CHAPTER FIVE: PETROGRAPHY

This work follows the international standard nomenclature (IUGS) in naming the different Platreef rock types. It should be noted that new lithologies not described in chapter 3 (Geology of the Platreef on Nonnenwerth), e.g. recrystallized gabbronorite will be discussed in this chapter. It was not possible to pick up such lithologies on hand specimen as these rocks are relatively thin and occur at the interface between two different lithologies probably as a secondary feature i.e. recrystallization.

The modal abundances of major rock forming minerals are given below.

Rock type	Plag-ioclase (modal %)	Ortho-pyroxene (modal %)	Clino-pyroxene (modal %)	inverted pigeonite (modal %)	Minor phases
Platreef Gabbronorite and recrystallized	46-68	32-48	5-10	15-20	amphibole, biotite, magnetite, sericite and sulphides
norite	60 - 70	25-30	2-5		amphibole, sericite, chlorite, sulphides
Recrystallized norite	60-70	25-30	2-5		sulphides, sericite
Anorthosite	90-97	1-3	<1 - 7		sericite, amphibole, sulphides
Gabbro	58 - 62		38-42		sericite, chlorite, amphibole and spinel
Main Zone gabbronorite	55-65	10-15	8-10	5-10	amphibole, sericite, biotite, sulphides, clay

5.1 Platreef

5.1.1 Gabbronorite

Gabbronorites are the most abundant rocks at Nonnenwerth and constitute about 80 - 85 % of the Platreef. The gabbronorites are mostly medium grained, but finer grained varieties may occur in places. Plagioclase (48 - 65 modal %) occurs as subhedral, equant to prismatic, poorly twinned crystals (up to 4 mm) and as an interstitial phase. The crystals show evidence of minor deformation in the form of bent lamellae (Fig. 5.1a). Slight deuteric alteration to sericite (particularly along cracks and fractures) and to patchy, fine grained, brown clays is common (Figs. 5.1b, c and d).

Orthopyroxene (32 - 48 modal %) forms subhedral granular crystals and anhedral poikilitic crystals (up to 1.5 mm) enclosing anhedral plagioclase crystals that are mostly < 0.3 mm in size (Fig. 5.1e). Orthopyroxene typically contains irregular exsolution lamellae and blebs of clinopyroxene. Minor to moderate alteration of orthopyroxene to uralite along cleavage planes (Figs. 5.1b and c) and along grain margins to amphibole, biotite and oxides is common.

Clinopyroxene (5 – 10 modal %) forms anhedral and subhedral grains, reaching up to 7 mm in size that may form simple twins. Orthopyroxene exsolution lamellae are developed parallel to prismatic cleavages. They may coalesce to form blebs that are mostly altered to amphibole and sericite, with iron oxides forming along the cleavage planes. Clinopyroxene is commonly replaced by hydrothermal veinlets filled with uralite.

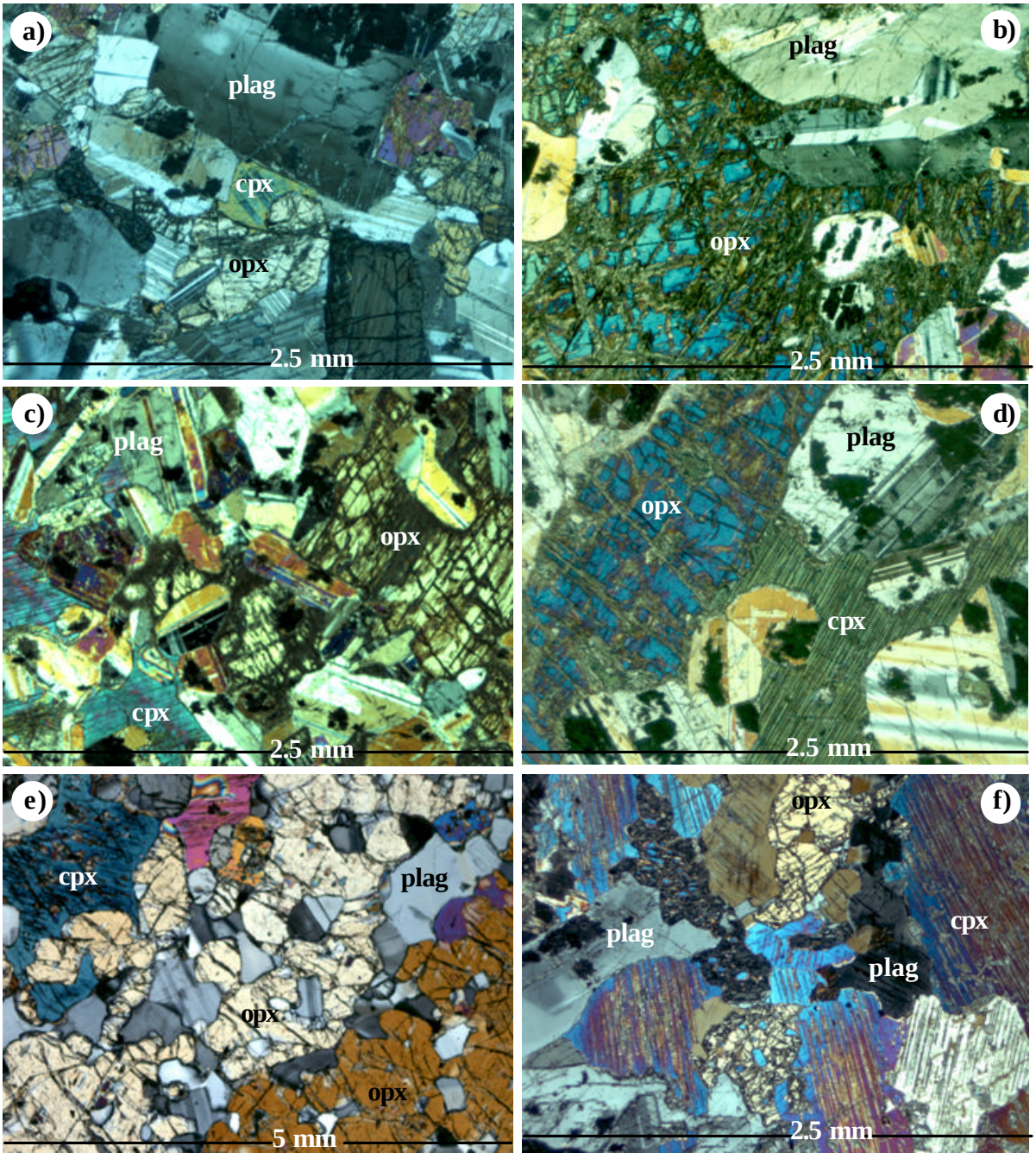

Fig. 5.1: **Platreef Gabbronorite** (a) Cumulus plagioclase (plag) and orthopyroxene (opx) with interstitial clinopyroxene (cpx), sample MO 20. (b, c and d) Orthopyroxene moderately altered to uralite along fractures, samples MO 63, MO 65 and MO 68, respectively. Note the patchy alteration to dark brown clays in plagioclase, the intercumulus nature of clinopyroxene, and the poikilitic nature of orthopyroxene and clinopyroxene. (e) Poikilitic orthopyroxene enclosing plagioclase. Clinopyroxene is interstitial and partially encloses orthopyroxene, sample MO 20. (f) Cumulus and intercumulus plagioclase intergrown with clinopyroxene that partially encloses orthopyroxene, sample MO 74. Transmitted cross polarised light.

Inverted pigeonite (15 - 20 modal %) is developed in places. This forms poikilitic, anhedral or subhedral crystals that enclose corroded plagioclase and, occasionally, clinopyroxene and orthopyroxene. Inverted pigeonite is characterised by thick, bleb-like lamellae of exsolved augite. Occasionally, two sets of augite exsolution lamellae are developed with the second set at about 74^0 to (100) in the zone of (010).

Minor phases are biotite, magnetite and sulphides. Biotite occurs around altered orthopyroxene where the latter is in contact with plagioclase or as flakes in orthopyroxene metamorphosed to amphibolite facies grade. The sulphides (< 1 modal %) consist of pyrrhotite, pentlandite, chalcopyrite and pyrite. Chalcopyrite and pyrrhotite occur intergrown in small interstitial blebs, or as fine disseminations in orthopyroxene altered to amphibole and chlorite. Pyrite forms veinlets, predominantly in plagioclase. Magnetite is interstitial and tends to be associated with the sulphides. In general, the rocks are poorly mineralized.

5.1.2 Norite

Norites constitute ca. 3 to 5 % of the Platreef rocks. Norites occur as medium grained rocks with no obvious mineral fabric. They are composed mostly of plagioclase and orthopyroxene with minor interstitial augite. Plagioclase (60 to 70 modal %) is mostly an intercumulus phase (Fig. 5.2a). It occurs as anhedral or subhedral, medium grained (up to 1.5 mm) oikocrysts as well as equant and lath-shaped crystals. Occasionally, polysynthetic twinning may be developed. Moderate to strong alteration of plagioclase to sericite and to patchy, dark brown, fine grained, clays is common.

Orthopyroxene (25 to 30 modal %) occurs as medium grained (< 2 mm) subhedral, equant to elongate, prismatic grains (Fig. 5.2a). Fine clinopyroxene exsolution lamellae are commonly developed in the orthopyroxene crystals. Orthopyroxene grains are occasionally altered along fractures. Alteration minerals are fine grained brown amphibole (uralite) and chlorite which may also partially replace adjacent plagioclase grains. Orthopyroxene may occasionally enclose a few plagioclase grains.

Augite is a minor interstitial phase constituting generally between 2 - 5 modal %, and forming anhedral grains that occasionally enclose small rounded orthopyroxene and plagioclase grains (Fig. 5.2c). Thin (100) lamellae of exsolved orthopyroxene are commonly developed. Augite may be altered to chlorite and amphibole, mostly along cleavage planes, with the alteration phases sometimes invading adjacent plagioclase. In places, norites may be biotite- and sulphide-rich (up to 5 modal %). Sulphides consist of chalcopyrite and pentlandite with minor pyrrhotite and secondary pyrite. Sulphides and biotite occur associated with each other in the interstitial space (Fig. 5.2d). Pyroxenes located adjacent to the biotite and sulphides tend to be highly altered to fine grained amphibole and chlorite.

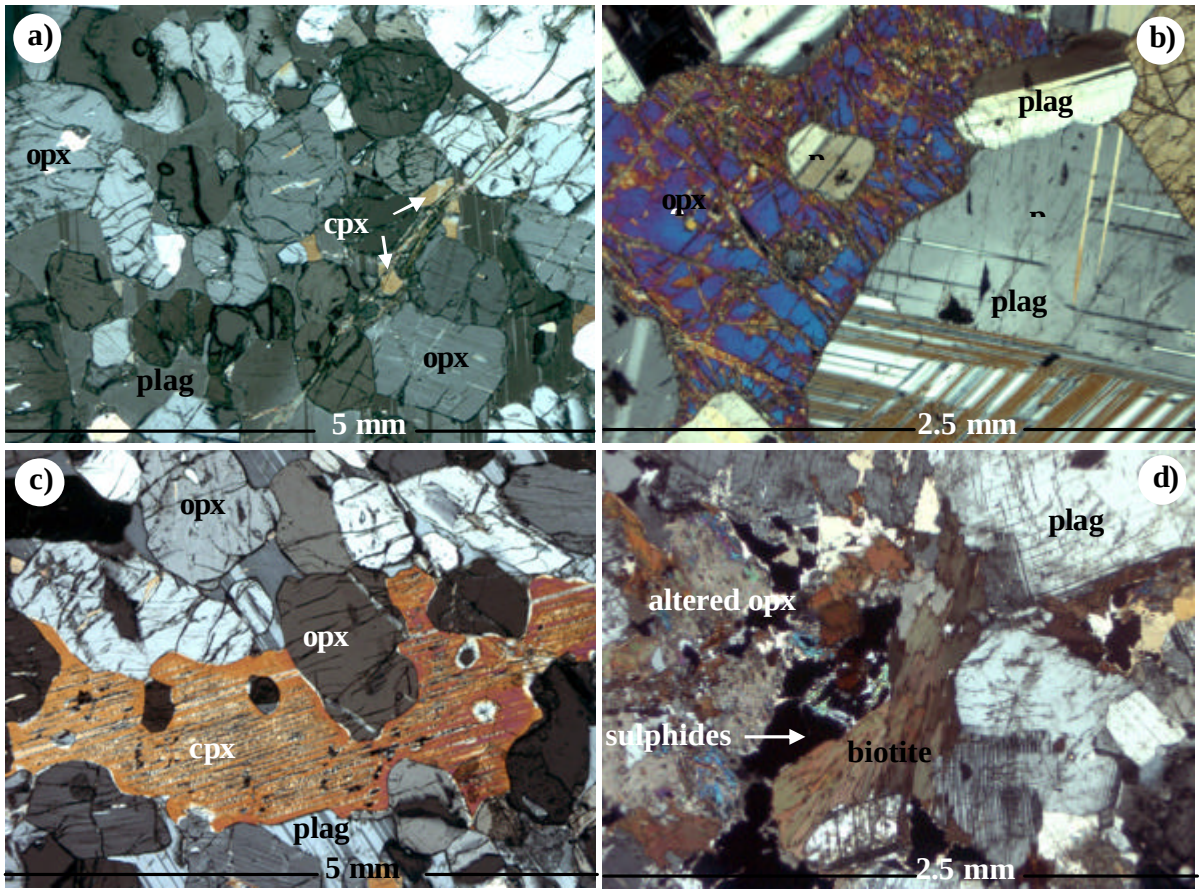

Fig. 5.2: **Norite:** (a) Cumulus orthopyroxene (opx) intergrown with interstitial plagioclase (plag), and minor clinopyroxene (cpx), sample MO 67. (b) Orthopyroxene interstitial to plagioclase and containing anhedral inclusions of plagioclase, sample MO 19. (c) Cumulus orthopyroxene with intercumulus plagioclase and clinopyroxene. Note the small, subrounded orthopyroxene enclosed in clinopyroxene. Sample MO 18. (d) Cumulus plagioclase and orthopyroxene highly altered to amphibole and chlorite with interstitial sulphides rimmed by brown biotite, sample MO 75. Transmitted cross polarised light.

5.1.3 Recrystallized gabbronorite and norite

5.1.3.1 Recrystallized gabbronorite

Recrystallized gabbronorites occur mostly towards the upper half of the Platreef where they form relatively thin layers at the contact between different rock types, possibly due to shearing during intrusion. They constitute ca. 4 - 6 % of the Platreef

rocks. The recrystallized gabbronorites are fine- to medium grained and characterised by clusters of small (up to 0.4 mm) orthopyroxene and plagioclase crystals that are situated between, and adjacent to, coarse plagioclase, orthopyroxene and clinopyroxene crystals (Fig. 5.3a and b). Modal proportions of the minerals are similar to those of other gabbronorites in the Platreef.

Plagioclase forms coarse (up to 6 mm) subhedral crystals that are polysynthetically twinned, or small (up to 0.4 mm) subrounded and recrystallized grains. The large plagioclase grains have bent twin lamellae and show undulose extinction (Fig. 5.3b). The lamellae may be tapered away from grain margins. Fine grained plagioclase occurs as interlocking grains with 120° triple junctions (Fig. 5.3a and b). The above features suggest deformation. Plagioclase is slightly to moderately altered to sericite and patchy dark brown clays.

Orthopyroxene may form coarse, anhedral (up to 5 mm) crystals enclosing plagioclase, or aggregates of small (< 0.3 mm) subhedral to subrounded crystals with 120^0 triple junctions (Fig. 5.3a and c). Orthopyroxene is commonly altered to uralite along fractures and cleavage planes. Clinopyroxene may occur as coarse, up to 10 mm, but more often less than 3 mm wide grains containing orthopyroxene exsolution lamellae and simple twins (Fig. 5.3b). The coarser grains are often deformed as evidenced by bent/curved orthopyroxene lamellae (Fig. 5.3c). Sulphides (up to 4 modal %) include pyrrhotite, subordinate chalcopyrite and pentlandite, and minor

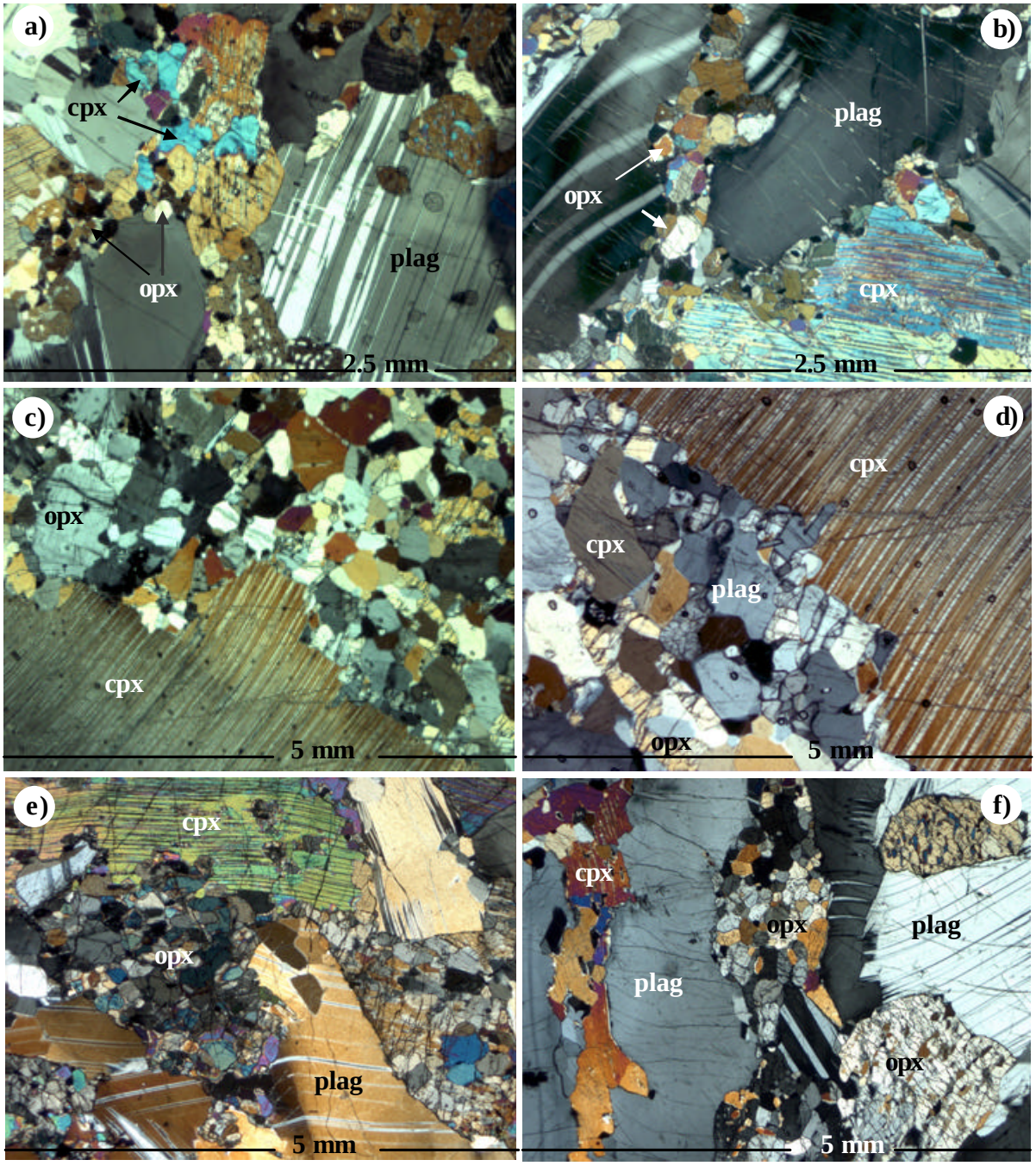

Fig. 5.3 **Recrystallized gabbronorite** (a and b) Recrystallized orthopyroxene (opx) and minor clinopyroxene (cpx) along deformed plagioclase grain boundaries, sample MO 70. (c and d) Recrystallized gabbronorite in contact with coarse clinopyroxene from medium to coarse grained gabbronorite, sample MO 66. Note the bent lamellae in clinopyroxene and plagioclase. (e and f) Recrystallized orthopyroxene and clinopyroxene along strained plagioclase margins and fractures, sample MO 12 and MO 70, respectively. Transmitted cross polarised light.

pyrite. Rare intergrown magnetite and ilmenite grains may be associated with recrystallized orthopyroxene grain boundaries or they may occasionally be intergrown with pyrrhotite.

It is notable that gabbronorite adjacent to the recrystallized domains tends to be extensively hydrothermally altered. As a result the pyroxenes are altered to amphibole and chlorite and cut by hydrothermal veinlets filled with fine grained amphibole. Plagioclase is chloritised and sericitised, particularly when in contact with interstitial sulphides. The fluids responsible for this alteration were probably derived from the recrystallized domains. Importantly, the recrystallized gabbronorite and the adjacent altered gabbronorite are among the best mineralized lithologies.

5.1.3.2 Recrystallized norite

Norites within the Platreef may also locally be recrystallized, constituting ca. 1 % of the Platreef. The rocks occur at and towards the base of the Platreef. They are fine grained and show no change in modal abundances relative to undeformed norites. Plagioclase (60 to 70 modal %), is anhedral or subhedral, lath-shaped and mostly of intercumulus habit (Fig. 5.3g). Occasionally, polysynthetic twinning may be developed and the plagioclase may enclose orthopyroxene (Fig. 5.3g).

Orthopyroxene (25 to 30 modal %) occurs as fine grained (< 0.5 mm) subhedral, equant to elongate or subrounded crystals (Fig. 5.3 g and h). Orthopyroxene may occasionally enclose plagioclase grains. Augite is a minor interstitial phase constituting generally between 2 - 5 modal % of the rock and forming anhedral grains

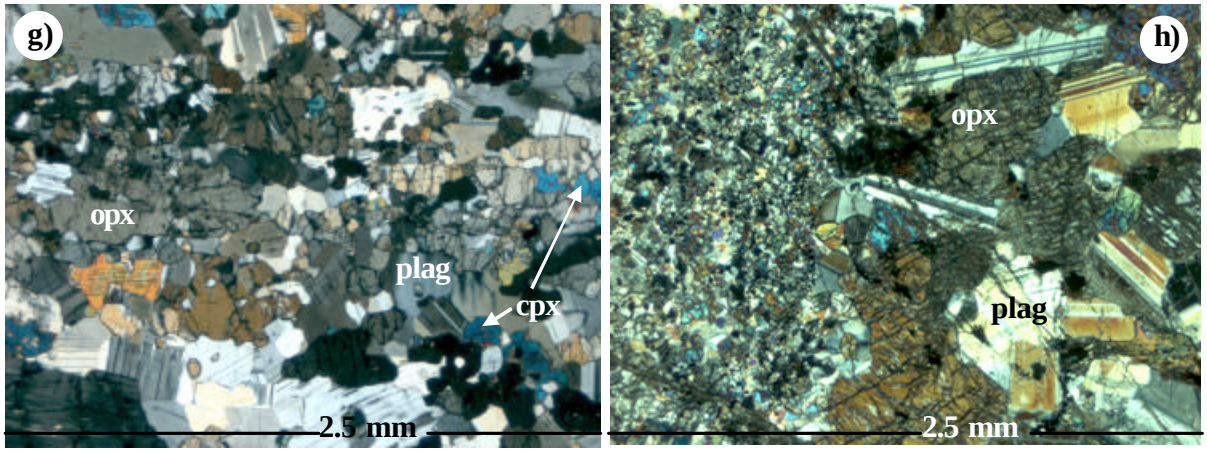

Fig. 5.3: **Recrystallized norite:** (g) Subrounded orthopyroxene intergrown with plagioclase and in places enclosed in plagioclase, sample MO 17. (h) Fine-grained recrystallized norite in contact with medium grained gabbronorite, sample MO 84.

that occasionally contain thin (100) lamellae of exsolved orthopyroxene. Recrystallized norite is generally barren containing only traces of chalcopyrite, pentlandite and pyrrhotite.

5.1.4 Anorthosite

Anorthosites constitute ca. 9 – 11 % of the Platreef rocks. The anorthosites are medium-grained or, locally, pegmatoidal. They contain between 1 and 7 modal % pyroxene. Plagioclase (90 - 97 modal %) occurs as randomly oriented, elongate, subhedral cumulus crystals (up to 25 mm long) forming an adcumulate texture (Fig. 5.4a). In pegmatoidal varieties, plagioclase may be replaced by clinopyroxene along cleavage planes (Fig. 5.4b and c.). Most plagioclase crystals have irregular margins but are mutually interlocking with each other. Patchy alteration to dark brown, fine grained clays is pronounced giving the thin section and hand specimen a white speckled appearance when viewed with the naked eye. Along grain boundaries with oxides, plagioclase may be altered to radiating chlorite, minor amphibole and biotite.

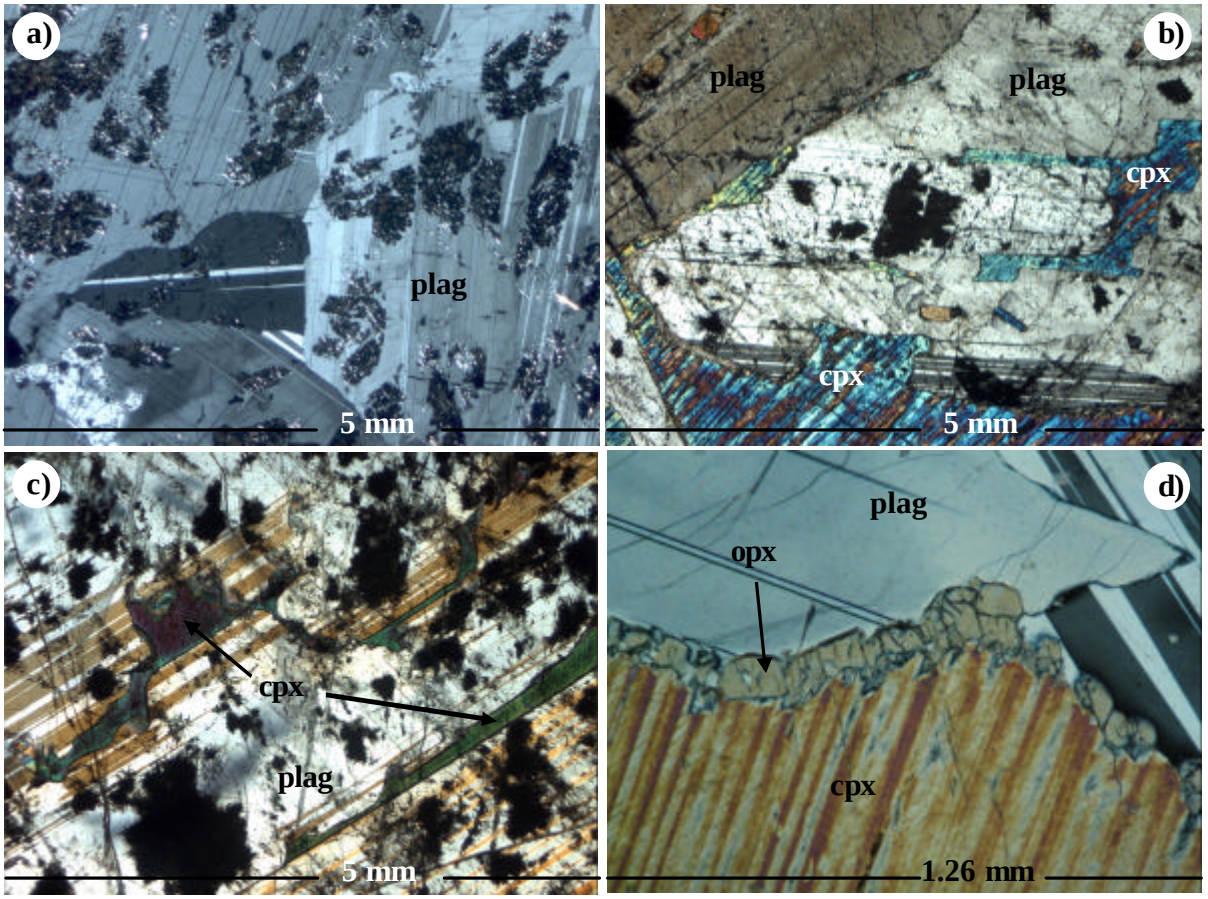

Fig. 5.4. **Anorthosite** a) Plagioclase (plag) crystals patchily altered to dark brown clays, sample MO 8. (b and c) Plagioclase replaced by clinopyroxene (cpx) along cleavage planes and fractures. Also note the patchy alteration to dark brown clays, sample MO 68 and MO 73, respectively. (d) Clinopyroxene rimmed by orthopyroxene (opx) – plagioclase intergrowth when in contact with plagioclase, sample MO 27. Transmitted cross polarised light.

In fractures, sericite alteration dominates.

Clinopyroxene (< 1 – 7 modal %) forms large interstitial crystals (up to 9 mm long) that contain orthopyroxene lamellae along the prismatic cleavage. Some portions of the grains are hydrothermally altered to tremolite and oxides. Clinopyroxene locally includes small plagioclase grains (~1 mm). When in contact with plagioclase, clinopyroxene is rimmed by coronas of orthopyroxene – plagioclase intergrowth (Fig.

5.4d) suggesting localized partial melting processes resulting from emplacement of the gabbronorites. Crystallization of the melt produced plagioclase and orthopyroxene at the expense of clinopyroxene. Orthopyroxene (1 – 3 modal %) forms coarse interstitial grains, up to 9 mm in size, containing fine clinopyroxene exsolution lamellae. The orthopyroxene crystals may be partially altered to green amphibole. Sulphides (~ 3 modal %) mostly occur interstitial to, or along, plagioclase fractures and include pyrrhotite, subordinate chalcopyrite and pentlandite, and minor pyrite.

5.1.5 Gabbro

Gabbros are rare in the Platreef and occur as thin lenses within gabbronorites. The gabbros are medium grained rocks consisting mostly of plagioclase (58 - 62 modal %) and clinopyroxene (38 – 42 modal %). Plagioclase occurs as elongate subhedral to euhedral laths which display polysynthetic twinning and have no preferred orientation. The crystals are mostly unaltered, although minor sericite alteration may occur along fractures. Fine grained dark brown clays may form patchy zones within the crystals.

Clinopyroxene forms large (up to 9 mm) cumulus or interstitial, anhedral or subhedral crystals, with orthopyroxene lamellae occurring along prismatic cleavage planes. The orthopyroxene lamellae may coalesce and form blebs (Fig. 5.5a and c). Some crystals are hydrothermally altered to chlorite, amphibole and minor green spinel. When in contact with plagioclase, clinopyroxene reacts to form orthopyroxene coronas (Fig. 5.5c). Orthopyroxene is a minor phase and occurs as cumulus or intercumulus crystals with abundant fine clinopyroxene exsolution lamellae. Orthopyroxene is moderately to intensely altered to fine grained uralite.

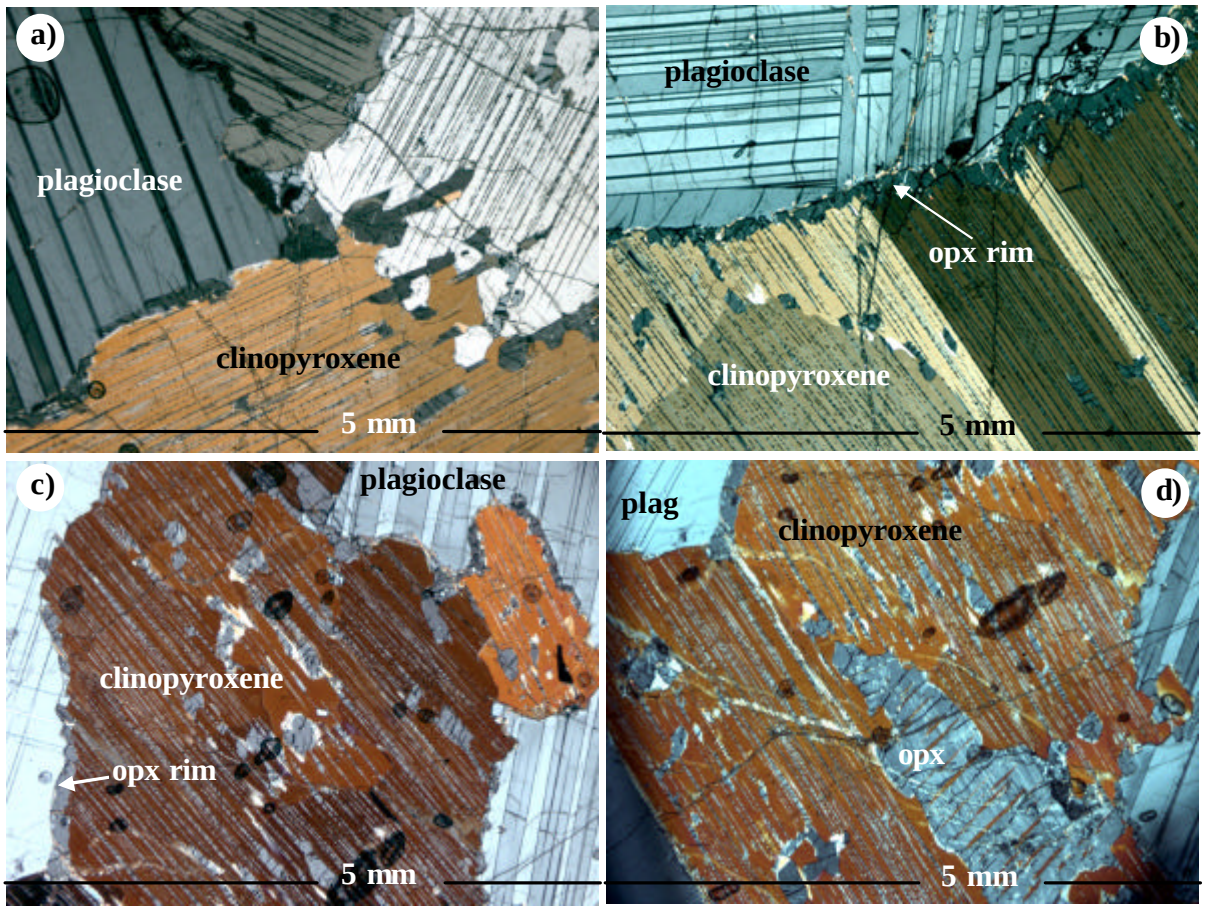

Fig. 5.5: **Gabbro** (a-d) Clinopyroxene with exsolved blebs and lamellae of orthopyroxene (opx) intergrown with plagioclase. Note the thin orthopyroxene corona around clinopyroxene when in contact with plagioclase in Fig. 5.4b.

5.1.6 Serpentinized peridotite

Serpentinites constitute les than 2 % of the Platreef rocks. These include some partially altered peridotites (Figs. 5.6a and b) occurring near the base of the sequence (Figs. 3.2 and 3.16). Serpentine occurs as veinlets and flakes replacing olivine with very high Fo contents (average 90). Subrounded and occasionally corroded orthopyroxene crystals are partially altered to green amphibole. Secondary hydrous minerals include biotite, chlorite and amphibole. Chlorite and amphibole are mostly found associated with the oxides.

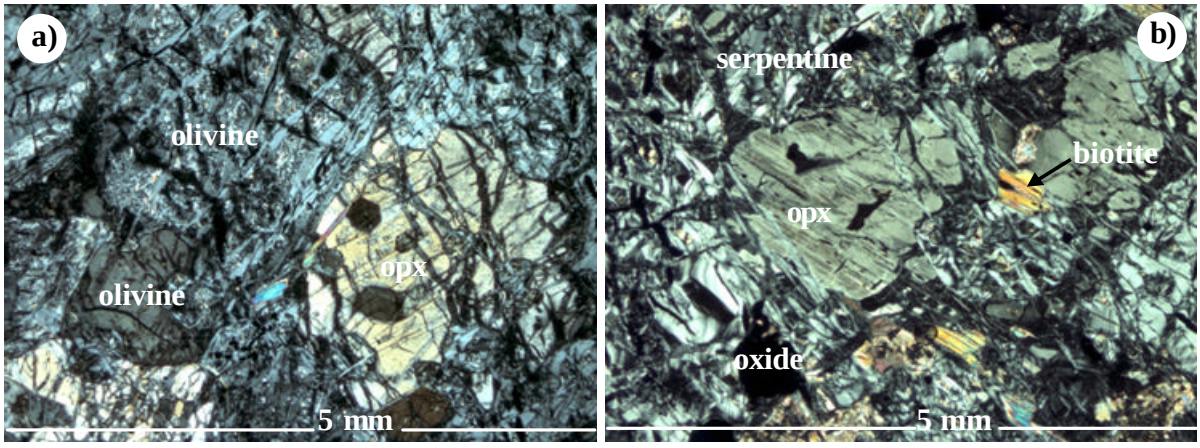

Fig. 5.6: **Serpentinized peridotite** (a and b) Relict, partially serpentinised olivine and orthopyroxene, sample MO 26. Note the biotite flakes intergrown with serpentine in b. Transmitted cross polarised light.

5.2 Main Zone

In the two boreholes examined, the Main Zone consists of medium grained gabbronorite characterised by plagioclase, orthopyroxene, inverted pigeonite and augite. The gabbronorite has an adcumulus to mesocumulate texture and exhibits a subtle mineral fabric defined by sub-parallel alignment of pyroxene and plagioclase laths (Fig. 5.7a).

Plagioclase (55 to 65 modal %) forms subhedral or euhedral, equant or lath-shaped, mostly medium-grained (up to 9 mm) cumulus grains. The grains show prominent polysynthetic twinning. Plagioclase shows evidence of increased deformation with depth, characterised by bent twin lamellae and undulous extinction (Fig. 5.7a and b). Alteration of plagioclase to patchy, fine grained dark brown clays and sericite is common.

Orthopyroxene (10 – 15 modal %) forms medium grained (0.5 to 8 mm), subhedral or anhedral, equant to prismatic, cumulus and intercumulus grains. The orthopyroxene grains are weakly pleochroic in pale yellowish-brown to pale green shades. Orthopyroxene may be subophitic, partially enclosing undeformed (< 1.5 mm) plagioclase laths, and has a single set of bleb-like augite exsolution lamellae parallel to the prismatic cleavage (100). Orthopyroxene is partially altered along fractures and grain boundaries to fine grained brown amphibole (uralite), disseminated iron oxides and minor biotite, but in some cases most of the grains may be altered to green amphibole. Biotite occurs as small < 1 mm brown flakes mostly associated with interstitial sulphides in contact with pyroxenes.

Inverted pigeonite (5 – 10 modal %) occurs as anhedral, sub-poikilitic to poikilitic crystals with thick bleb-like lamellae of exsolved augite (Figs. 5.7e). Occasionally, two sets of augite exsolution lamellae are developed with the second set at about 74^0 to (100) in the zone of (010) (Figs. 5.7f). This suggests that the orthopyroxene is an iron-rich hypersthene. Plagioclase crystals may occur ophitically enclosed in inverted pigeonite (Fig. 5.7f).

Augite (8-10 modal %) forms cumulus or interstitial, subhedral or anhedral grains (up to 4.3 mm wide). The grains may show simple twinning and thin (100) lamellae of exsolved orthopyroxene. The crystals are slightly altered to fine grained amphibole, mostly along cleavage planes and internal fractures.

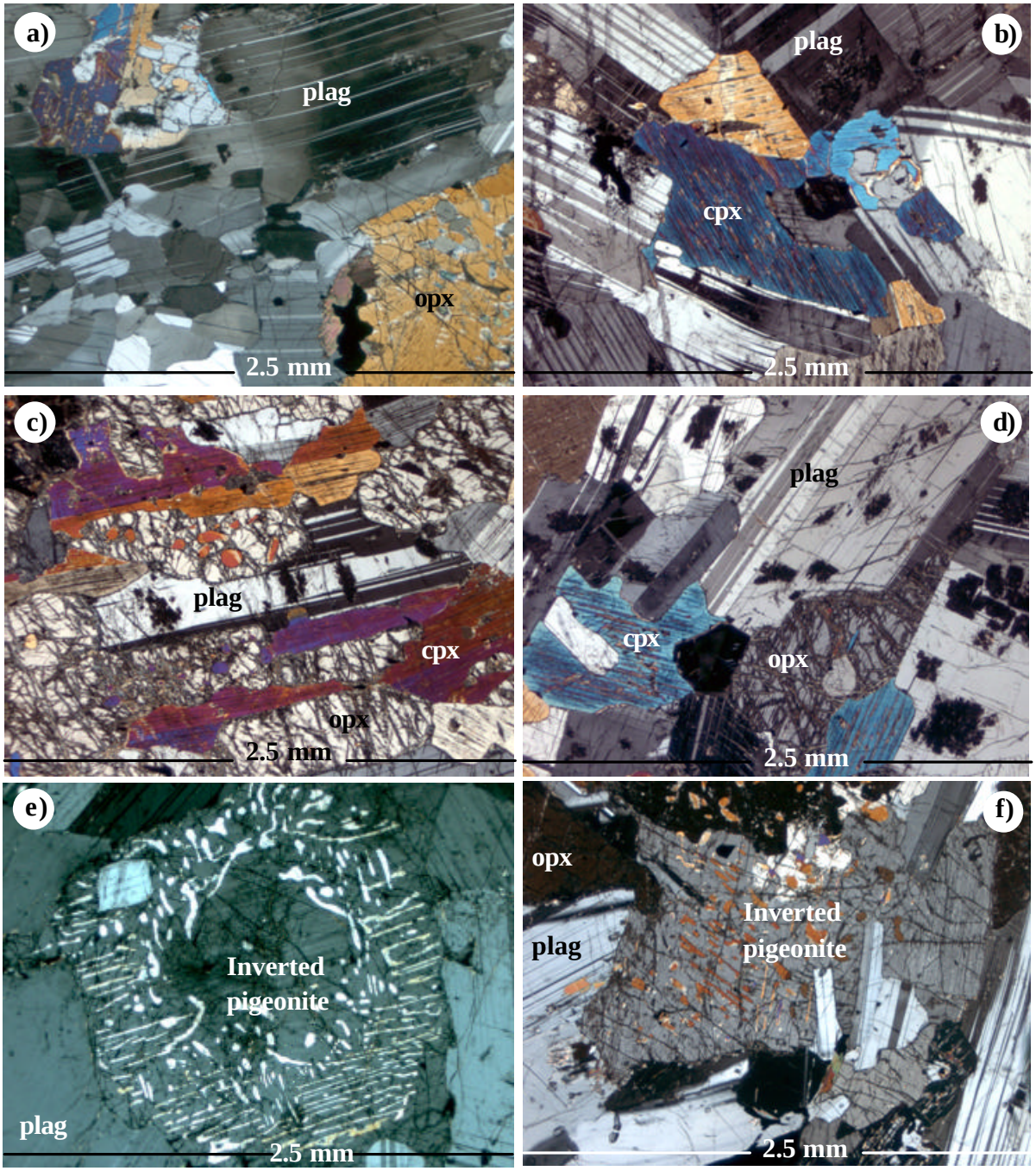

Fig. 5.7 **Gabbronorite** (a) Deformed and recrystallized plagioclase showing 120^0 triple junctions and bent twin lamellae. Small corroded plagioclase grains are enclosed in orthopyroxene (opx), sample MO 4. (b) Interstitial clinopyroxene intergrown with cumulus plagioclase. Note the deformed twin lamellae in plagioclase; sample MO 50. (c) Orthopyroxene replacing clinopyroxene, sample MO 51. (d) Interstitial clinopyroxene and orthopyroxene intergrown with cumulus plagioclase that shows patchy alteration to dark brown clays. (e and f) Sub-poikilitic inverted pigeonite with two sets of exsolved augite lamellae, sample MO 2.