Chapter 3 –
PETROGRAPHIC FEATURES

3.1 Serre dykes

3.1.1 "Mammola – Piani di Limina" dykes (LMA-PDL samples)

LMA samples show a porphyritic (P. I. ~ 7 - 10%), intergranular, locally sub-ophytic, texture with phenocrysts of subhedral clinopyroxene and less abundant altered plagioclase (Fig. 3.1a) widespread in a microcrystalline groundmass mainly consisting of euhedral plagioclase, clinopyroxene, amphibole and less abundant quartz.

Fresh Augite clinopyroxene is subhedral, fine to medium sized and occasionally twinned (Fig. 3.1b). Concentric and, more rarely, sector compositional zoning seldom occur. Crystals are locally extensively fractured, with fractures commonly marked by oxides rims.

Plagioclase usually forms smaller phenocrysts than pyroxene and it is affected by widespread sericitization and saussuritization, with original Albite twinning rarely visible. Sieve textures are occasionally recognized. Compositional zoning is not observed.

Rounded quartz xenocrysts are commonly observed (Fig. 3.1c); they are commonly mantled by minute crystals of clinopyroxene and amphibole suggesting mixing processes with a more felsic magma.

"Mantled quartz xenocrysts" or "*quartz ocelli"* are terms commonly used to indicate this type of quartz xenocrysts and usually, they are indeed interpreted as a texture related to magma-mixing processes (e.g., *Vernon, 1990; Hibbard, 1991, 1995; Palivcovà et al., 1995; Baxter and Feely, 2002*).

Amphibole crystals are fine-sized and widely diffuse in the matrix (Fig. 3.1d); they consist of brown colored hornblende, characterized by high relief, prismatic and pseudo-hexagonal sections and a strong pleochroism (X = pale yellow; Y = brown; Z = pale brown).

Opaque, quartz, titanite, acicular or stubby prismatic apatite and rare zircon grains complete the paragenesis.

Secondary minerals consist of abundant epidote, sericite and chlorite.

Numerous vesicles are present and they are usually filled by chlorite.

Textural and mineralogical zoning in analyzed samples is occasionally observed; samples belonging to the border dyke portions are characterized by a very fine groundmass, in which alteration effects are widespread: plagioclase is extensively seriticized and saussuritized, and pyroxene is occasionally extensively replaced by chlorite. Conversely, samples from central dyke portions are coarser grained and characterized by fresh pyroxene grains and less altered plagioclase crystals.

PDL samples suffered a *spilitization*-type hydrothermal alteration (*hydrothermal metamorphism of basaltic rocks*) during which Ca is usually largely removed (chiefly from primary calcic plagioclase) as well as transition metals (e.g., Cu, Ni, Co and Mn), while Na, H_2O, and occasionally Mg, are added. Ti and Al often remain constant (*Cann, 1969; Hellman and Henderson, 1977; Shaw et al., 1977; Hall, 1990; Skelton et al., 2010*)

This type of alteration produced in PDL samples a typical metasomatic assemblage essentially made of albitic plagioclase, chlorite, calcite and epidote.

The groundmass is felt-like, made of acicular and mainly skeletal laths of plagioclase and less abundant quartz and opaque minerals, widespread in dark stains of fine-sized chlorite and calcite.

Phenocrysts are represented by still recognizable sericitized and saussuritized plagioclase (Fig. 3.2a) while the original mafic phases are totally replaced by chlorite showing anomalous blue interference colors (Fig. 3.2b, c).

Plagioclase is fine to coarse grained, twinned according to albite, albite-Carlsbad, albite-periclino laws and seldom embayed, with gulfs filled by matrix or quartz grains.

Compositional zoning is not identifiable, conversely sieve textures are common.

Edges of coarse grains are usually rounded and this, together with embayment, suggests magmatic corrosion resulting from a change in pressure or a change in chemical composition of the melt caused by mixing of magmas.

Quartz *ocelli* occur in these samples too (Fig. 3.2d). Here, they are mantled by minute quartz grains and by a chlorite – Fe-Ti oxides rim. They are seldom embayed, favoring the hypothesis of mixing between two compositional distinct melts.

Accessory phases are sphene and acicular apatite. The latter is commonly considered a typical mixing texture (*Hibbard, 1991; Kuman and Pieru, 2010; Şahin et al., 2010).* Secondary assemblage consists of chlorite, calcite, epidote and white mica. Amygdales are filled by chlorite and calcite.

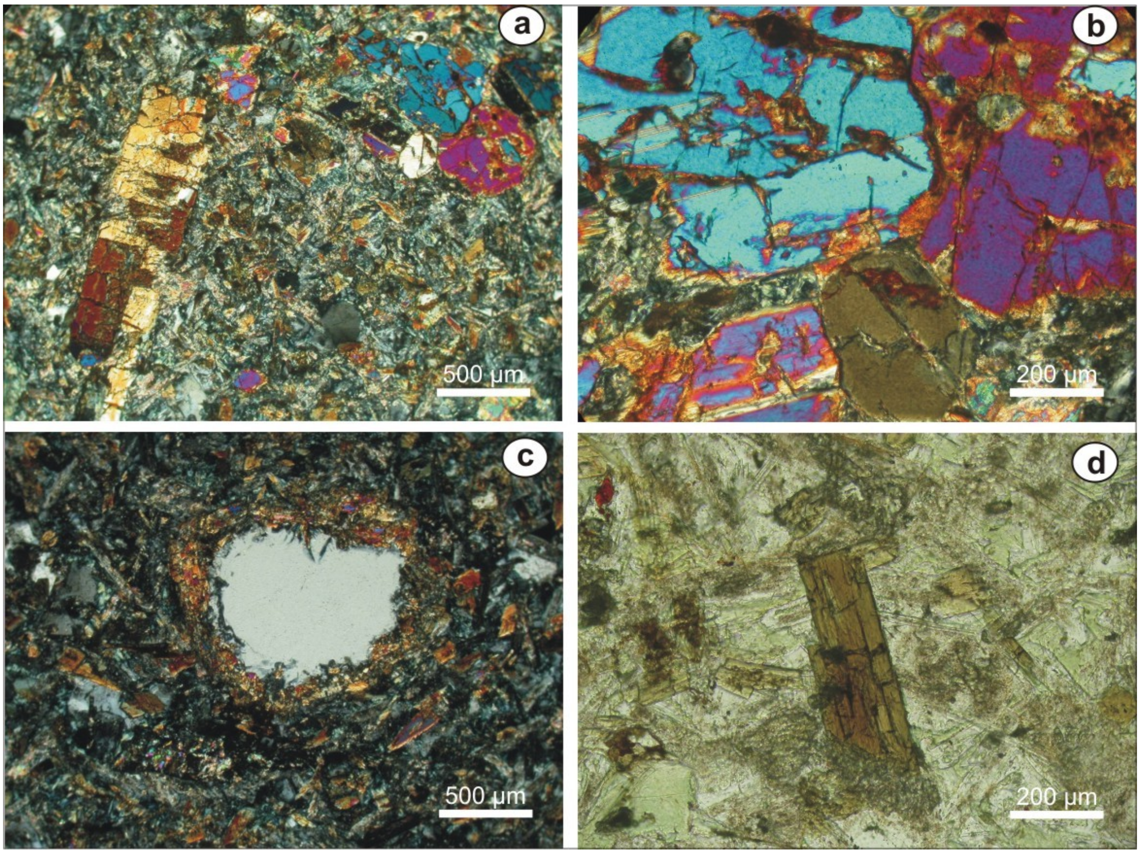

Fig. 3.1: Representative microphotographs of LMA samples showing **a)** clinopyroxene phenocrysts set in a plagioclase, clinopyroxene and amphibole fine groundmass; **b)** clinopyroxene phenocrysts aggregate. Some crystal shows twinning (left bottom side of photo); **c)** Quartz *ocello* mantled by an amphibole and pyroxene rim; **d)** pale green to brown amphiboles set in the fine groundmass.

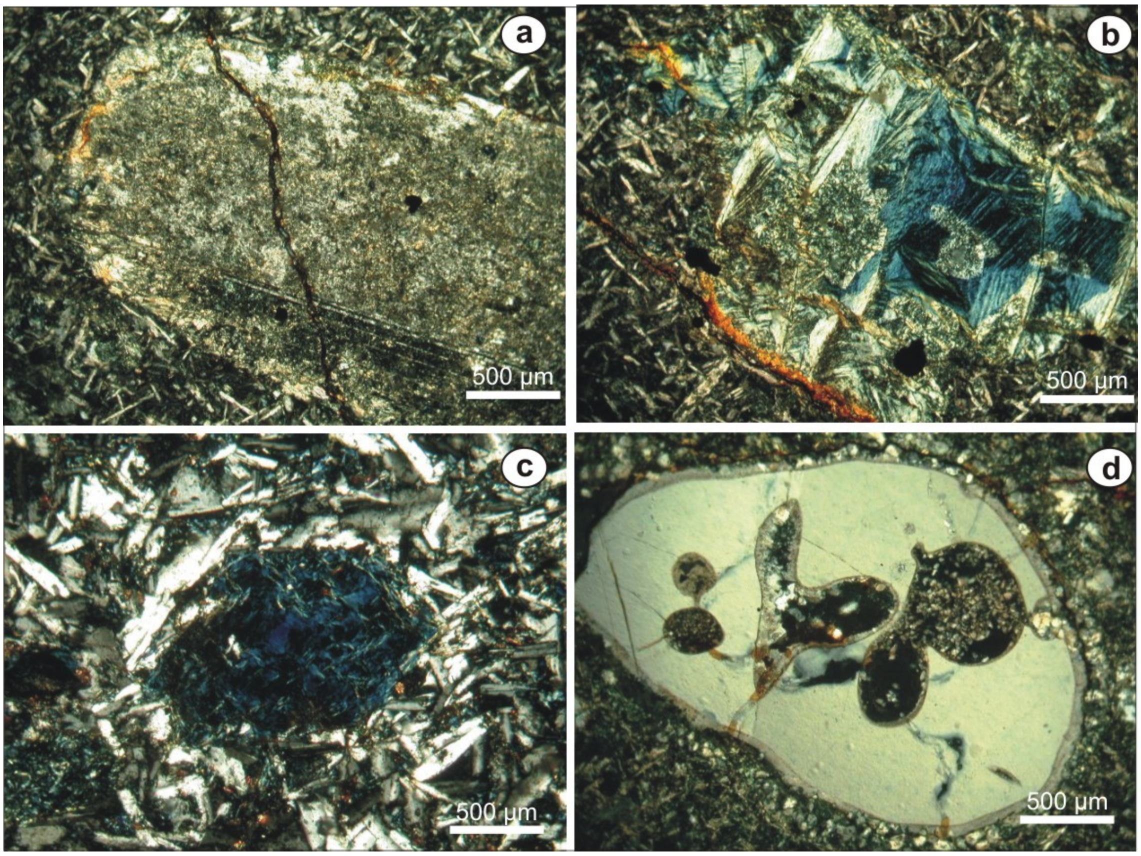

Fig. 3.2: Representative microphotographs of PDL samples showing **a)** altered plagioclase phenocryst with rounded edges and traces of albite twinning; **b)** and **c)** primary mafic crystals replaced by chlorite; **d)** deeply embayed Qtz *ocello*.

3.1.2 “*Foletti valley*” dykes (F samples)

F samples have a porphyritic texture (P.I. ~20-25%) with euhedral clinopyroxene and rare plagioclase phenocrysts set in a fine-grained groundmass made up of euhedral plagioclase, amphibole, quartz and K-feldspar (Fig. 3.3a, b).

Clinopyroxene phenocrysts are rarely well preserved; they often are totally transformed into pseudomorphic chlorite aggregates In other cases, pyroxene is almost completely replaced by actinolite (*uralitization*), starting from the rims, but occasionally leaving intact little pyroxene portions in which the typical high interference colors are preserved (Fig. 3.3b, c). Sometimes, chlorite-actinolite aggregates replace the original mafic grains.

Very tiny green hornblende grains, mainly acicular in shape, as well as secondary actinolite grains, widely occur in the matrix (Fig. 3.3c).

Plagioclase is nearly absent among phenocrysts, but abundant in the groundmass. In both case it is extensively sericitized so that twinning or compositional zoning are not visible.

Micrographic intergrowth of quartz and K-feldspar are also present in the groundmass.

Accessory phases consist of Fe-Ti oxides, ilmenite, apatite, titanite and few and tiny zircon grains.

Secondary minerals include chlorite, epidote, sericite, actinolite and calcite.

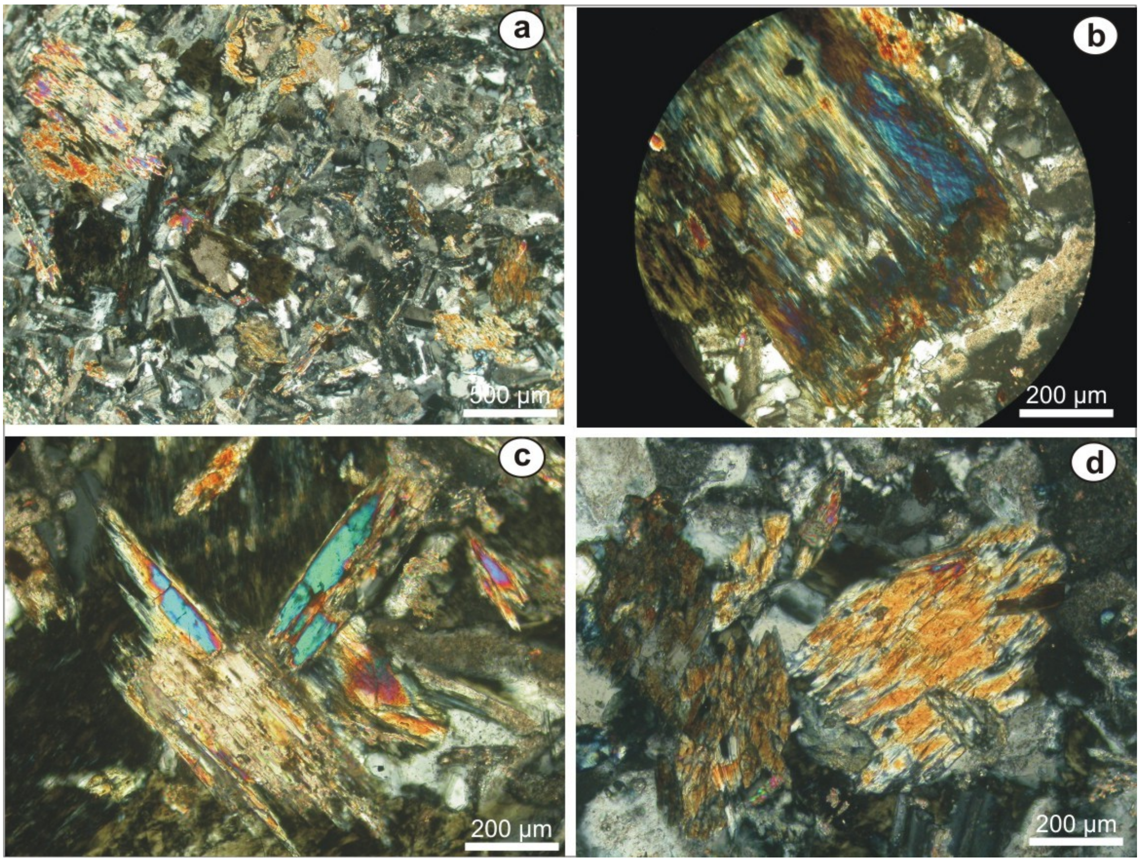

Fig. 3.3: Representative microphotographs of F samples showing **a)** primary mafic phenocrysts replaced by actinolite and chlorite, set in a groundmass made of plagioclase, quartz and K-feldspar; **b)** uralitization of clinopyroxene **c)** little portions of clinopyroxene spared by alteration; **d)** actinolite crystals in the matrix.

3.1.3 “Antonimina” dykes (A samples)

A samples have a porphyritic, locally glomeroporphyric, texture with a P.I. of ~10-15%, with abundant euhedral to subhedral clinopyroxene, plagioclase and much rarer amphibole phenocrysts (Fig. 3.4a). The same phases are present also in the microcrystalline groundmass.

Augite phenocrysts (Fig. 3.4b), frequently fractured and with corroded cores, are commonly affected by chlorite replacement, sometimes leading to formation of complete chlorite pseudomorphs.

Sector and concentric compositional zoning are rarely observed.

Feldspars are represented by extensively sericitized plagioclase, albite and albite-Carlsbad twinned, and K-feldspar. Micrographic intergrowths between quartz and K-feldspar are widespread in the matrix.

Brown to pale green hornblende phenocrysts and microcrysts show prismatic and pseudo-hexagonal outline, high relief, marked cleavage system and a strong pleocrhoism (Fig. 3.4c, d).

Accessory phases are represented by Fe-Ti oxides, ilmenite, titanite and very abundant apatite needles. Zircons are very rare and tiny.

Among the secondary products, chlorite, sericite, actinolite and epidote are the most abundant phases.

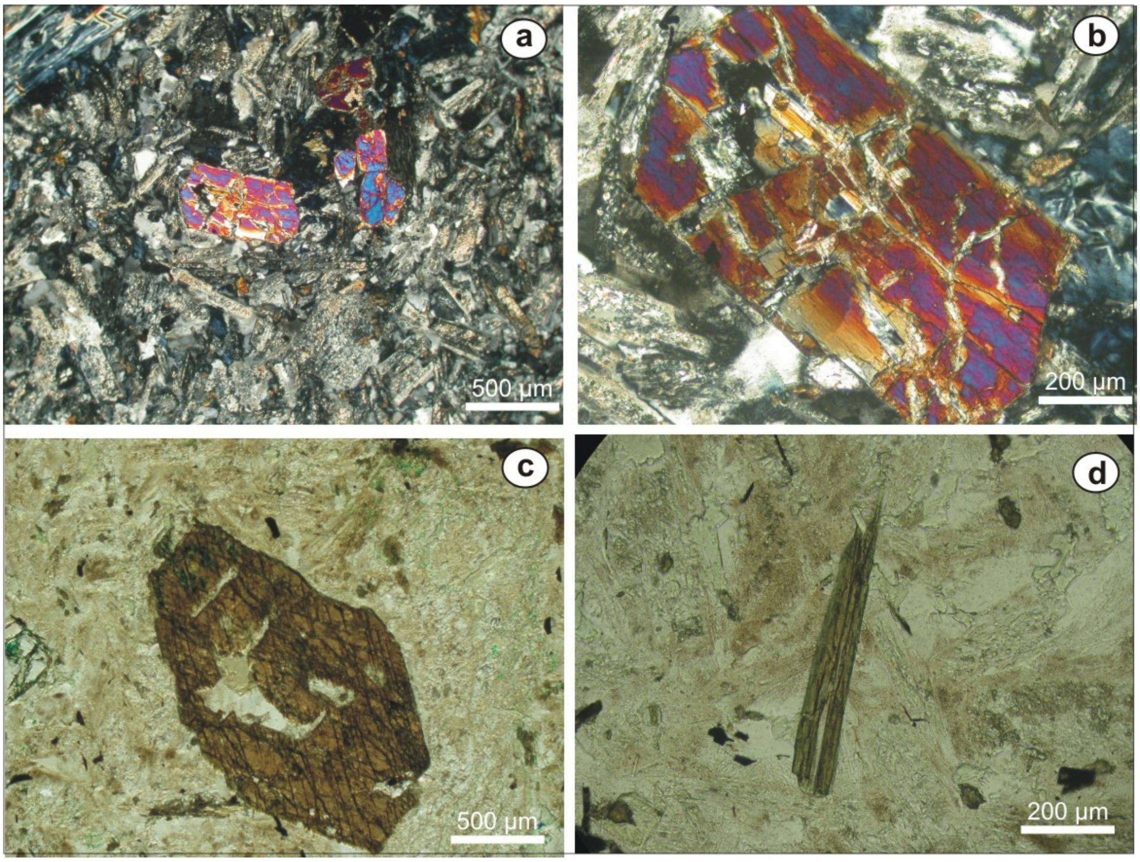

Fig. 3.4: Representative microphotographs of A samples showing **a)** clinopyroxene phenocrysts in a plagioclase, quartz and K-feldspar matrix; **b)** detail of a zoned clinopyroxene phenocryst; **c)** pseudo-hexagonal section of a brown amphibole phenocryst; **d)** prismatic amphibole crystal in the matrix.

3.1.4 “Villaggio Zomaro” dykes (VZ samples)

VZ samples have a porphyritic phaneritic texture (P.I. ~10-15%) with K-feldspar phenocrysts set in a medium-grained groundmass made up of subhedral to anhedral K-feldspar, quartz, and white mica (Fig. 3.5a, b).

K-feldspar phenocrysts are Carlsbad twinned or not twinned, affected by extensive sericitization and often mantled by a rim of quartz.

Quartz *ocelli*, ~1.5-2.0 mm in size, commonly occur as large rounded grains bordered by K-feldspar and quartz defining a coronitic texture (Fig. 3.5c).

Accessory phases are rutile, titanite, apatite and zircon.

Abundant white mica of probably secondary origin pervades the rocks.

Rare actinolite grains complete the secondary assemblage.

The present composition of VZ samples could reflect the redistribution of Na, K, Ca and Si during the secondary feldspathization.

Feldspathization and silicification of felsic volcanic rocks are widely reported in literature (*Magnusson, 1970; Parak, 1975; Lofgren, 1979; Hersoy and Griffin, 1983*). Mechanisms invoked to explain these processes are numerous: Battey (*1955*) described local variations in K/Na ratios within the New Zealand volcanic rocks ("*keratophyres*") and related these to the redistribution of alkalies through circulating fluids, during burial metamorphism.

Dickinson (*1962*) described albitization of vitreous rhyodacite tuff as due to low-T reactions with connate sea water. These tuffs were first converted to heulandite-laumontite and then to albite and quartz rocks, still preserving volcanoclastic textures, and finally converted to a K-feldspar-quartz rock, as a consequence of circulating fluids resulting from the albitization process itself.

Munha et al. (*1980*) described the K-feldspathization of felsic volcanites as the result of the spilitization of primary more basic volcanites and calculated that K-feldspathization is favored at T < 140° C. Additionally, they demonstrated that metasomatic processes in many felsic volcanics are likely to take place soon after eruption, while rocks are still warm, or during burial.

Hersoy and Griffin (*1983*) describe the feldspathization and silicification of the felsic metavolcanites of Avnik Area (Turkey) as a metasomatism event occurred at low T and related to the interaction of rocks with heated sea water, both during burial and/or during the early stages of Eoalpine metamorphism.

In our case, VZ dykes may have been emplaced within crustal weakness zone that could also coincide with the preferential pathway for the circulating fluids operating the alkali metasomatism. Additionally, a possible source of fluids may be represented by larger granitoids body; albitization of such granitoids could have released large volumes of potassium thus supplying K for the K-feldspathization of dykes.

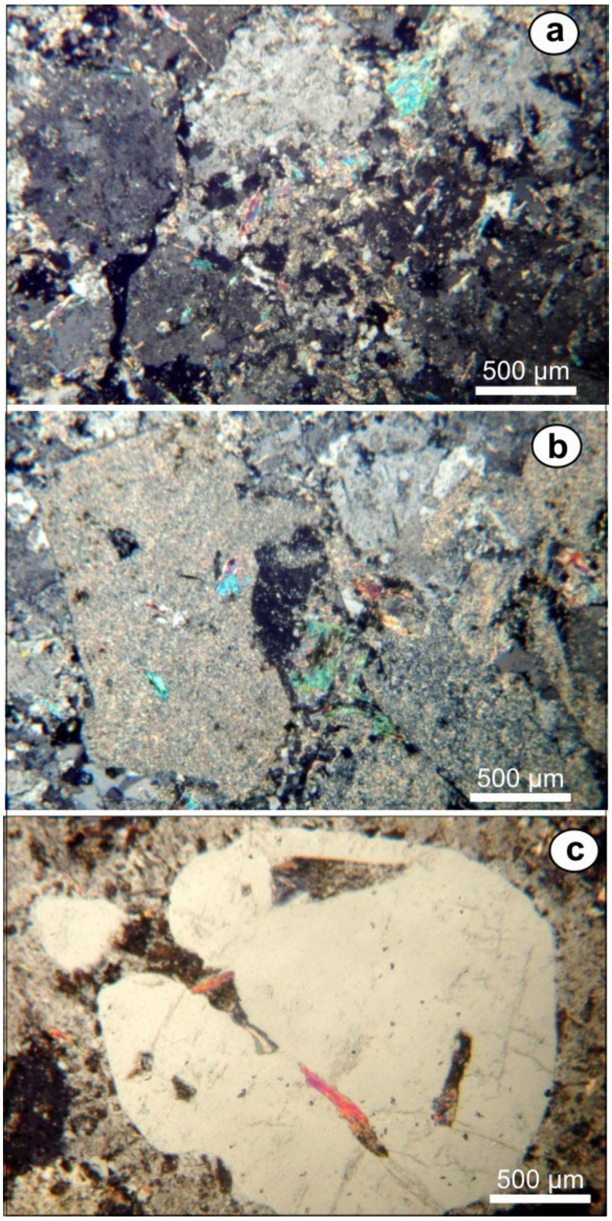

Fig. 3.5: Representative microphotos of VZ samples showing **a)** medium-grained matrix made of K-feldspar, quartz and white mica; **b)** subhedral altered K-feldspar phenocryst; **c)** embayed and rounded quartz *ocello*.

3.1.5 “San Todaro” dykes (ST samples)

ST samples show a porphyritic to equigranular, seldom vesicular, texture, with a very low porphyritic index (P.I. < 7%).

Matrix, from fine to medium-grained, consists of plagioclase, K-feldspar, quartz, chloritized biotite, white mica and opaque minerals.

Phenocryst assemblage is formed by euhedral, extensively saussuritized and sericitized, K-feldspar and plagioclase, locally forming glomerules (Fig. 3.6a).

K-feldspar is commonly twinned according to Carlsbad law, whereas plagioclase is frequently albite-Carlsbad and albite –periclino twinned.

Prismatic and pseudo-hexagonal sections of chlorite polymorphs after former mafic phases commonly occur (Fig. 3.6b). No relic of the original minerals have been found due to complete replacement; however crystal forms and common association with rutile and/or titanite may suggest former amphibole occurrence.

Biotite is also almost totally replaced by chlorite. Only small residual brownish patches of biotite still occur.

Rarely, mm-sized quartz xenocrysts, larger than average phenocrysts size, are recognized (Fig. 3.6c).

Accessory phases consist of zircon and acicular apatite.

Secondary assemblage is formed by chlorite, sericite, epidote and calcite.

Vesicles are filled by chlorite and rimmed by quartz grains.

On the whole, in function of textural and mineralogical features, ST samples can be subdivided in two sub-groups:

- group I (Fig. 3.6d) is characterized by a fine to medium grained matrix, a porphyritic texture, the lacking of primary white mica and low amounts of secondary one;
- group II (Fig. 3.6e, f) is characterized by a medium-grained and quartz-rich matrix, a porphyritic to equigranular texture, the presence of quartz xenocryst, interstitial and radial white mica, micrographic intergrowths and variolitic texture formed by quartz and K-feldspar.

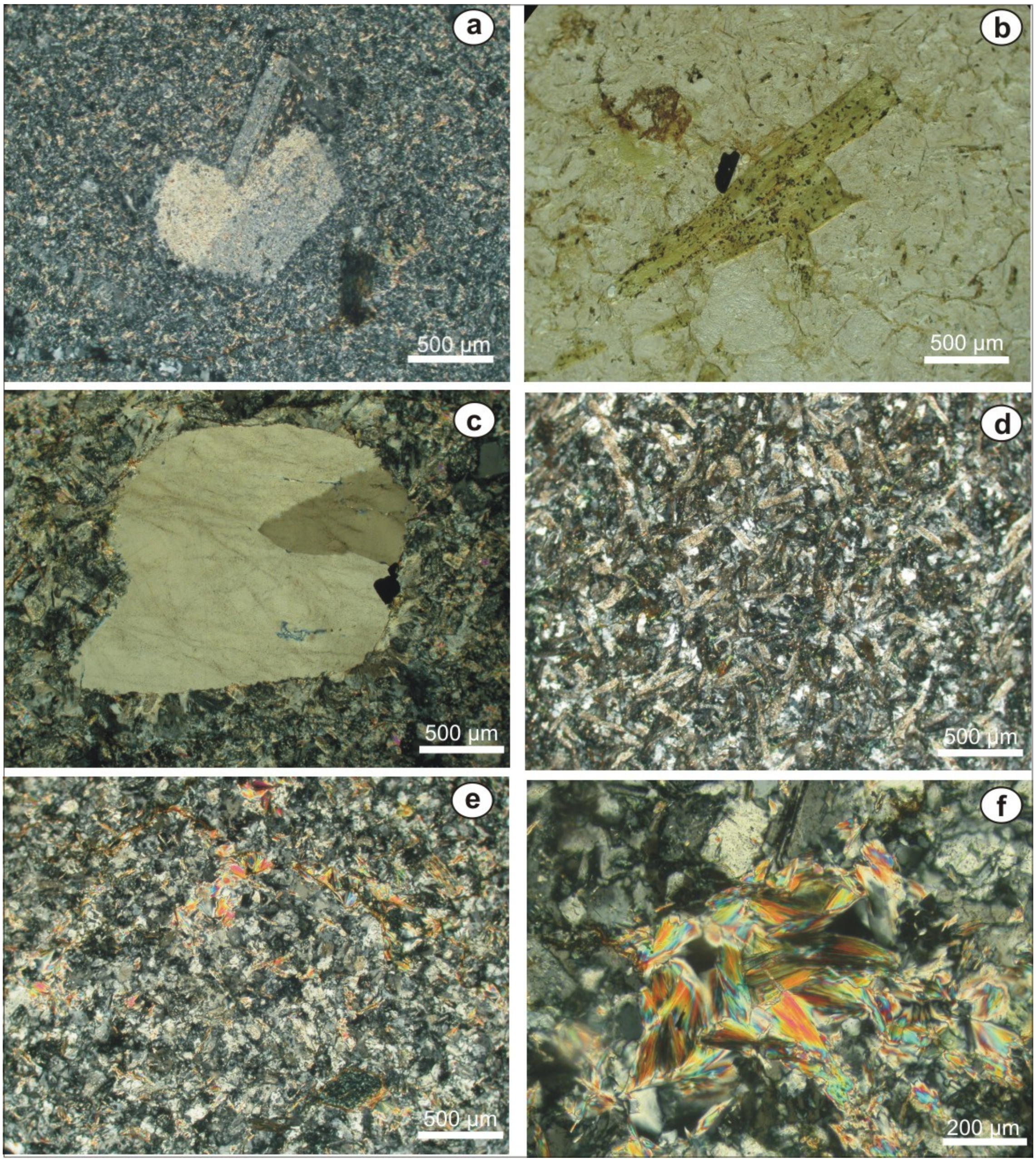

Fig. 3.6: Representative microphotographs of ST samples showing **a)** K-feldspar and plagioclase phenocrysts forming a glomerule set in a fine-grained groundmass mainly made of plagioclase, K-feldspar, quartz and chloritized biotite; **b)** primary prismatic femic mineral replaced by chlorite; **c)** Quartz xenocrysts; **d)** example of Group I white mica-poor texture; **e)** example of Group II white mica-rich texture; **f)** Group II detail: radiating white mica.

3.2 Sicilian dykes

3.2.1 “Leonforte” dyke (VG samples)

VG samples are holocrystalline, fine to medium grained, and show an ophitic texture, where laths of plagioclase are embedded in zoned augite crystals (Fig. 3.7a). Plagioclase is euhedral, albitized and sericitized, not zoned, and twinned according to albite or albite-Carlsbad laws.

Augite clinopyroxene is colorless, subhedral in shape, intensively fractured but unaltered, and very often concentrically or sector (“*hour-glass*”) zoned (Fig. 3.7b).

Small amounts of interstitial biotite, partially replaced by chlorite, also occur (Fig. 3.7c, d).

Skeletal ilmenite (Fig. 3.7c, d), opaque minerals, apatite and very few zircon and titanite grains occur as accessory phases.

Secondary minerals are represented by epidote and calcite. Additionally, actinolite (Fig. 3.7e) and radial prehnite (Fig. 3.7f) crystals are also recognized. They mainly fill the fractures forming “*comb-like*” structures.

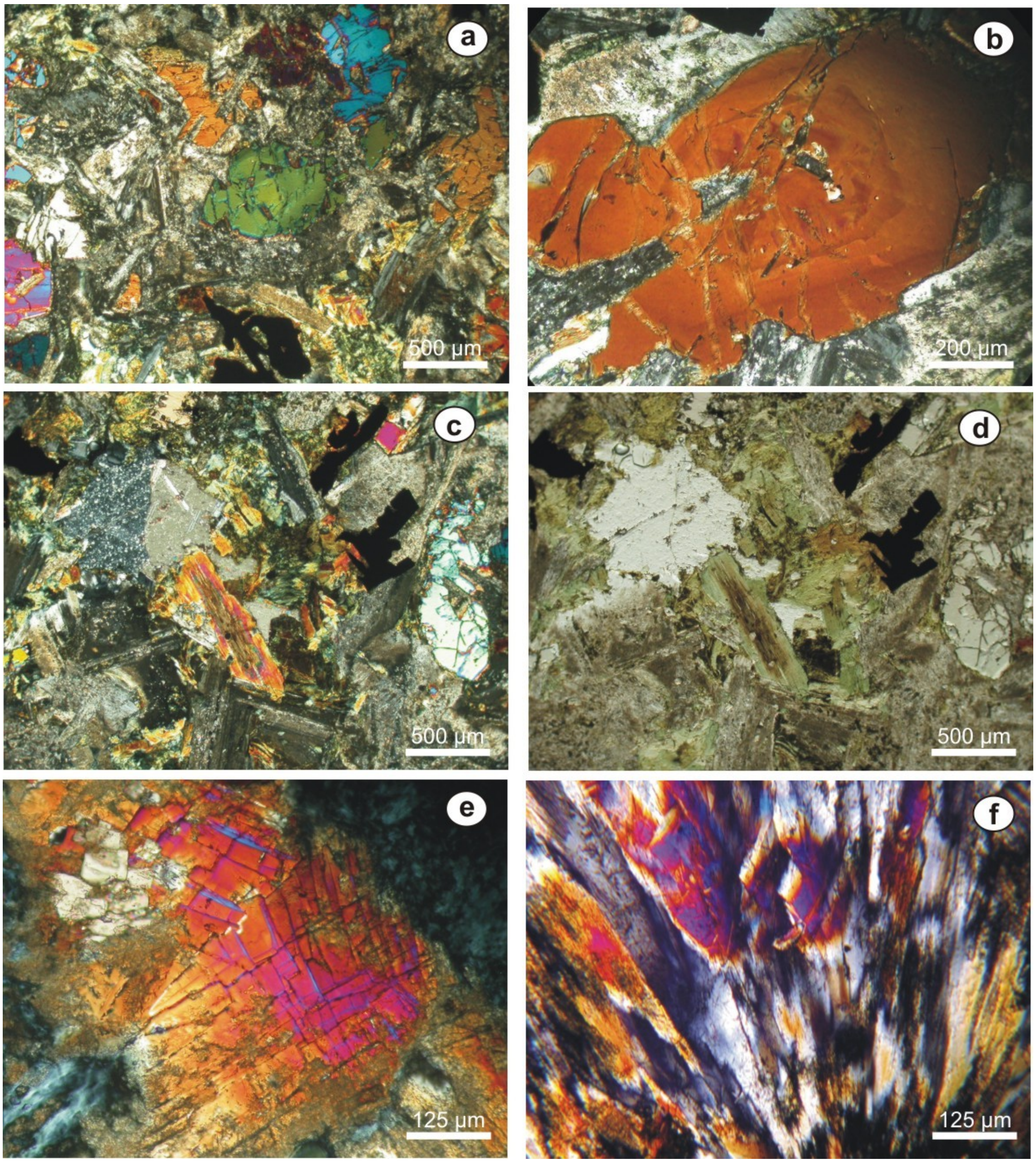

Fig. 3.7: Microphotographs of VG samples showing **a)** plagioclase and zoned augite crystals; **b)** concentrically zoned clinopyroxene; **c)** and **d)** chloritized biotite and skeletal ilmenite crystals; **e)** actinolite grain; **f)** actinolite/prehnite intergrowth filling a vein.

3.2.2 “Roccapalumba-Margana-Lercara” dykes

- *“Contrada Margana” dykes (MA samples)*

MA samples show an equigranular fine to coarse-grained texture mainly consisting of plagioclase, biotite/chlorite, quartz, calcite and opaque minerals, where the original ophitic texture and the primary mafic phases, are now completely overprinted by crystallization of a secondary chloritic assemblage (Fig. 3.8a, b).

Plagioclase is euhedral and twinned according to the albite or albite-Carlsbad laws. It is heavily altered to clay minerals and largely albitized. Albitization is sometimes associated with development of chessboard textures. No compositional zoning is observed. Occasionally, plagioclase crystals show a parallel alignement (Fig. 3.8c) suggesting a preferential orientation in the magmatic flow.

Biotite, small and interstitial, is mostly completely replaced by chlorite (Fig. 3.8e, f).

Rare and small quartz grains also occur as interstitial phase or as minute aggregates filling veins.

Skeletal, dendritic and sub-parallel ilmenite rods are very abundant (Fig. 3.8d).

Acicular apatite also occurs as an accessory phase.

Secondary phases consists of clay minerals, chlorite, calcite and Fe-oxides.

The “Contrada Margana” outcrop is characteristically locally cut by narrow red dykes. Grain size of the magmatic host rock decreases while color index increases towards the contact zone with the red dykes. These are essentially composed of plagioclase, abundant quartz, chlorite, calcite and opaque minerals. Characteristically, at the contact zone, euhedral plagioclases of the host rocks show overgrowths of fan-like reddish plagioclase.

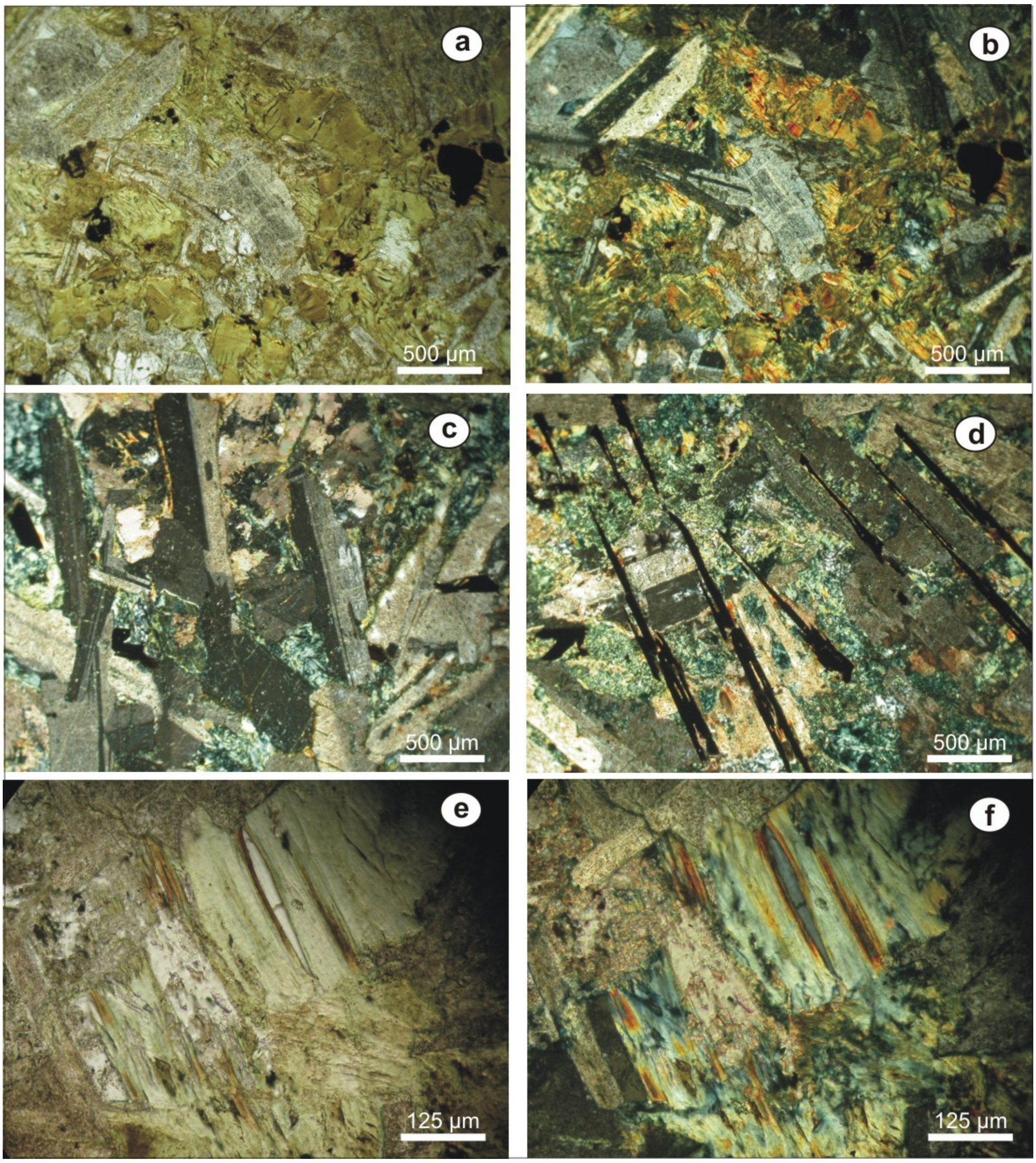

Fig. 3.8: Representative microphotographs of MA samples showing **a)** and **b)** Carlsbad twinned plagioclase crystals set in a fine grained chlorite aggregate; **c)** parallel aligned twinned plagioclase; **d)** skeletal and aligned ilmenite crystals; **e)** and **f)** chloritization of biotite.

- "*Bivio Manganaro*" dyke (BM samples)

BM samples are holocrystalline, mainly fine to coarse grained, equigranular rocks essentially made up of plagioclase, quartz, biotite/chlorite, ilmenite and calcite (Fig. 3.9a, b).

Fine-grained samples are characterized by a variolitic texture defined by fan-like plagioclase arrangement.

On the whole, euhedral plagioclase is commonly twinned according to albite-Carlsbad and albite –periclino laws; antiperthite textures are also common.

In addition, although secondary minerals (e.g. calcite, epidote and clay minerals) occasionally grow at expense of plagioclase, concentric zoning is seldom observed.

Also in these samples, the abundant chlorite widespread in the matrix derives from the alteration of primary mafic grains, now totally transformed in chlorite aggregates (Fig. 3.9a, b).

Interstitial and very small biotite lamellaes are also almost completely replaced by chlorite (Fig. 3.9d).

Finally, anhedral and small quartz grains also occur in the matrix.

Ilmenite forms equant or elongated skeletal grains partially replaced by rutile (Fig. 3.9c).

Needles of apatite that represents a very common accessory phase, mainly growth on the quartz grains. In addition to chlorite, epidote, clay minerals and calcite, acicular pumpellyite grains have been found locally as post-magmatic phase.

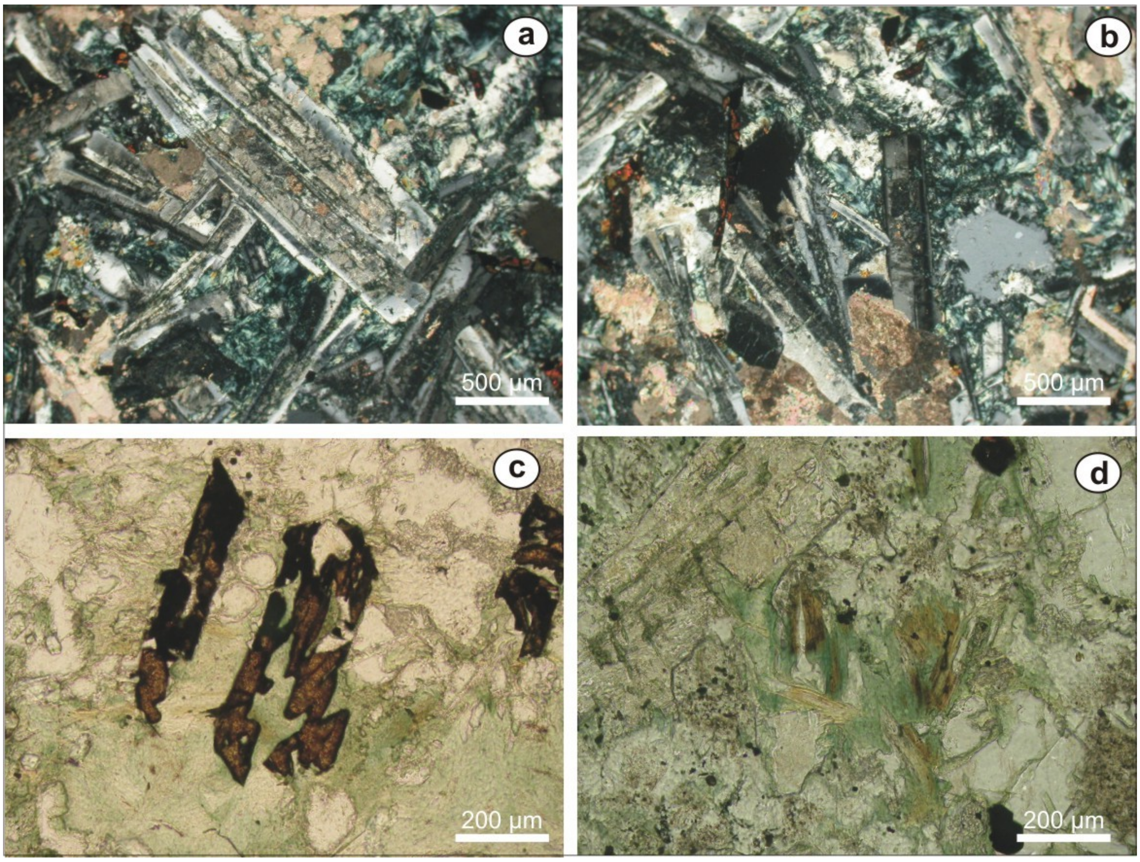

Fig. 3.9: Representativemicrophotographs of BM samples showing **a)** concentrically zoned and twinned plagioclase; **b)** zoned plagioclases and fine grained chlorite aggregate replacing primary mafic grains; **c)** skeletal ilmenite transformed in rutile; **d)** chloritized biotite.

3.3 Remarks on hydrothermal metamorphism

Several petrographic features observed within a number of studied dykes are typical of rocks affected by hydrothermal alteration. In particular, the occurrence of calcite together with pumpellyite/prehnite and chlorite marks the beginning of sub-greenschist facies metamorphism and the various changes in composition of primary rocks resulting from metasomatism typically accompany metamorphism at variable extent.

The term hydrothermal metamorphism is usually referred to the formation of metamorphic minerals deriving from the interaction of a rock with circulating aqueous fluids. In addition, according to some authors (e.g*., Frey et al., 1991; Alt, 1995; Schiffman and Day, 1995; Frey and Robinson, 1999*), the terms “alteration” and “metamorphism”, in the earliest phases, could be used interchangeably, even if the former indicates the partial recrystallization of rocks at lower temperatures (<100°C down to 0°C), and the latter is limited to the formation of minerals that characterize metamorphic facies at higher temperatures.

On the whole, hydrothermal metamorphism of basaltic rocks leads to extensive recrystallization, even if igneous primary textures can be well preserved.

The most significant modification consists of the albitization of plagioclase and replacement of mafic minerals, mostly by chlorite.

The former process causes the release of Ca and Al that promotes crystallization, within veins or within the primary plagioclase itself, of calcite, mafic layer silicates, and calc-silicates such as prehnite, pumpellyite, epidote and titanite.

Release of Al is also important for recrystallization of titanite after Fe-Ti oxides.

Clinopyroxene usually suffers replacement by actinolite (uralitization) and in a lesser extent by chlorite.

Fe-Ti oxides, principally titanomagnetite and ilmenite, may be pseudomorphosed by mixtures of low Ti-magnetite and titanite or, in low pH and high fluid/rock conditions, by a mixture of low Ti magnetite and TiO_2 (rutilo or anatase).

All these mechanisms could be invoked to explain the petrographic features observed in studied rocks. In addition, in the case of BM and MA samples (Roccapalumba – Margana – Lercara area), circulation of Ca-rich fluids could be considered responsible for the production of the observed large and abundant patchy calcite.

On the whole, the features detected in the studied rocks that can be ascribed to hydrothermal metamorphism are:

- extensive albitization of plagioclase,
- high abundance of secondary chlorite
- uralitization of pyroxene,
- widespread crystallization of epidote and calcite,
- rutile replacement of primary ilmenite grains;
- occurrence of phrenite/pumpellyite grains in VG and BM Sicilian dykes.