CHAPTER FOUR: PETROGRAPHY

4.1 Sedimentary Rocks

The sedimentary rocks of the Silverton Formation that form the floor rocks to the Platreef on the farm Townlands consist of shales (hornfelsed when in contact with the intrusion), quartzites and calcsilicates.

The hornfels are ferruginous and mostly consist of fine grained quartz, plagioclase, and magnetite as the major phases with minor cordierite, spinel, hornblende, orthopyroxene and biotite. They display a non foliated fine grained texture typical of hornfels. Plagioclase ranges from 30-40 modal %, quartz from 15-25 modal % and magnetite from 30-40 modal %. Plagioclase is anhedral with grain sizes generally < 1 mm. Slight alteration of plagioclase to sericite is common and the grains often show evidence of deformation expressed by bent lamellae. Quartz is fine-grained (< 1mm) and anhedral with serrated grain boundaries suggesting recrystallisation. Magnetite is anhedral and has a poorly developed skeletal texture. Cordierite is fine grained (≤ 1mm) and anhedral. The crystals are altered along cracks. Spinel is fine-grained (< 0.2mm), transluscent and is found associated with magnetite grain boundaries. Biotite occurs as alteration product of plagioclase and magnetite, and is found mostly surrounding magnetite. Orthopyroxene is mostly elongate (1-3 mm in size) and encloses tiny plagioclase crystals.

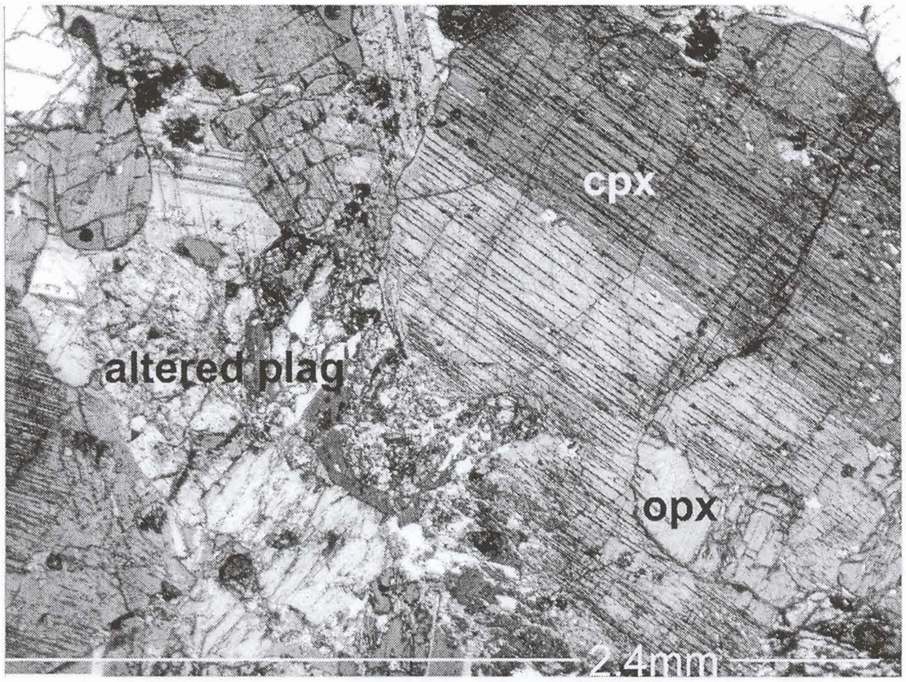

Fig. 4.13: Poikilitic, twinned clinopyroxene (cpx), with orthopyroxene exsolution lamellae enclosing orthopyroxene (opx). Sample TM 1. Transmitted light.

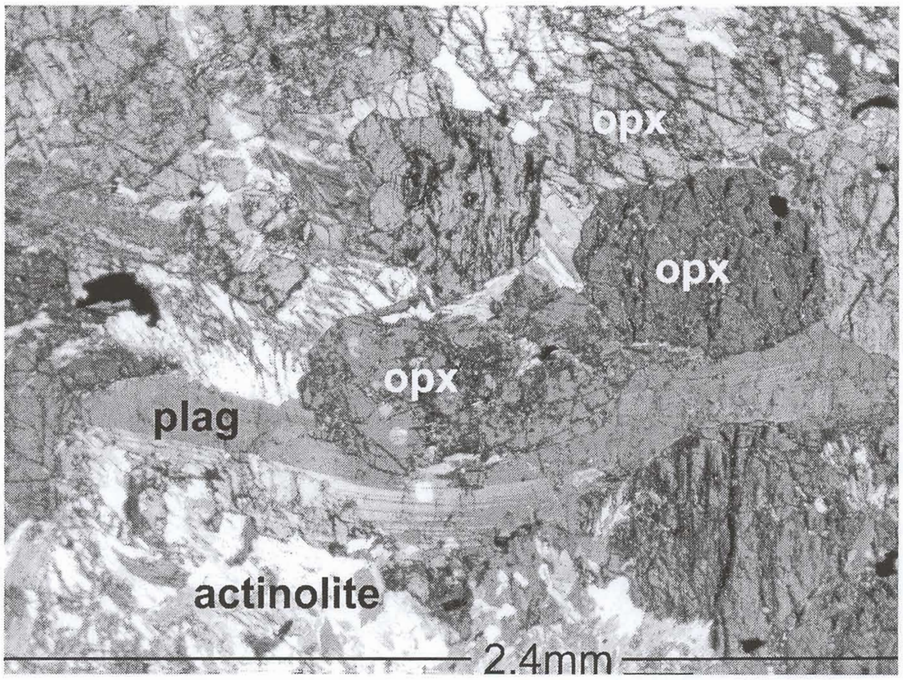

Fig. 4.14: Deformed plagioclase (plag) lamellae in feldspathic pyroxenite. Sample TM 9. Transmitted light.

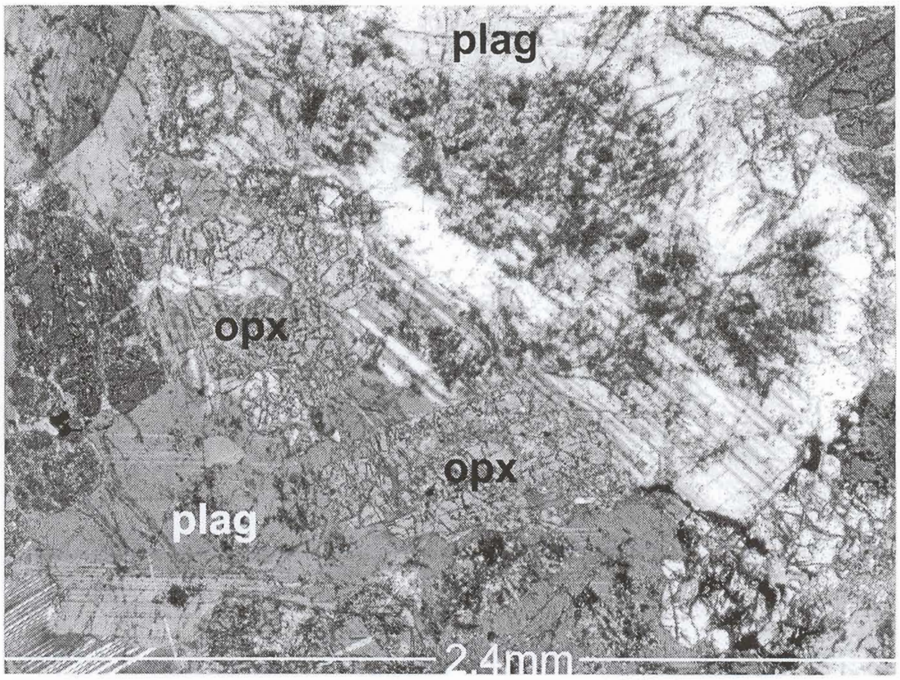

Fig. 4.15: Plagioclase (plag) showing saussuritization beginning at the core. Also note the partially altered orthopyroxene (opx). Sample TM 7. Transmitted light.

The calcsilicates are composed of interlocking calcite (70-85 %) and olivine (15-30 %) crystals. Calcite is subhedral with grain sizes ≤ 1 mm. Olivine crystals (<0.3 mm in size) may also be euhedral, partly when they are locally enclosed in calcite. Otherwise, olivine is subhedral

4.2 Platreef

Modal mineral abundances in the three Platreef horizons are given in Table 4.1. Orthopyroxene increases in abundance whereas feldspar decreases in abundance with height. The grain size of feldspar and orthopyroxene generally increases with height (not shown in Table 4.1). Sulphide is most abundant in the Middle Platreef and less so in the Upper Platreef, whereas the Lower Platreef is relatively sulphide-poor. The amount of olivine is locally variable within the Middle and Upper Platreef, while no olivine was found in the Lower Platreef.

	Lower Platreef	**Middle Platreef**	**Upper Platreef**
Orthopyroxene	55-75	65-80	75-85
Clinopyroxene	0-20	10-15	0-10
Plagioclase	20-40	10-25	5-10
Olivine	-	0-20	0-10
Quartz	-	-	0-3
Sulphides	1-2	0-10 with massive veins up to 3 cm in width	0-3
Secondary minerals after primary silicates	-biotite -amphibole -sericite -epidote -chlorite -magnetite	-biotite -amphibole -sericite -epidote -calcsilicate -magnetite	-biotite -amphibole -sericite -epidote -magnetite
Lithology	Norite and gabbronorite	Gabbronorite /feldspathic pyroxenite and norite	Gabbronorite/feldspathic pyroxenite and norite

Table 4.1. Phase abundances (in modal %) in the Platreef

4.2.1 Lower Platreef

Orthopyroxene and plagioclase are the major silicate minerals in the Lower Platreef. Clinopyroxene may locally reach major status. Minor phases are magnetite, sulphides, biotite and amphibole (Table 4.1). The rocks are mainly medium grained, but fine grained in places and have a granular texture. The size of the crystals ranges from 0.2 mm to 2 mm and averages 1 mm.

Orthopyroxene is subhedral or anhedral. Most grains are subrounded but elongate crystals are common. Towards the top of the Lower Platreef, 120^0 dihedral angles between orthopyroxene crystals are common, bearing evidence of textural equilibrium. Also towards the top of the reef, orthopyroxene crystals are sometimes enclosed in oikocrystic interstitial clinopyroxene.

Plagioclase forms lath shaped crystals averaging 1 mm in length but locally reaching 4 mm in length. Rare clinopyroxene occurs as subhedral, mainly elongate crystals ranging in size from 1 mm to 4 mm and averaging 2 mm. The crystals are twinned and have parting planes filled with magnetite. Additionally, clinopyroxene may form inclusions in plagioclase.

Sulphide (pyrrhotite and chalcopyrite) occurs mainly interstitial to the primary silicates, forming fine disseminations and veins. Fine grained pyrite, with minor chalcopyrite, may also be included in orthopyroxene and, in places, in plagioclase. Near the base of the reef, the amount of sulphides may locally increase to about 30 modal percent, but in general it amounts to less than 2 %.

Alteration

Plagioclase is slightly to heavily saussuritised resulting in the formation of sericite, epidote and sometimes chlorite. Biotite and amphibole are present as alteration products of plagioclase and orthopyroxene, especially where in contact with sulphide. The hydrous phases are usually found associated with each other and form fringes around the sulphide, orthopyroxene and plagioclase. Amphibole may also form large euhedral crystals about 4 mm in size, or fibrous masses.

4.2.2 Middle Platreef

The rocks of the Middle Platreef layer are predominantly composed of orthopyroxene, clinopyroxene and plagioclase. In addition, variable amounts of olivine may occur. Minor phases are biotite, sulphide, magnetite and amphibole (Table 4.1). According to IUGS terminology, the rock is a gabbronorite, but locally pyroxenite may occur.

Orthopyroxene crystals are mostly subhedral or euhedral. They may be elongate and up to 4 mm in length by 1 mm in width, usually showing a weak preferred horizontal orientation. The equigranular crystals average 2-3 mm in size. Exsolution lamellae of clinopyroxene are common (Fig. 4.1). Orthopyroxene sometimes shows granular textures with 120^0 dihedral angles (Fig. 4.2), indicating textural re-equilibration during cooling or re-crystallization. In some thin sections, clinopyroxene chadacrysts may be found enclosed in orthopyroxene. Some crystals are pervasively altered with associated development of magnetite filling the alteration cracks.

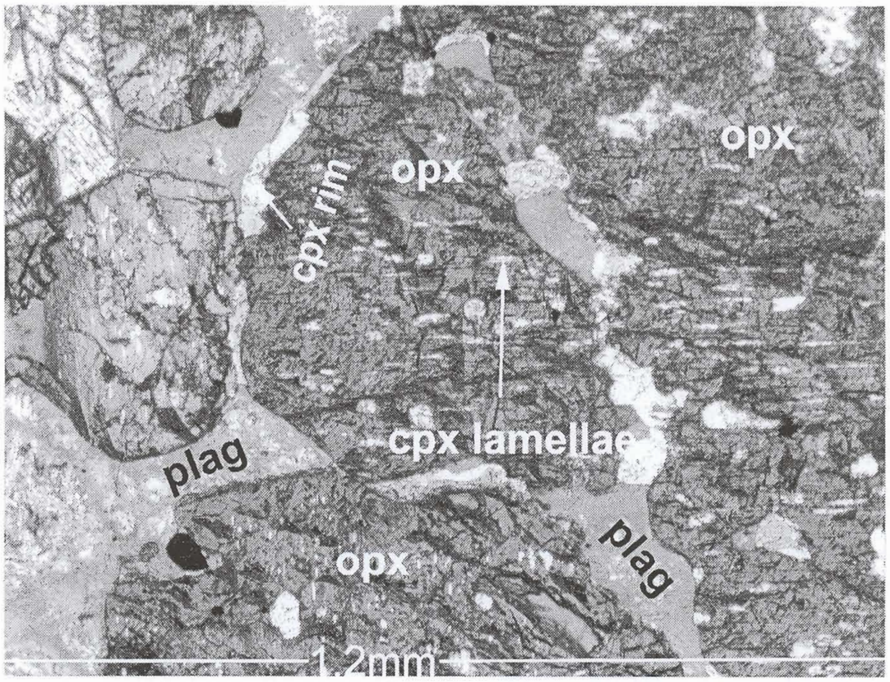

Fig. 4.1: Subhedral orthopyroxene (opx) with clinopyroxene exsolution lamellae, in sericitised interstitial plagioclase (plag). Note the secondary clinopyroxene rim (cpx rim) around opx. Sample TM 14. Transmitted light.

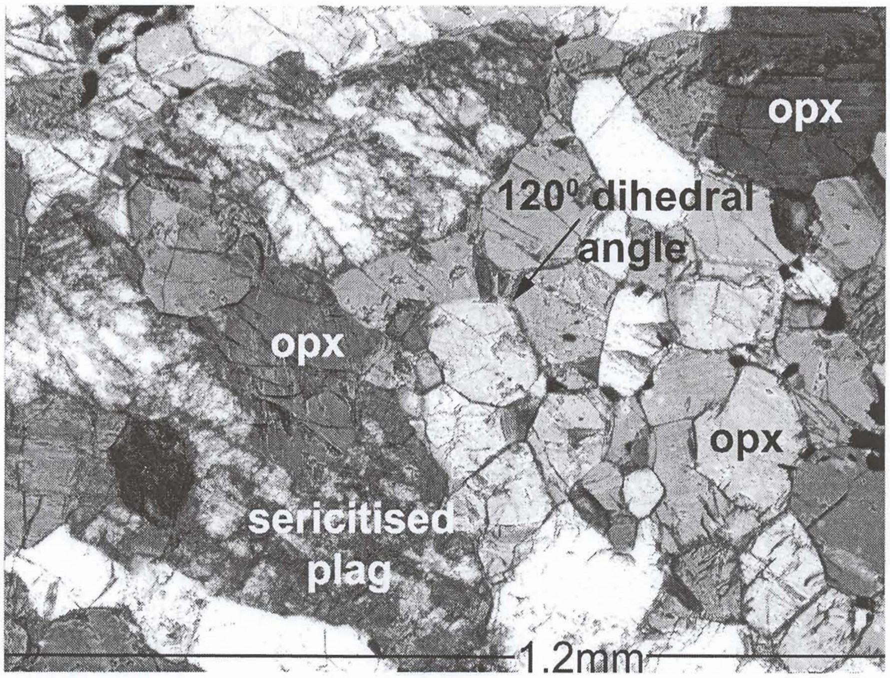

Fig. 4.2: Subhedral orthopyroxene (opx) crystals in a mixture of altered plagioclase (plag). Opx show 120^0 dihedral angles. Sample TM 29. Transmitted light.

Clinopyroxene is mostly anhedral, filling interstices between orthopyroxene and olivine. Large subhedral or euhedral cumulus crystals are less abundant. Interstitial grains average 2 mm in size while cumulus grains range from 2 to 8 mm in size (Fig. 4.3 and 4.4). The cumulus crystals have a high relief and contain slightly pleochroic, blebby to wormlike inclusions believed to consist of actinolite. The inclusions cut across clinopyroxene grain boundaries suggesting they formed after the clinopyroxene. The inclusions are altered (see Fig. 4.5 and 4.6) and sometimes show a fibrous texture. Some of the clinopyroxenes are partially altered to hornblende. Secondary clinopyroxene is sometimes present surrounding orthopyroxene and separating it from altered plagioclase. This may suggest that the secondary clinopyroxene is a reaction product of the two phases it separates.

Plagioclase is interstitial to the orthopyroxene and olivine (where present) and is slightly to pervasively saussuritised, giving a brownish appearance to the matrix. Small rounded olivine crystals may be included in the interstitial plagioclase.

Olivine occurs in varying proportions in the reef and displays a varied grain size distribution ranging from about 0.2 to 2 mm in diameter. The crystals are subhedral and occur enclosed in orthopyroxene, poikilitic interstitial plagioclase and sometimes clinopyroxene. Accordingly, olivine appears to have crystallised before the phases enclosing it. Most olivines are pervasively serpentinised. Secondary orthopyroxene is developed as thin rims between some of the olivines that are enclosed in altered plagioclase (Fig. 4.7 and 4.8).

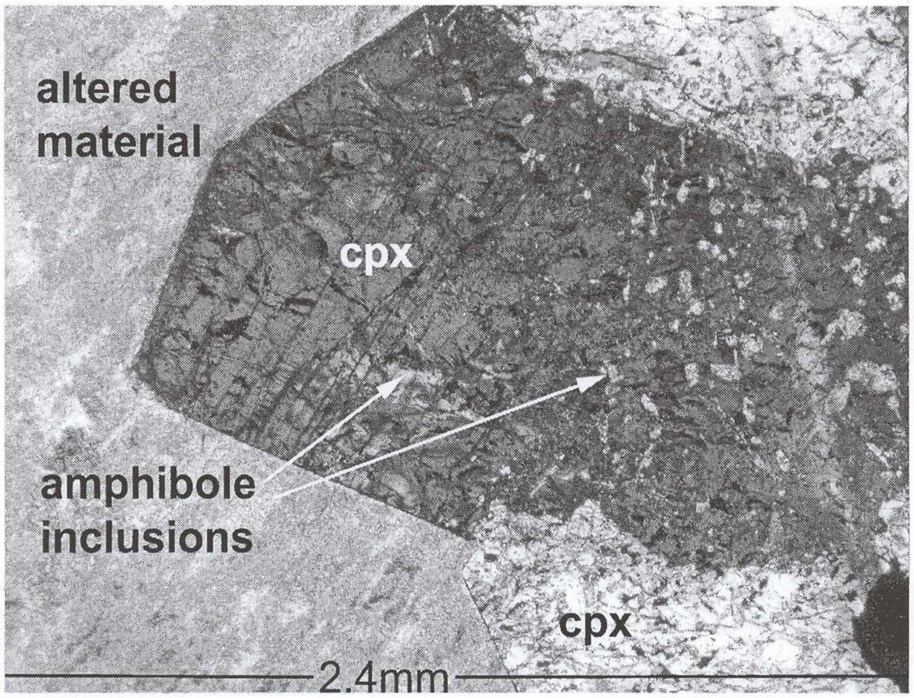

Fig. 4.3: Subhedral clinopyroxene (cpx) (with amphibole inclusions) growing into altered material. Sample TM 19. Transmitted light.

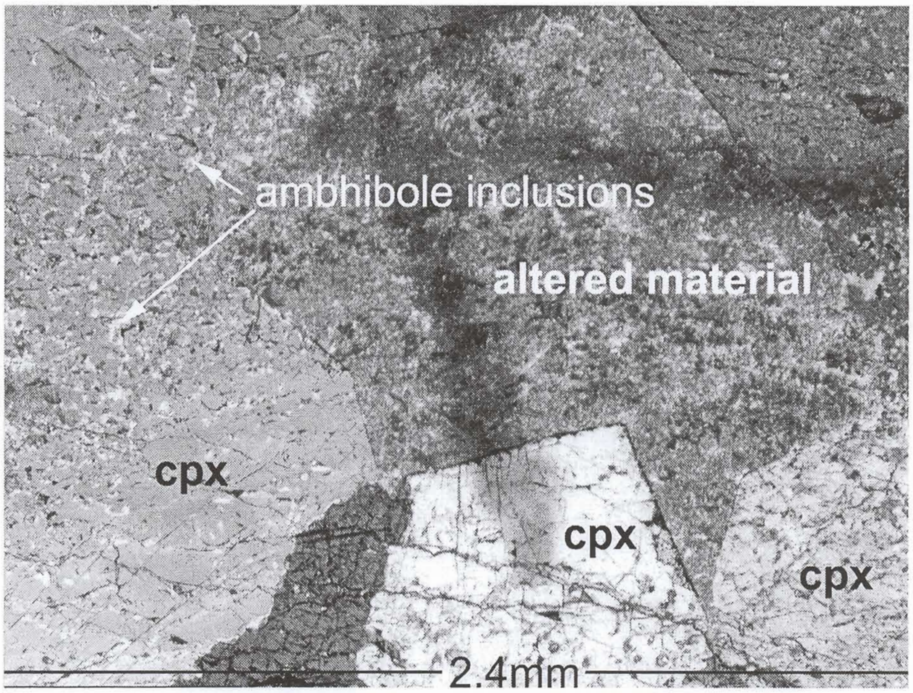

Fig. 4.4: Subhedral clinopyroxene (cpx) (with amphibole inclusions) growing into altered material. Sample TM 24. Transmitted light.

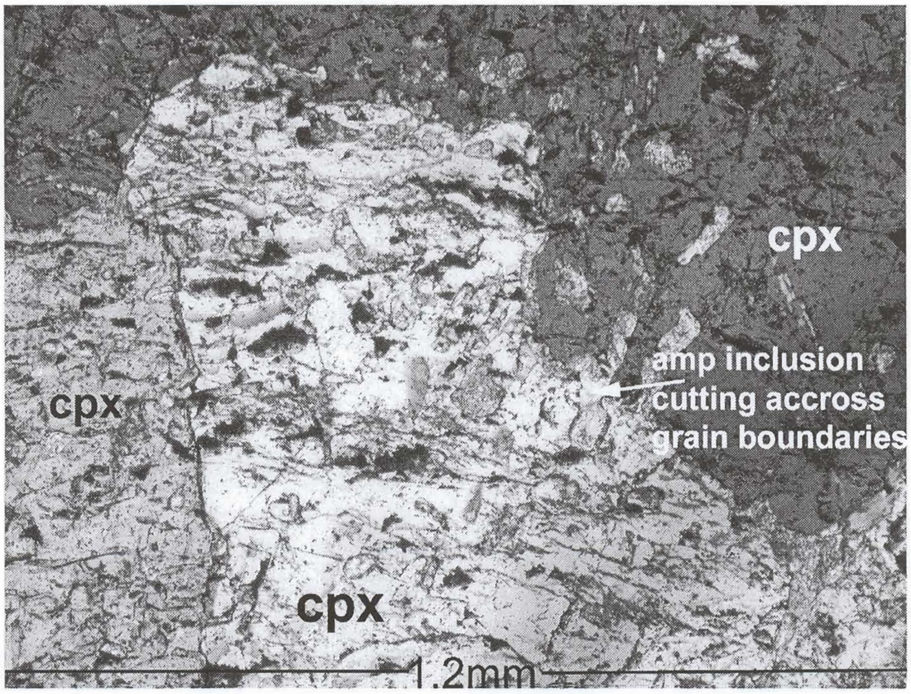

Fig. 4.5: Clinopyroxene (cpx) with amphibole and orthopyroxene (opx) inclusions, some cutting across clinopyroxene grain boundaries. Sample TM 19. Transmitted light.

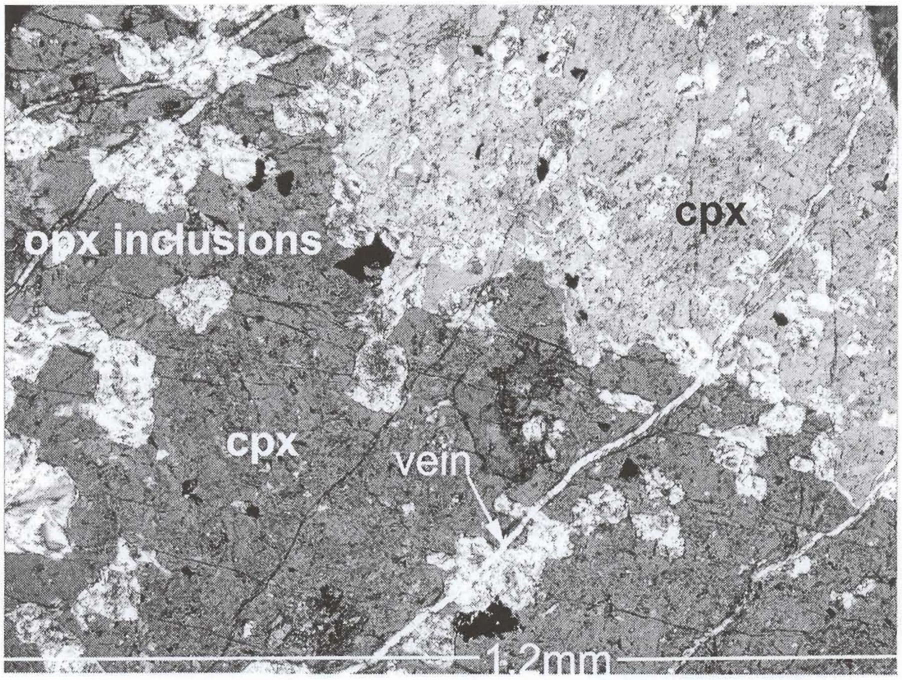

Fig. 4.6: Orthopyroxene (opx) inclusions in clinopyroxene (cpx). Note that the inclusions are altered to amphibole. Sample TM 22. Transmitted light.

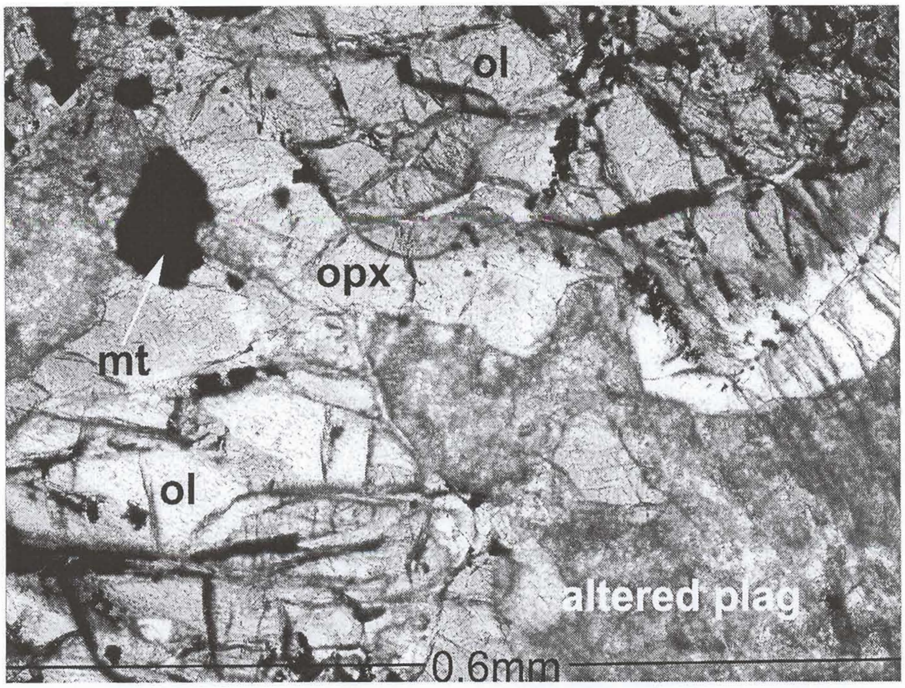

Fig. 4.7: Orthopyroxene (opx) rim around olivine (ol). Note the magnetite (mt) and altered plagioclase (plag). Sample TM 11. Transmitted light.

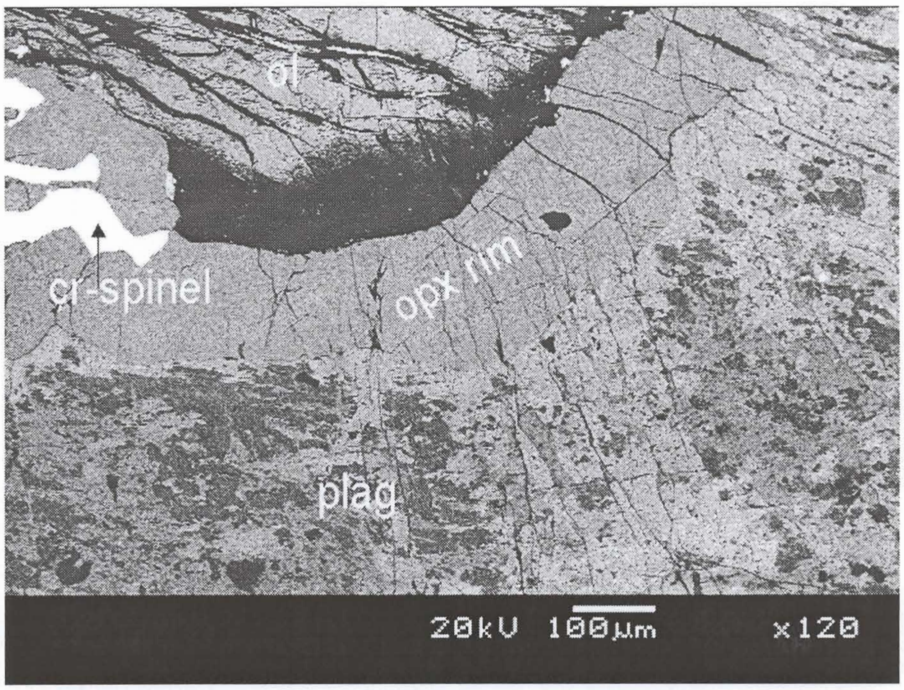

Fig. 4.8: Orthopyroxene (opx) rim around olivine (ol). Note the cr-spinel. BSE image. Sample TM 11.

Coronas consisting of orthopyroxene and a symplectic intergrowth of spinel around olivine are common in ultramafic and gabbroic rocks, for example in the Sulitjelma troctolite where they were considered (Mason, 1967) to be a result of diffusion of the appropriate ions in solution in an aqueous medium across the olivine-plagioclase.

Deer, Howie and Zussman (1978) provide the following chemical equation for the above reaction.

$$\underbrace{(6-4x)(Mg,Fe)_2SiO_4}_{\text{olivine}} + \underbrace{3CaAl_2Si_2O_8}_{\text{anorthite}} = (6-4x)(Mg,Fe)SiO_3 + \underbrace{2x(Mg,Fe)Al_2SiO_6}_{\text{Al-orthopyroxene}}$$

$$+\underbrace{(3-2x)Ca(Mg,Fe)Si_2O_6 + 2xCaAl_2SiO_6}_{\text{Al-clinopyroxene}} + \underbrace{(3-4x)(Mg,Fe)Al_2O_4}_{\text{spinel}}$$

Where $0 < x < 0.75$

N.B: Clinopyroxene was not identified in the present corona assemblages, possibly due to its fine grain size.

An alternative explanation could be reaction between olivine and silica-rich magma to produce the orthopyroxene coronas, but this model fails to explain the presence of spinel.

Some portions of the Middle Platreef have a pegmatoidal texture, due to the presence of large intercumulus plagioclase crystals. The pegmatoidal portions are more altered, with plagioclase being heavily sericitised and orthopyroxene being altered to amphibole and biotite possibly suggesting enhanced fluid activity. Serpentinised olivine is common and gives the rock a heterogeneous texture.

Alteration

Minor biotite and amphibole are present as secondary alteration minerals formed by reaction of orthopyroxene and plagioclase. Biotite occurs as platy crystals, about 1mm in size, and is associated with orthopyroxene and sulphides. Amphibole occurs either as unaltered euhedral diamond shaped hornblende crystals (Fig. 4.9) or as fibrous actinolite (Fig. 4.10 and 4.11). The actinolite may have formed in response to reaction of calcsilicate with silica-rich hydrous magmatic fluids. Amphibole is found mostly associated with sulphides and saussuritised feldspars. Olivine is commonly partially or completely altered to serpentine and iron magnetite. At Sandsloot, due to the prevalence of serpentinite, the pyroxenite is referred to as parapyroxenite by the mine geologists, but at Townlands, the platiniferous rocks are less altered. Some olivine crystals show embayment textures (Fig. 4.12).

Calcsilicate xenoliths are common in the Middle Platreef and have been metamorphosed to skarns. Skarns are metamorphic rocks surrounding an igneous intrusive where the later has come in contact with limestone or dolomite rocks. The skarns have a heterogeneous mineral assemblage. Skarn assemblages resulting from xenoliths completely engulfed by silicate magma comprise of lizardite, magnetite, talc, calcite, hematite, biotite and minor quartz. Close to the contact with the intrusive rocks, the mineral assemblage comprises of lizardite, magnetite, hematite, andradite garnet, brucite, monticellite and fosterite as determined by X-ray diffraction. Lizardite, hematite and brucite are probably not primary skarn minerals, but of secondary origin after alteration primary silicate minerals.

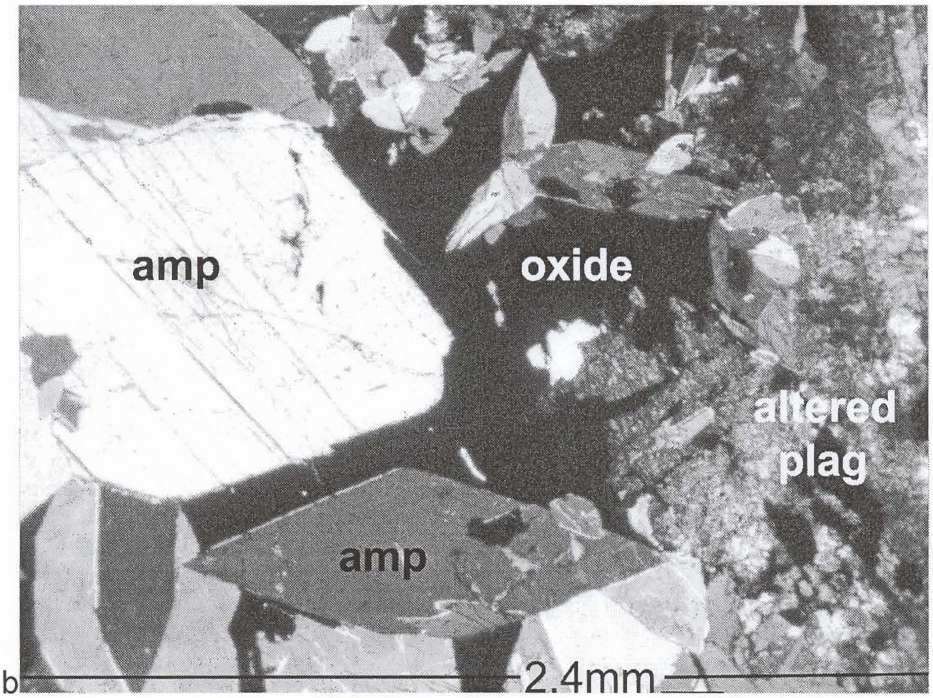

Fig. 4.9: Euhedral amphibole (amp) in magnetite next to altered plagioclase (plag). Sample TM 19. Transmitted light.

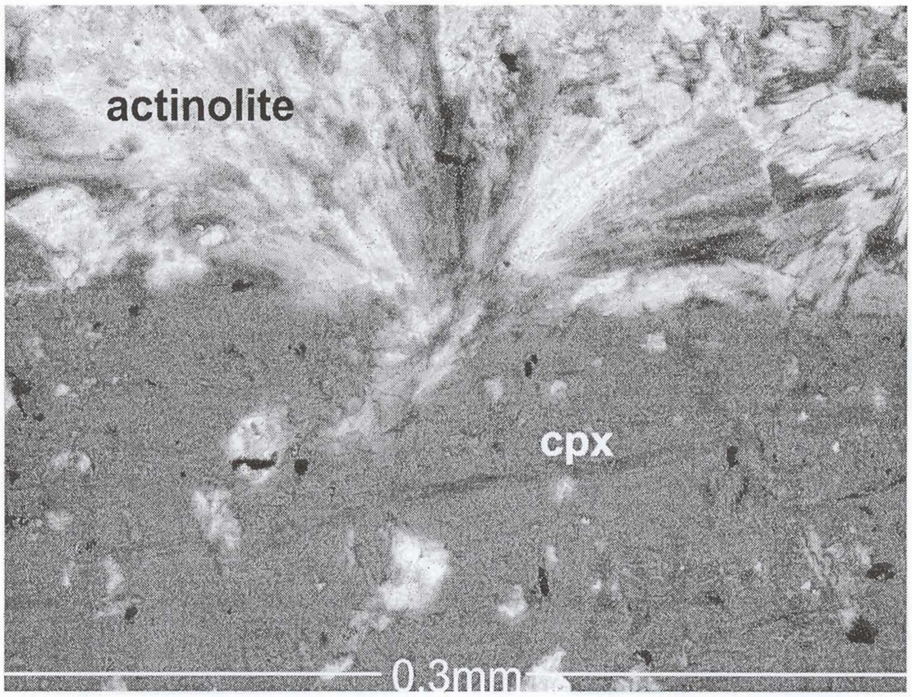

Fig. 4.10: Actinolite apparently growing on clinopyroxene (cpx). Sample TM 24. Transmitted light

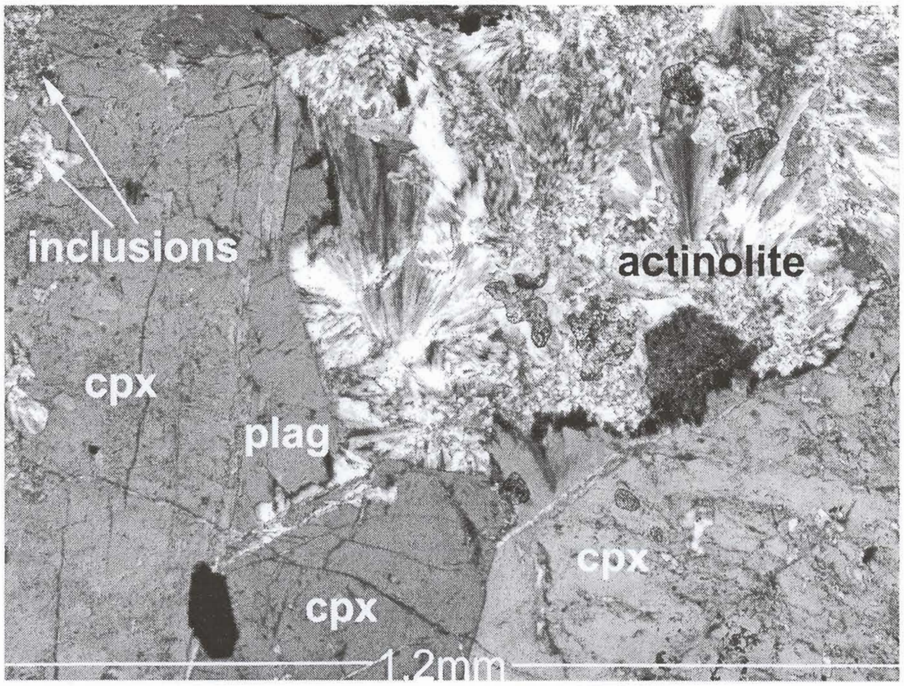

Fig. 4.11: Actinolite apparently growing on clinopyroxene (cpx) and plagioclase (plag). Sample TM 24. Transmitted light.

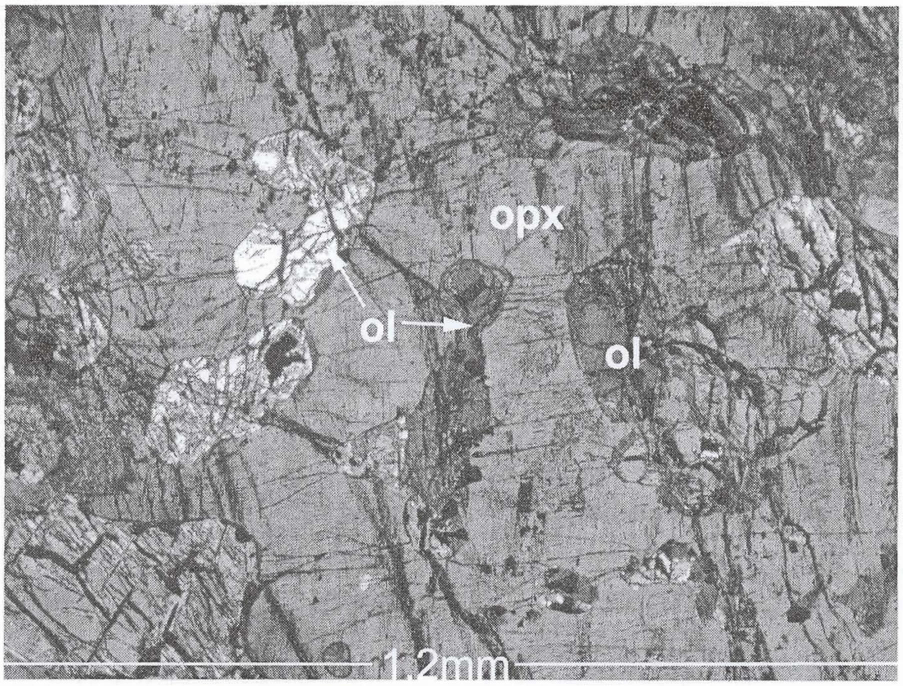

Fig. 4.12: Olivine (ol) enclosed in orthopyroxene (opx). Note the embayment texture. Sample TM 16. Transmitted light.

4.2.3 Upper Platreef

The Upper Platreef consists predominantly of orthopyroxene, with subordinate clinopyroxene and plagioclase. According to IUGS terminology, most of the rocks are gabbronorites. Olivine, quartz, biotite, magnetite, sulphide and amphibole are minor phases (Table 4.1). Quartz occurs as an accessory interstitial mineral (<1.5 mm in size) and sometimes encloses small anhedral orthopyroxene crystals. Orthopyroxene crystals are subhedral, being subrounded to prismatic in shape and averaging 2-4 mm in size. Most grains show bleb-like exsolution lamellae of clinopyroxene along the 110 direction.

Clinopyroxene occurs as large, 3-7 mm, prismatic, subhedral, poikilitic crystals enclosing small orthopyroxene crystals, and locally as interstitial material between orthopyroxene. The clinopyroxene crystals show twinning and exsolution lamellae of orthopyroxene (Fig. 4.13). Clinopyroxene locally contains inclusions of orthopyroxene and minor plagioclase.

Plagioclase is interstitial to orthopyroxene and almost always pervasively altered. It infrequently encloses small anhedral orthopyroxene crystals. In places, e.g. below the norite sill at 48.70m, plagioclase shows evidence of deformation in the form of bent lamellae (Fig. 4.14). The deformation could be related to intrusion of the norite sill or it may reflect a phenocrystic origin of the plagioclase.

Olivine may reach about 30 % in modal abundance. The portions with olivine are highly altered and olivine replaces clinopyroxene. The crystals are subrounded in shape and have variable sizes ranging from 0.3 mm to 2 mm in diameter. The olivine always occurs included in orthopyroxene or plagioclase but is more commonly associated with plagioclase-rich domains.

Alteration

Plagioclase is generally altered to sericite and epidote. The process of saussuritisation begins at the core of individual plagioclase grains, as shown by some relatively fresh plagioclase crystals (Fig. 4.15). This may point to zoning in plagioclase since An-rich parts of plagioclase are more readily sericitised by the exchange of Ca^{2+} for K^{+}. When adjacent to calcsilicate xenoliths, the orthopyroxenes tend to be serpentinised. Serpentinisation is accompanied by the occurrence of fine-grained magnetite and sulphides which are intergrown with the secondary silicates. The sulphides and magnetite increase in abundance with an increase in alteration suggesting some S mobility. Amphibole may replace clinopyroxene, orthopyroxene, magnetite and sulphides. Actinolite needles sometimes penetrate into the sulphides. Near the granite dyke, (at 53.55 – 53.25m) the rocks are cut by numerous veins rich in sericite and quartz and K-feldspar. Magnetite and biotite are present as alteration products of orthopyroxene and tend to occur along its grain boundaries. Olivine is generally partially altered to serpentine with the cores remaining unaltered. Secondary orthopyroxene is developed as thin rims between some of the altered crystals of serpentinised olivine embedded in altered plagioclase (as in the Middle Platreef).

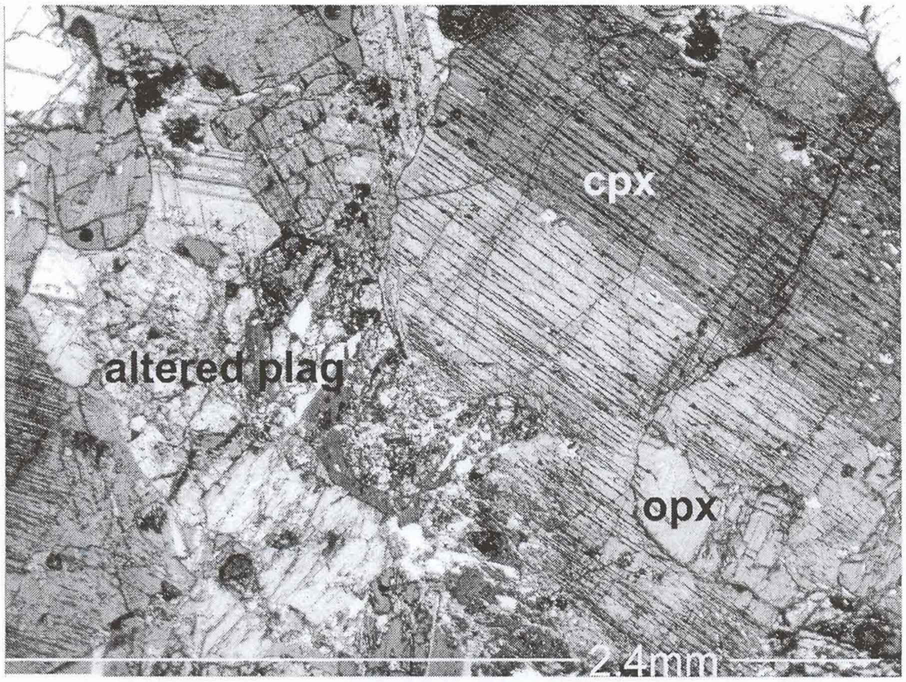

Fig. 4.13: Poikilitic, twinned clinopyroxene (cpx), with orthopyroxene exsolution lamellae enclosing orthopyroxene (opx). Sample TM 1. Transmitted light.

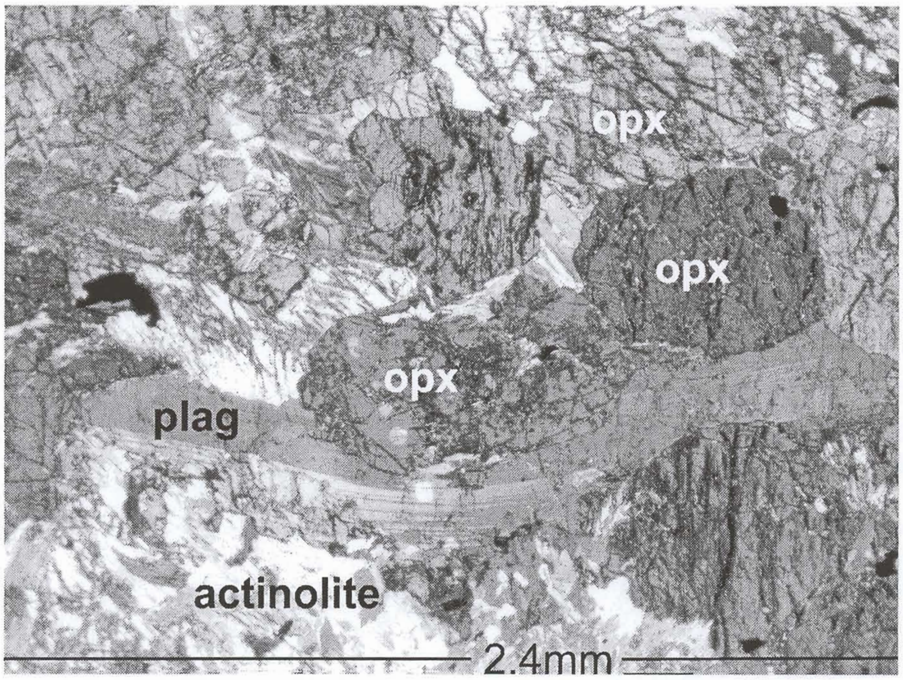

Fig. 4.14: Deformed plagioclase (plag) lamellae in feldspathic pyroxenite. Sample TM 9. Transmitted light.

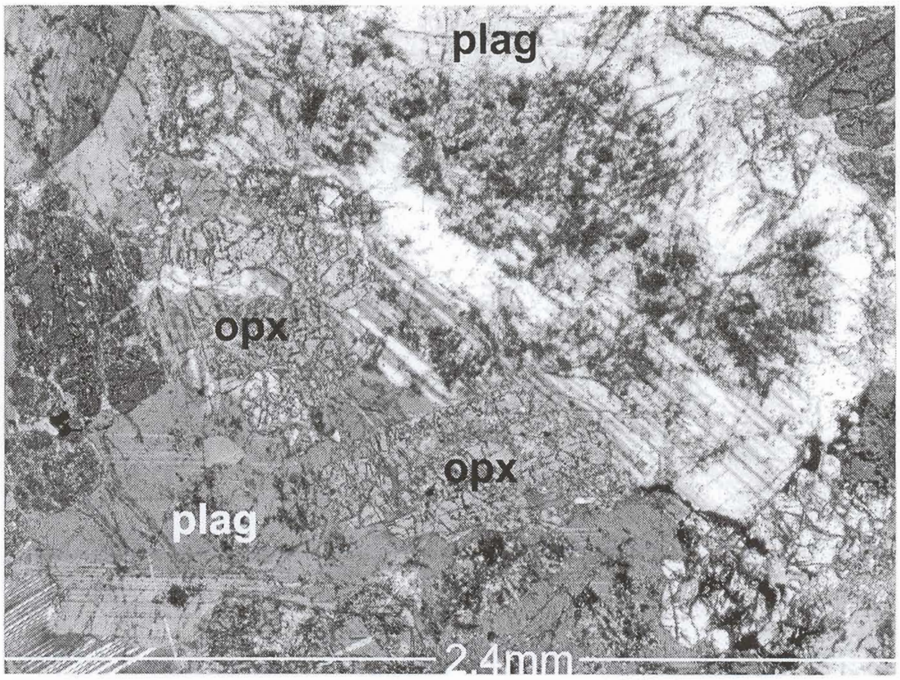

Fig. 4.15: Plagioclase (plag) showing saussuritization beginning at the core. Also note the partially altered orthopyroxene (opx). Sample TM 7. Transmitted light.

4.3 Other Intrusive Rocks

Fine to medium grained norites with a sub-ophitic texture that are interpreted as sills occur at 41.44 to 53.04 m. They contain subhedral orthopyroxene and plagioclase set in a matrix of anhedral plagioclase and quartz. Other minor phases present are magnetite and hornblende.

The norite shows a granular texture of interlocking orthopyroxene and plagioclase crystals. The orthopyroxene crystals have an average size of 3 mm and show minor exsolution lamellae of clinopyroxene. Plagioclase forms laths and oikocrysts. Crystal sizes average 2 to 3 mm. Alteration to sericite and epidote is common. Orthopyroxene and magnetite are locally included in the plagioclase. Quartz, magnetite and hornblende occur as post cumulus phases. Quartz occurs mainly interstitial to orthopyroxene, along parting planes in orthopyroxene and along orthopyroxene grain boundaries. It may sometimes enclose small orthopyroxene grains. Fibrous hornblende has grown on orthopyroxene and altered plagioclase, probably after the reaction between the two phases. Magnetite is interstitial or is included in orthopyroxene and plagioclase.

4.4 Sulphides

The sulphide assemblage in all three layers consists dominantly of pyrrhotite and chalcopyrite with minor pentlandite and pyrite. The sulphide minerals average 2-5 wt. % in abundance in the three layers. They are fine-grained and are mostly located in the interstitial spaces between the silicates (olivine, plagioclase and pyroxene) which tend to be altered along their contacts with the sulphide phase to form reaction rims of hornblende and biotite. Fine grained pyrite with minor chalcopyrite is locally included in orthopyroxene and plagioclase. Sparsely developed larger blebs of sulphides, up to 2 cm, may occur particularly in the more felsic, pegmatoidal patches within the Middle Platreef. Near the base of the Middle Platreef, the sulphides locally increase in abundance to about 10 wt. %, and the texture changes to large blebs of composite base metal sulphides sometimes reaching 2 cm in size. Zones of massive sulphide (mostly containing pyrrhotite) occur at 101.43 – 101.49 m, 102.46–102.51 m and 102.67–102.72 m. The coarse sulphides, including the massive zones mentioned above, are associated with the relatively more felsic and pegmatoidal parts of the core. Some portions of the reef (99.81–100.54 m) are barren or have only trace amounts of sulphides.

The hornfels may have fine-grained disseminated interstitial pyrite and pyrrhotite usually in amounts < 1 %. The pyroxenite sills are mostly barren but may contain traces of pyrrhotite. Minor (<1 modal %) chalcopyrite and pyrrhotite are found disseminated in the norite sills where they occur interstitial to the silicates. The pyroxenite sills tend to be barren of sulphides.