CHAPTER FIVE: MINERAL CHEMISTRY

5.1   Introduction

The chemical composition of the most important rock forming minerals was determined with a Jeol CXA – 733 Superprobe at Rhodes University. Representative analyses are given in Table 5.1. The remainder of the analytical data and details of analytical procedures are given in Appendices IV and I, respectively. In this chapter, Fo will be used to denote 100 x cationic ratio of Mg $\div$ (Mg + Fe) in olivine, An to denote 100 x cationic ratio of Ca / (Ca + Na) in plagioclase, and Mg# to denote 100 x cationic ratio of Mg $\div$ (Mg + Fe) in orthopyroxene and clinopyroxene.

5.2   Orthopyroxene

Orthopyroxene compositions cluster in the enstatite field of the pyroxene quadrilateral (Fig. 5.1) and show a range of Mg# between 68 and 82 (Fig. 5.2).

Orthopyroxene from the three Platreef layers shows a wide compositional variation in terms of Al_2O_3. In comparison, orthopyroxene from rocks of the Upper Critical Zone (UCZ) in the western Bushveld (Maier and Eales, 1997) have Al_2O_3 contents between 0.7 and 1.7 wt. %, at broadly similar Mg# as the Platreef orthopyroxenes. TiO_2 and MnO contents are similar in the UCZ and the Platreef but Cr_2O_3 and NiO contents, for corresponding Mg#, are markedly lower in the Platreef than in the UCZ (0.1-0.4 versus 0.1-0.55 in the UCZ of the western Bushveld Complex). Of further note is that Al_2O_3, TiO_2, Cr_2O_3, NiO, and MnO show a poor correlation with Mg# (Fig 5.2), when compared with e.g. the UCZ (Maier and Eales, 1997).
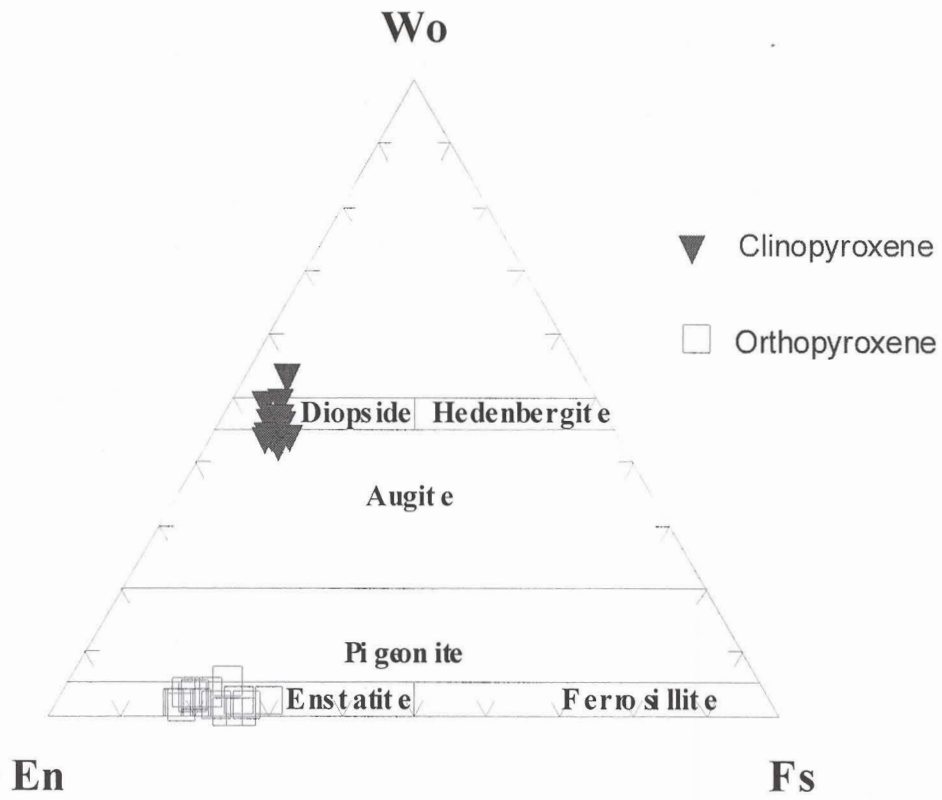
Fig. 5.1: Average pyroxene composition from the Platreef, plotted in the conventional pyroxene triangle.
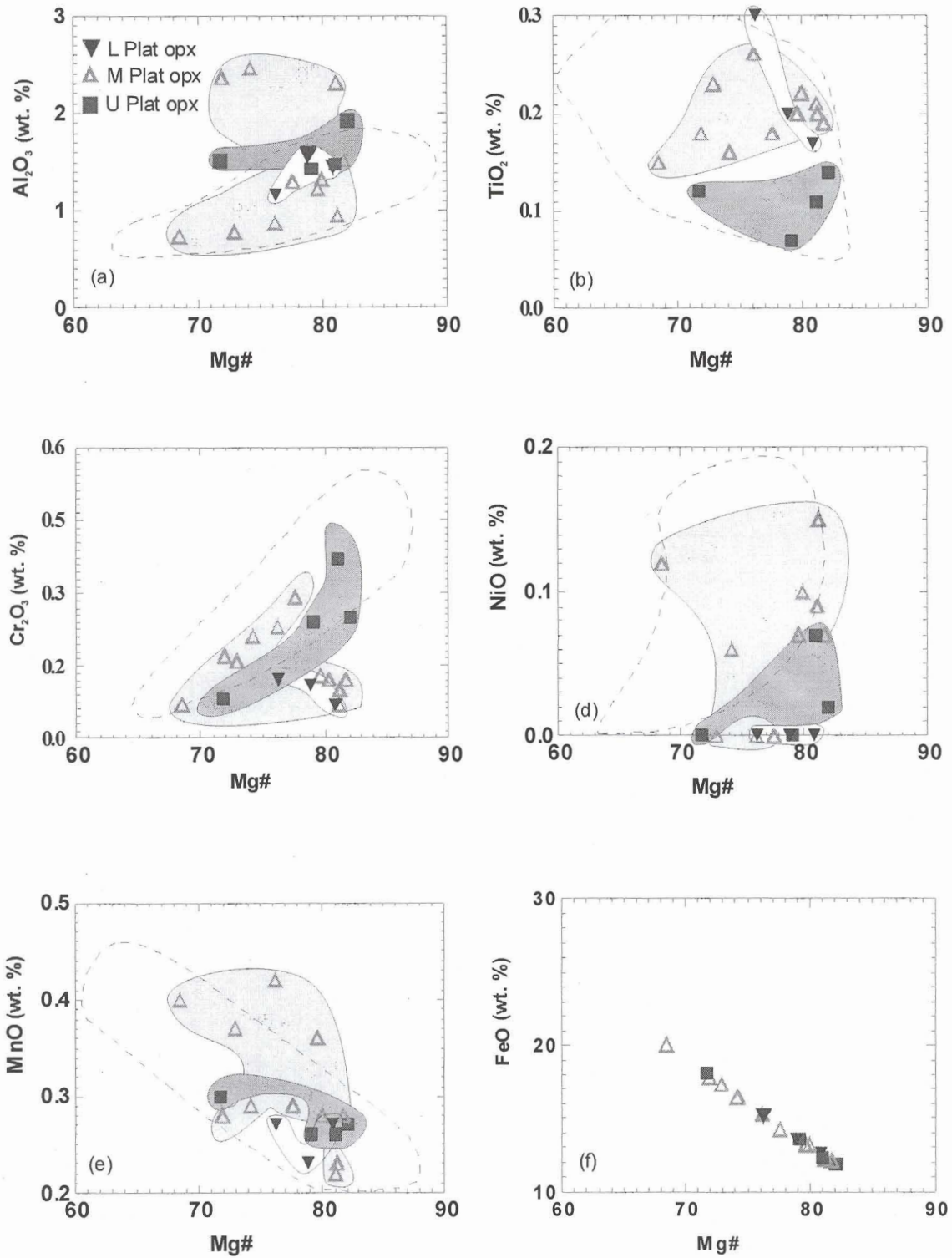
Fig. 5.2: Plot of Al_2O_3, TiO_2, Cr_2O_3, NiO, MnO and FeO in orthopyroxene (opx) versus Mg# of orthopyroxenes. Stippled area represents the field of Merensky-UG2 interval of the Bushveld Complex (Maier and Eales, 1997). U Plat = Upper Platreef, M Plat = Middle Platreef and L Plat = Lower Platreef.

Table 5.1: Compositions of selected minerals

	Orthopyroxene						Clinopyroxene				Olivine		Plagioclase				
sample: Type:	TM2opx2 UP	TM4opx3 UP	TM13opx1 MP	TM20opx5 MP	TM36opx1 LP	TM37opx4 LP	TM2cpx1 UP	TM4cpx1 UP	TM13cpx1 MP	TM22cpx3 MP	TMol4 UP	TMol3 MP	TM4 pl1 UP	TM9 pl1 UP	TM16 pl2 MP	TM 30 pl2 MP	TM37pl1 LP
SiO2	51.73	53.11	53.07	52.82	53.93	53.45	49.98	50.70	51.33	54.73	37.79	38.68	45.39	52.47	45.72	47.93	49.52
Al2O3	1.57	1.62	0.65	1.79	1.40	1.19	2.21	2.65	1.40	0.76	0.00	0.00	32.77	28.60	33.46	33.15	34.12
Na2O	nd	nd	nd	nd	0.03	0.19	0.31	0.24	0.10	nd	nd	nd	1.99	4.98	1.78	2.43	3.24
MgO	29.12	29.09	25.69	26.04	28.80	26.41	16.31	16.15	18.44	17.75	43.03	42.44	nd	nd	nd	nd	0.02
FeO	13.34	12.66	17.97	17.36	13.82	15.30	6.04	5.74	10.06	2.94	18.39	18.70	0.55	0.25	0.54	0.62	0.40
MnO	0.24	0.29	0.41	0.32	0.18	0.32	0.22	0.15	0.24	0.08	0.31	0.31	nd	nd	nd	0.05	0.00
Cr2O3	0.24	0.29	0.19	0.19	0.10	0.16	0.48	0.72	0.28	0.07	nd	nd	nd	nd	nd	nd	0.02
NiO	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.03	0.32	0.30	0.02	nd	nd	nd	nd
K2O	nd	nd	nd	nd	0.00	0.00	nd	nd	nd	nd	nd	nd	0.09	0.19	0.06	0.09	0.20
CaO	1.19	1.43	0.91	0.36	0.70	2.72	22.88	23.42	17.06	25.60	0.05	0.06	16.98	11.61	17.55	16.34	14.75
TiO2	0.10	0.13	0.24	0.17	0.26	0.38	0.20	0.10	0.13	0.10	nd	nd	nd	nd	nd	nd	0.01
Total	97.54	98.64	99.13	99.05	99.48	100.12	98.63	99.86	99.04	102.09	99.90	100.49	97.81	98.12	99.15	100.63	102.28
Cations (based on 6 oxygen)							(6 oxygen)				(4 oxygen)		(32 oxygen)				
Si	1.91	1.93	1.96	1.94	1.95	1.94	1.89	1.89	1.92	1.96	0.97	0.99	8.57	9.70	8.52	8.77	8.87
Al	0.07	0.07	0.03	0.08	0.06	0.05	0.10	0.12	0.06	0.03	0.00	0.00	7.30	6.23	7.35	7.15	7.20
Na	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.01	0.00	0.00	0.00	0.73	1.78	0.64	0.86	1.13
Mg	1.60	1.57	1.41	1.43	1.55	1.43	0.92	0.90	1.03	0.95	1.65	1.61	0.00	0.00	0.01	0.00	0.00
Fe	0.41	0.38	0.56	0.53	0.42	0.47	0.19	0.18	0.32	0.09	0.40	0.40	0.09	0.04	0.09	0.10	0.06
Mn	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.00
Cr	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ni	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00
K	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.01	0.02	0.05
Ca	0.05	0.06	0.04	0.01	0.03	0.11	0.92	0.93	0.69	0.98	0.00	0.00	3.44	2.30	3.51	3.20	2.83
Ti	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	4.05	4.03	4.02	4.01	4.02	4.03	4.07	4.05	4.04	4.02	3.03	3.01	20.15	20.10	20.13	20.10	20.12
Mg no.	79.57	80.39	71.81	72.81	78.79	75.45	82.84	83.41	76.58	91.51							
fo											80.4	79.9					
An													82	56	84	78	71

NB: UP = Upper Platreef, MP = Middle Platreef, LP = Lower Platreef

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When plotted against depth, there is little systematic variation between the three Platreef layers in terms of Al_2O_3 and Mg# of orthopyroxene (Fig. 5.3). There appears to be a broad increase in Cr_2O_3 with height, i.e. from the Lower Platreef through the Middle Platreef to the Upper Platreef, and a decrease in TiO_2. NiO contents show considerable variation, but the Lower Platreef orthopyroxenes are particularly Ni-depleted (Fig. 5.3). In contrast, several other samples from the Upper and the Middle Platreef have NiO values similar to orthopyroxenes from the UCZ in the Western Bushveld Complex (Maier and Eales, 1997).

5.3. Clinopyroxene

Cumulus clinopyroxene occurs together with orthopyroxene in the Middle and Upper Platreef, but is absent in the Lower Platreef. The occurrence of cumulus clinopyroxene in the Platreef constitutes a notable difference to cumulates of the UCZ in the remainder of the Bushveld Complex where cumulus clinopyroxene is absent until some 500m into the Main Zone.

The clinopyroxene mostly plot in the diopside field of the pyroxene quadrilateral (Fig. 5.1) with a few falling in the augite field. Some clinopyroxene from the Middle Platreef plot above the Di-Hd joint.
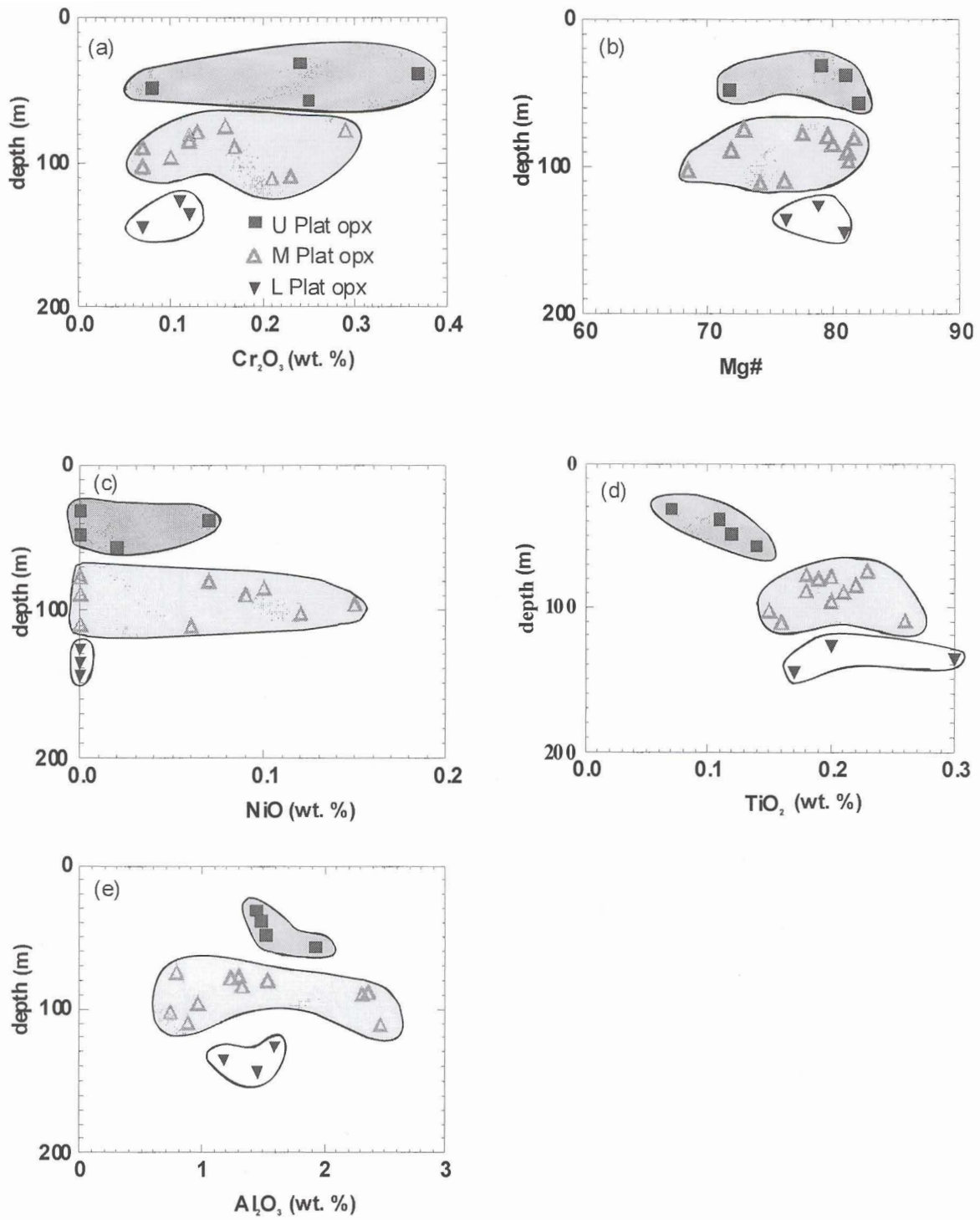
Fig. 5.3: Plot of depth versus Cr_2O_3, Mg#, NiO, TiO_2 and Al_2O_3 in orthopyroxene (opx). U Plat = Upper Platreef, M Plat = Middle Platreef and L Plat = Lower Platreef.

The Mg# of clinopyroxene from the Upper Platreef ranges from 82.3 to 83.41 while that from the Middle Platreef ranges from 76.58 to 91.51. Average Cr_2O_3 content of clinopyroxene is 0.53 wt. % in the Upper Platreef and 0.20 wt. % in the Middle Platreef, with the highest analysed value of 0.72 wt. % in the Upper Platreef. Thus there appears to be an analogous trend of Cr enrichment with height as observed for the orthopyroxenes. In comparison with the clinopyroxene from the Main Zone of the Bushveld Complex (0.45-0.77 wt. % Cr_2O_3), the average Cr contents of the Middle Platreef clinopyroxene is low (Table 5.1).

Clinopyroxene in samples TM 19, TM 22 and TM 26 of the Middle Platreef are notable for their high Al_2O_3 contents (generally above 5 wt. %, reaching 9.68 wt. % in sample TM 19). These clinopyroxene also have slightly higher CaO contents of about 24 wt. % compared to the other clinopyroxenes which have CaO mostly between 21-22 wt. %. In comparison, cumulus clinopyroxene from the Main Zone of the Bushveld Complex (Mitchell, 1990) has markedly lower Al_2O_3 (1-2 wt. %) and CaO contents (18-23 wt. %). Based on the combined textural and compositional evidence, I suggest that these pyroxenes are of metamorphic origin, probably related to reaction of calcsilicate xenoliths with silicate magma.

5.4   Olivine

Olivine is present in the Middle and Upper Platreef but is absent in the Lower Platreef. The olivine shows a restricted compositional range (Fig. 5.4). Analyses of core domains of olivine from the Upper Platreef display Fo contents between 80-83 (averaging Fo_{81}) and those from the Middle Platreef have Fo 78-83 (averaging Fo_{79}).
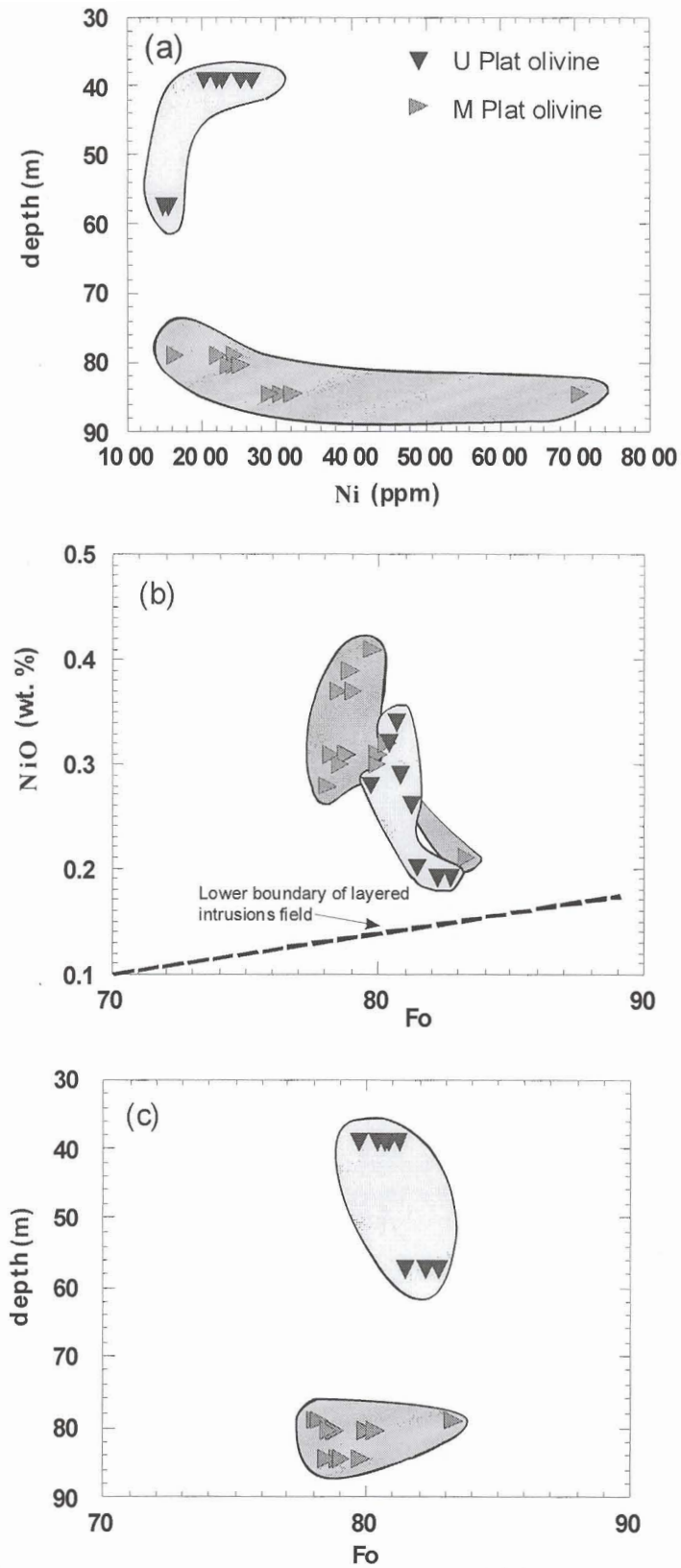
Fig. 5.4: (a) NiO versus Fo, (b) Ni versus depth and (c) Fo versus depth in Platreef olivine. . U Plat = Upper Platreef, M Plat = Middle Platreef and L Plat = Lower Platreef.

Thus the composition and distribution of olivine confirms the pattern of more primitive rock composition with height established by pyroxene compositions.

The analysed Platreef olivine has NiO contents varying from 0.19 to 0.39 wt. % (averaging 0.30 wt %), which is consistent with a magmatic origin of the olivine. There is considerable local variation in Ni content (Fig. 5.4a) possibly due to equilibration of olivine with sulphide. Such an interpretation is supported by the negative correlation between Fo and Ni (Fig. 5.4b). Alternatively, the negative correlation may be fortuitous and instead be related to distinct compositions of the magmas precipitating the Middle and Upper Platreef. Thus the Upper Platreef may have formed from a relatively more primitive magma (giving high Fo contents) that was relatively more Ni depleted (due to equilibration with sulphides) than the Middle Platreef.

Having said this, all analysed olivine in the Platreef studied are undepleted in Ni relative to Fo (Fig. 5.4b), when compared to the field of layered intrusions (Simpkin and Smith, 1970). This is notable as olivine from sulphide bearing ultramafic and mafic rocks are commonly depleted in Ni relative to Fo (e.g. Voisey's Bay, Li and Naldrett, 1999). In many of these examples, the Ni depletion is explained by scavenging of Ni from the magma by sulphide melt prior to olivine crystallisation. On the other hand, olivine within many of the sulphide-bearing intrusions at Noril'sk also shows little evidence for metal depletion (Arndt et al. 2003). The observation that olivine from the Platreef is undepleted in Ni, and that the Platreef sulphides are relatively metal-rich (as will be discussed in chapter 6) suggests that metal undepleted silicate magma was in equilibrium with Ni-rich sulphide.

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5.5 Plagioclase

Plagioclase is mostly of intercumulus nature in the three Platreef layers and plots in the labradorite and bytownite field of the An-Ab-Or triangle, with the exception of two samples from TM 33 which plot in the oligoclase field. In all three Platreef layers, An contents range from 54 to 85.2 averaging 70.52. These values are broadly similar to those of plagioclase from the UCZ in the Western Bushveld Complex (Maier and Eales, 1997). Two samples show An values of 25.8 and 28.7. These represent intercumulus plagioclase and the variation may be largely due to zoning.

In contrast to the UCZ in the Western Bushveld (Maier and Eales, 1997), the composition of the plagioclase in the Platreef shows a positive correlation with Mg# of orthopyroxene (Fig. 5.5). The outliers may be due to zonation and/or the presence of phenocrysts.
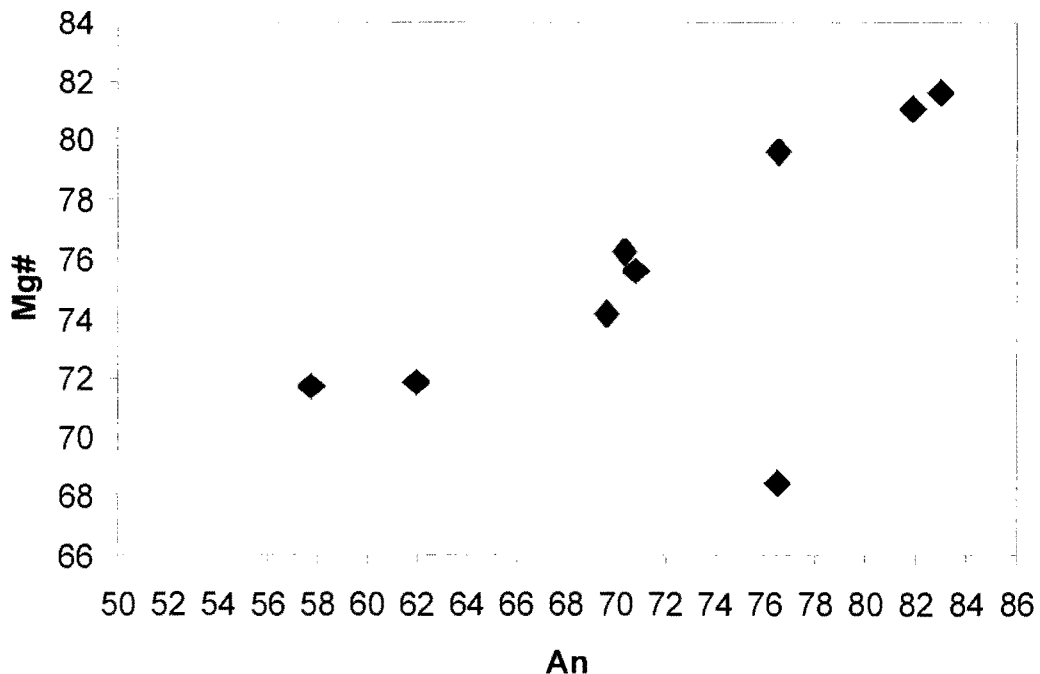

Fig. 5.5: Means of An content of plagioclase plotted versus Mg# of orthopyroxenes.