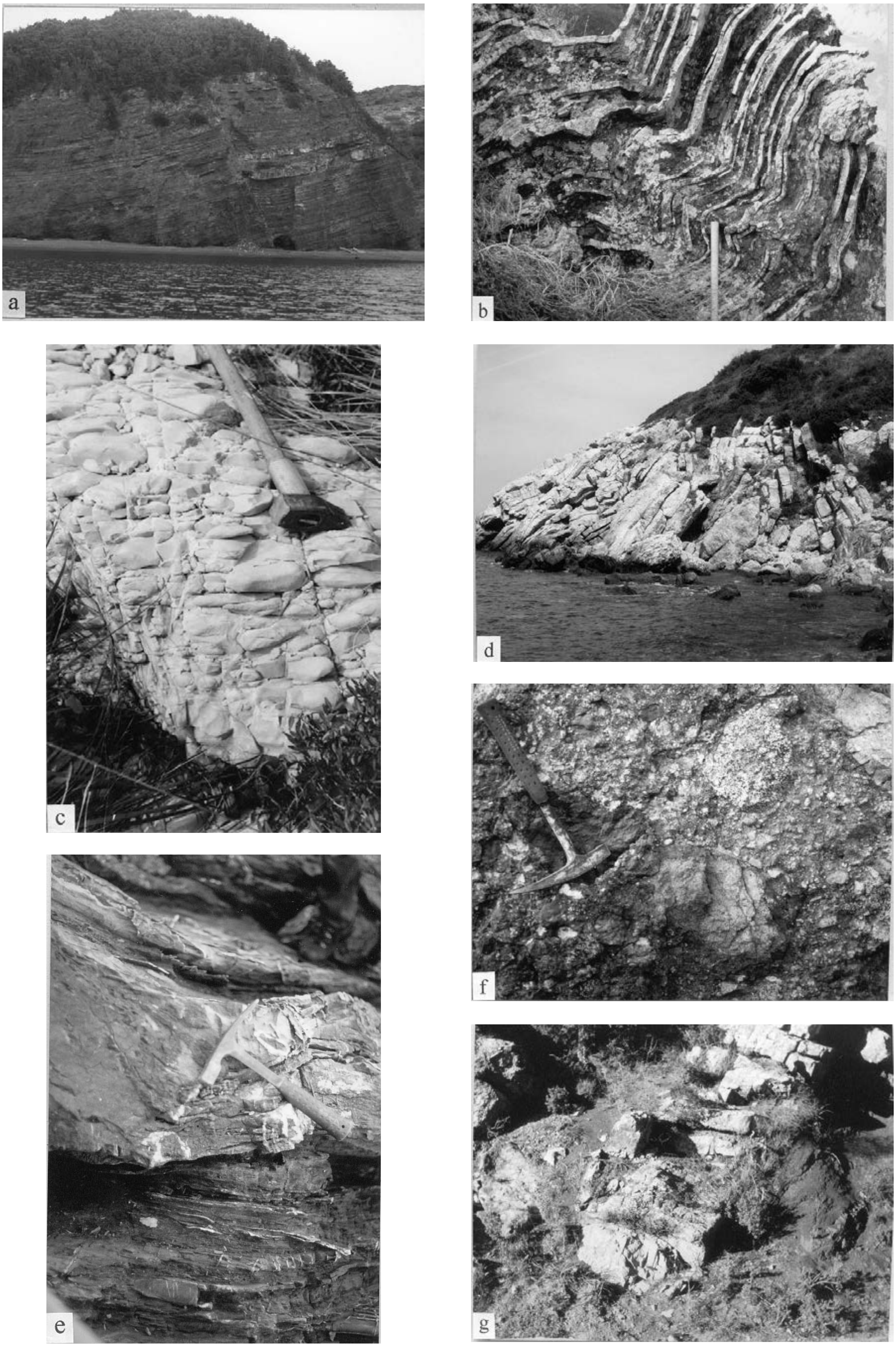

Plate 6 - a) Mt. Alpe Cherts along the Coast, south-east of le Secche (VSU). b) Facies b- of Mt. Alpe Cherts: ribbon radiolarites with abundant siliceous shales (see text), eastern slope of Mt. Serra (SSU). c) Marly limestones of the Rivercina Member of the Nisportino Fm., on the western slope of Pietre Rosse (VSU). d) Strongly folded Calpionella Limestones, along the coast, at Cala dell'Inferno (VSU). e) Thick calcilutite beds alternating with thin bedded shales and calcilutites of the Palombini Shales at Cala del Pisciatoio (CSU). f) Ophiolitic breccia with plagiogranite, microgabbro and basalt heterometric clasts in a sandy matrix, north of Casa Galletti (CU). g) Thick calcilutite beds alternating with abundant shales and thin calcilutites of Colle Reciso Fm., near Colle Reciso(EU).

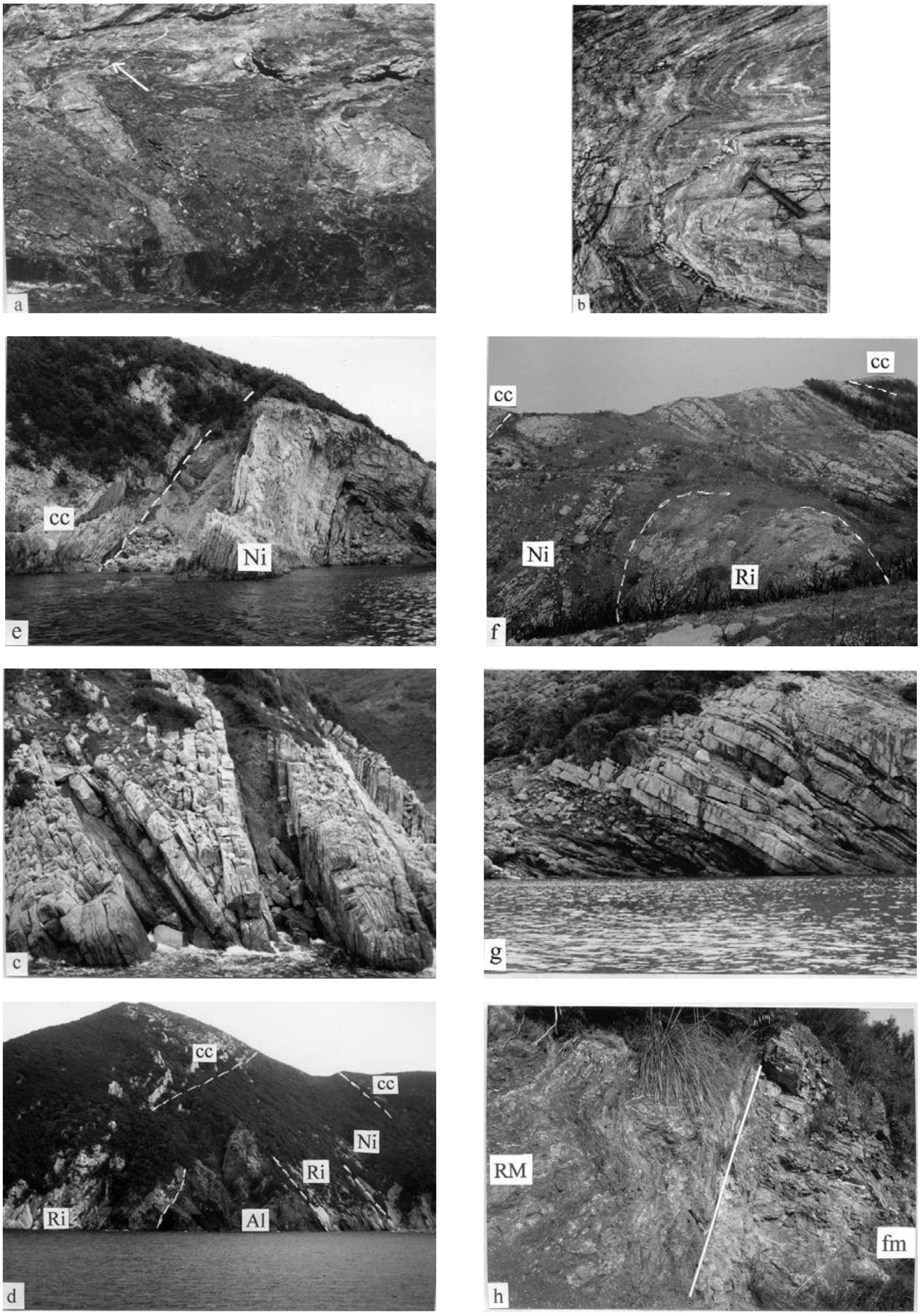

Plate 7 - a) F_2 folds within the Capo d'Arco Schists (OU), coast near Capo d'Arco Residence. The arrow indicates a thin post-tectonic aplite dike. b) F_2 folds within the Phyllites and Metasiltstones (AU) along the eastern coast of Golfo Stella. c) Close metric to decametric east-vergent close folds in the Calpionella Limestones (SSU), along the coast, north of Cala dei Mangani. d) Hectometric anticline on the western slope of Mt. Grosso (SSU).Al- Mt. Alpe Cherts; Ni- Nisportino Fm, with Ri- Rivercina Member; cc- Calpionella Limestones. e) East-vergent anticline on the southern side of Cala di Nisportino (VSU). From the left to the right: cc- the basal portion of the Calpionella Limestones, Ni- the top of Nisportino Fm. (tawny marly-silty shales and, at the nucleus, thin-bedded pinkish calcilutites. f) The anticline north of Mt. Castello from the northern slope of the mount (VSU). The eastern limb (right) is complicated by parasite minor folds. Ri- Rivercina Member of Ni- Nisportino Fm.; cc- Calpionella Limestones. g) Tectonic contact ("minor thrust") between the Palombini Shales of ASU and the overlying Calpionella Limestones of SSU. h) High angle Terranera Normal Fault (TNF) which downthrows the Rio Marina Fm. (MU) with respect to the Phyllites and Metasiltstones (AU) along the road to Capo d'Arco Residence.