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POTENTIAL FOR PLATINUM GROUP MINERALISATION IN AUSTRALIA

A REVIEW

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ABSTRACT

Platinum Group mineralisation in Australia appears to have greatest potential in three distinct geological settings: the Palaeozoic serpentinite belts of the Tasman Geosyncline, within large stratiform layered mafic-ultramafic intrusive complexes of stable Archaean-Proterozoic terrains, and tectonically disturbed layered complexes of Proterozoic Mobile Zones. The tight geographical distribution, association with placer deposits, positive relief characteristics and intensity of past exploration of the Eastern Australian alpine serpentinite bodies, collectively suggests this style of mineralisation holds little promise for further discoveries of large platinum group deposits.

Greater PGE potential is believed to exist within the variably deformed layered tholeiitic mafic-ultramafic intrusive complexes of the Yilgarn, Pilbara, Musgrave and Halls Creek Provinces. Many of these intrusions display similar characteristics to the great PGE hosting stratiform complexes, such as the Bushveld Complex - Transvaal. Stillwater - Montana and Lac des Iles - Ontario. However, several significant differences occur. These include, relating to the Australian intrusions:

- Scale: the mafic-ultramafic component of most Australian complexes rarely exceeds 3.0 km stratigraphical thickness, while the overseas examples are in the order of 6.0^{+} km.

- Gabbro type rocks clearly dominate over ultramafic lithologies.

- Widespread rhythmic and cyclic layering are often poorly developed, particularly in the Archaean.

- Scarcity of Ni-Cu sulphide deposits in the layered tholeiitic intrusions implies the sulphur saturation of the parental magmas is low. Sulphide content is believed to be of importance because of the role of sulphides as PGE collectors and subsequent concentrators.

- Absence of titaniferous-vanadiferous magnetite and chromitite zones within the one complex.

The PGE-Cr potential of most Australian layered intrusive complexes can be downgraded due to insufficient magma volume - at least 200 km^3 is believed to be a very rough approximate of a minimum volume, however the thicker higher pressure central intrusions of the Giles Complex, various gabbro-anorthosite complexes of the Yilgarn, Pilbara Blocks are believed to hold some potential for PGE mineralisation. A tectonic dismembered variant of a mineralized layered intrusive complex could exist in the Halls Creek-King Leopold Mobile Zone.

The apparent association of intracontinental rift zones and tholeiitic dolerite swarms showing favourable chemical-physical characteristics within the Lower Proterozoic Pine Creek Geosyncline and McArthur Basin may indicate these environments are favourable for Noril'sk-Talnakh of W. Siberia type PGE mineralisation, and bronzite pegmatoidal dunite pipes of the Eastern Goldfields Province should be investigated for Pt-Fe alloy dominant type mineralisation.

1. Introduction

Historically platinum group production was entirely derived from placer type deposits, with both Colombia and USSR-Urals dominating the world scene. In 1919 platinum minerals were obtained as a significant by-product from the copper-nickel ores of Sudbury-Ontario and in 1924 the platiniferous potential of the immense Bushveld Complex of the Republic of South Africa was being realised. Today, primary platinum deposits are significantly of greater importance, with the Bushveld repository containing over 80% of the world's known resources of platinum (Dixon, 1979).

Platinum group mineralisation throughout geological time shows a clear affinity with mafic-ultramafic rock associations of various tectonic terrains. However, it is the large intrusive layered mafic-ultramafic complexes, such as Bushveld-Transvaal, Stillwater-Montana and Lac des Iles - Ontario which are by far the most important in terms of PGE resources. These complexes (Jackson & Thayer, 1972) are characterised by:thick stratigraphic successions of diverse lithologies, namely harzburgite, orthopyroxenite, websterite, norite, gabbro, dolerite, anorthosite, granophyre which display prominent cumulate fabrics and extreme lateral continuity, age of emplacement generally pre 1000 m.y. within stable Precambrian shields or into basaltic terrains of any age, and economic deposits of high chromium to high iron chromite, titaniferous and vanadiferous magnetite, copper-nickel sulphides and native platinum, platinum sulphides.

The PGE layered ultramafic-mafic intrusive association forms a unique geological entity in style, time and space, and is distinct from the other major platinum sources related to iron-nickel-copper sulphide depsoits such as Sudbury-Ontario, Lyn Lake-Manitoba, Noril'sk Camp-Siberia, Duluth-Minnesota and Kambalda-Western Australia, or younger alpine type intrusions of the Appalachians, Ural Mountains-Russia, Philippines, Turkey, Cuba, New Caledonia, India, Pakistan, Eastern Europe (Yugoslavia and Greece) and Brazil. Although the platinum bearing layered complexes of the world show great variability in detail, several broad features relating to setting, age of emplacement, stratigraphy, style of mineralisation etc. are often common. It is an understanding of these features, collectively, which are invaluable in assessing the PGE potential of Australian layered complexes. The following discussion which is largely abridged from Naldrett (1981); and Watkinson & Dunning (1979) describes some of the more salient features relating to PGE mineralisation within the Bushveld, Stillwater and Lac des Iles complexes.

1.1 Bushveld Complex

The Bushveld intrusive complex located in the Transvaal State of the Republic of South Africa (see Fig. 1) forms an enormous elongated differentiated lopolith, covering a total area of 65 000 km^2. The complex consists of both basic and later acid phases which intrudes Proterozoic lavas and sediments (2.26×10^9 y, Hamilton, 1977) of the Transvaal System, that lie on an Archaean crystalline basement of granitoids and schists. Gravity data has shown that the non-acidic rocks do not persist below the centre of the complex, and that four or five separate centres of intrusion have subsequently transgressed to form the composite body. Magmatic ore deposits within the complex are diverse, ranging from layered pyroxenite and dunite pipe hosted PGE, vanadiferous

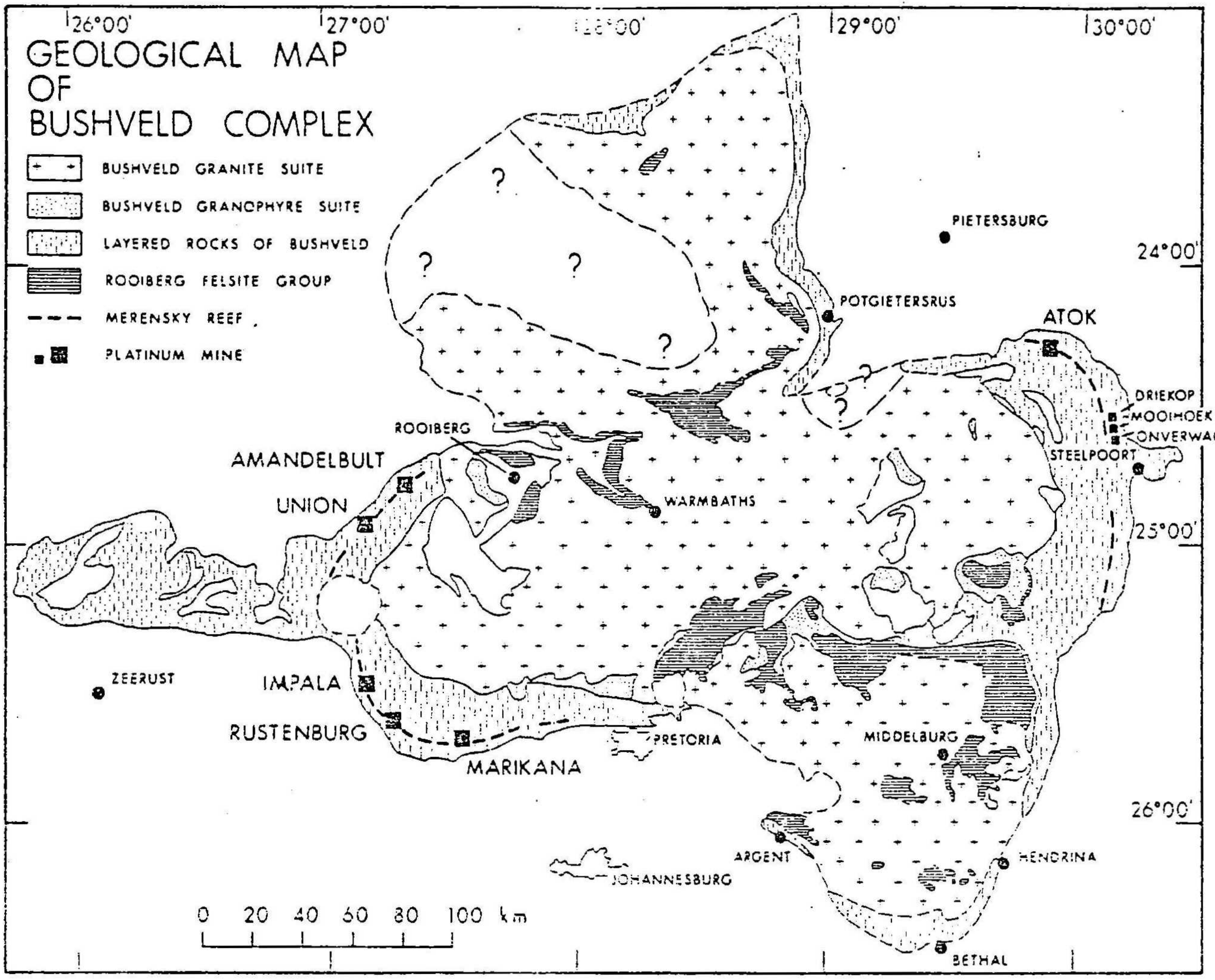

Figure 1. Geology of The Bushveld Igneous Complex. Reproduced, with permission, from Naldrett (1981)

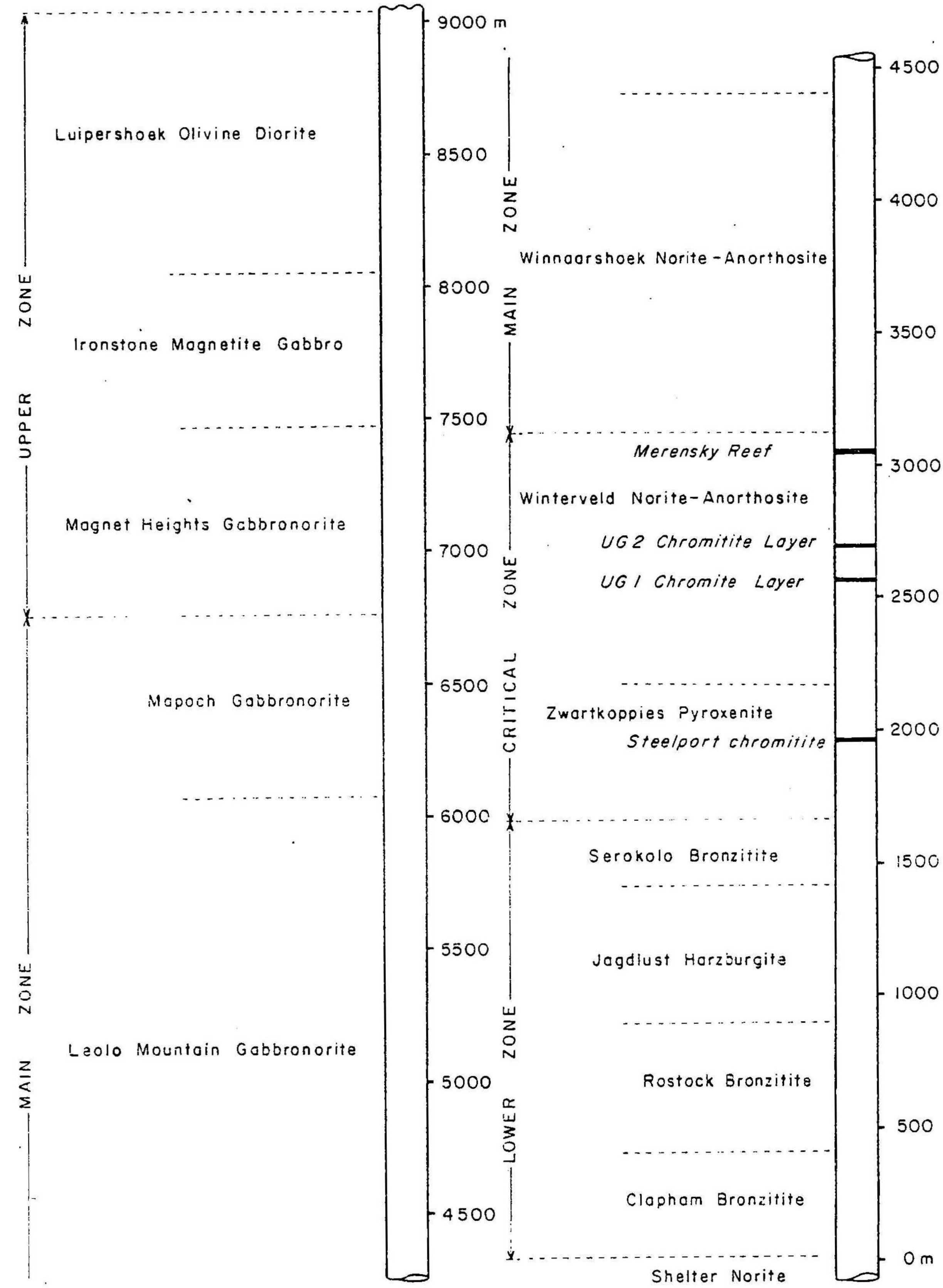

Figure 2 STRATIGRAPHY OF THE RUSTENBURG LAYERED SUITE. EASTERN BUSHVELD COMPLEX

Modified after Vermaak (1981)

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magnetite seams, gold and copper-nickel in layered pyroxenites and bronzite pipes, tin-fluorspar in discordant granites and telemagmatic ores of lead-zinc-fluorspar in the sedimentary country rock.

The mafic-ultramafic rocks of great economic significance, called the Rustenburg Layered Suite (2.095 $\pm$ 24 x 10^9y Rb/Sr, Hamilton, 1977) form a diverse thick (approx 7-9 km) sequence which have been subdivided into four main zones (see Fig. 2 for Rustenburg stratigraphy) as follows:

- The lower zone consisting dominantly of harzburgites - bronzitites, with minor dunites, approx. 1700 m thick.
- The critical zone consists mainly of bronzitites, anorthosites-norites and layers of chromite with associated PGE, approx. 1400 m thick.
- Gabbros-norites and anorthosites characterize the thick main zone approx. 3650 m thick.
- The upper zone composed of magnetite gabbros, olivine diorites and magnetite bands approx. 2250 m thick.

(The Rustenburg Sequence above applies to the Eastern Bushveld)

An upward enrichment of the albitic component of plagioclase and the iron end members of both pyroxene and olivine is present through the zones (see Fig. 3), although numerous disruptions to these trends occur. These reversals and disruptions are thought to result from influxes of fresh magma, or are a part of a more complex pattern of irregular variation in mineral compostion.

PGE Mineralisation-Bushveld Complex

PGE mineralisation occurs in four distinct settings within the complex; (i) the Merensky Reef, (ii) the UG2 Chromitite Layer (both in the western and eastern Bushveld, (iii) the Platreef of the Potgietersrus area, and (iv) various cross cutting dunite pipes. Table 1 illustrates the ore-metal character and resources of the first three environments.

1.1(i) Merensky Reef: The Merensky Reef is a coarse grained, pegmatoidal feldspathic pyroxenite that underlies a porphyritic feldspathic pyroxenite unit, which collectively form the basal portion of the Merensky unit. Chromite bands approximately 1 cm thick define the top and bottom of the reef which has a thickness of 0.3-0.6 m. The platinum arsenides and sulphides; sperrylite (Pt As_2), braggite (Pt, Pd, Ni)S, stibiopalladenite (Pd_3Sb) and laurite (RuS_2) together with native platinum and gold are concentrated in the vicinity of the chromitite layers. Sulphides, chalcopyrite-pyrrhotite-pentlandite-nickeliferous pyrite-cubanite-millerite and violarite are also present. Studies also indicate a close relationship between PGE mineralisation and nickel-copper sulphides as solid solution or as submicroscopic particles within the Ni-Cu sulphides.

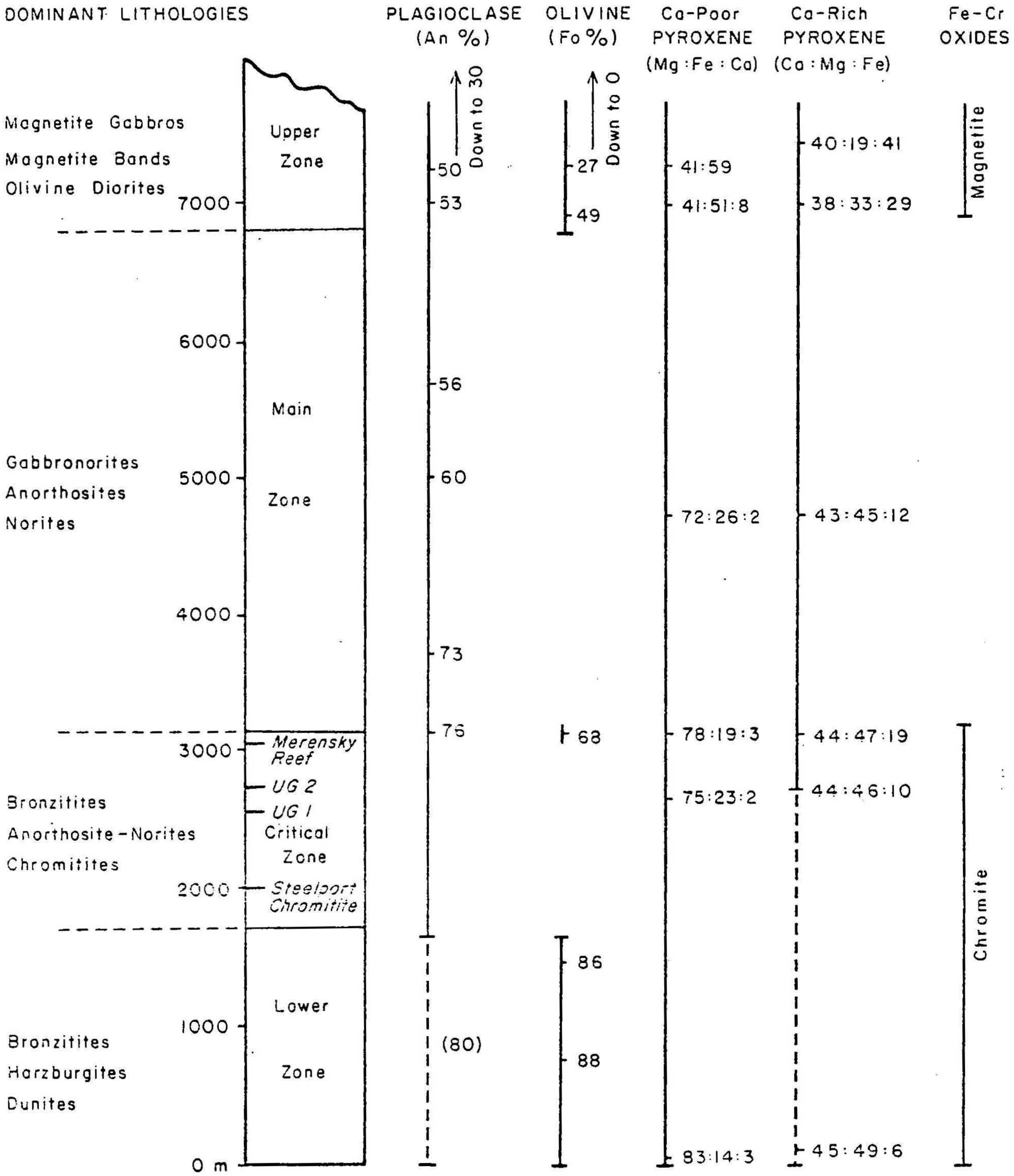

Figure 3 LITHOLOGICAL-CRYPTIC VARIATION OF THE BUSHVELD COMPLEX. BROKEN LINES INDICATE INTERCUMULUS PHASES

Modified after Wager and Brown (1968)

	Merensky Reef	UG 2 Chromitite Layer	Platreef	Total
Strike in kilometres			+60	
North of Pilanesberg	40	40		
South of Pilanesberg	70	90		
North of Steelport	90	90		
South of Steelport	30	30	Estimated Payable over	
Total	230	250	30	
Thickness in metres	0·80	0·90	+25	
Ore ($t \times 10^6$ – assumed to 1200m vertical depth)	3300	5420	4080	
Estimated recovery grade – PGE+Au (g/t)	5·5	6·0	3·0	
Resources ($kg \times 10^6$)	18·5	32·50	12·24	62·89
Ni and Cu				
Content %	0·18, 0·11	Low, Low	Var. Var.	
Estimated recovery grade (kg/t)	1·3, 0·8	– –	3·6, 1·8	
Resources ($t \times 10^6$)	4·3, 2·65	– –	14·7, 7·3	19·0, 9·95

PGE and Au Proportions

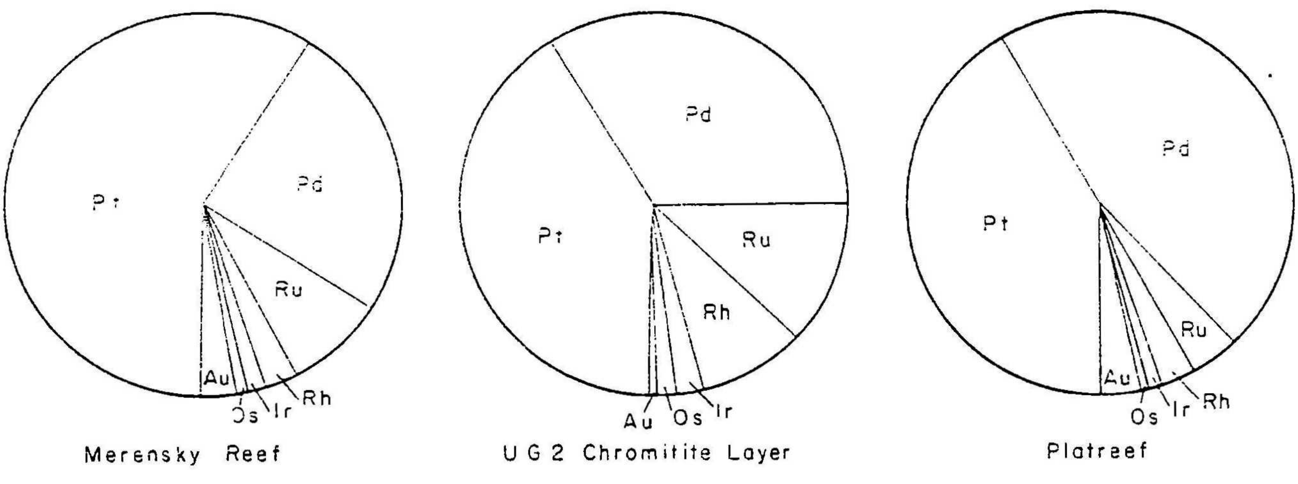

TABLE 1. DISTRIBUTION OF PLATINIFEROUS LAYERS AND ESTIMATED TONNAGES AND METAL CHARACTER AND RESOURCES OF MINERALIZED HORIZONS – BUSHVELD COMPLEX

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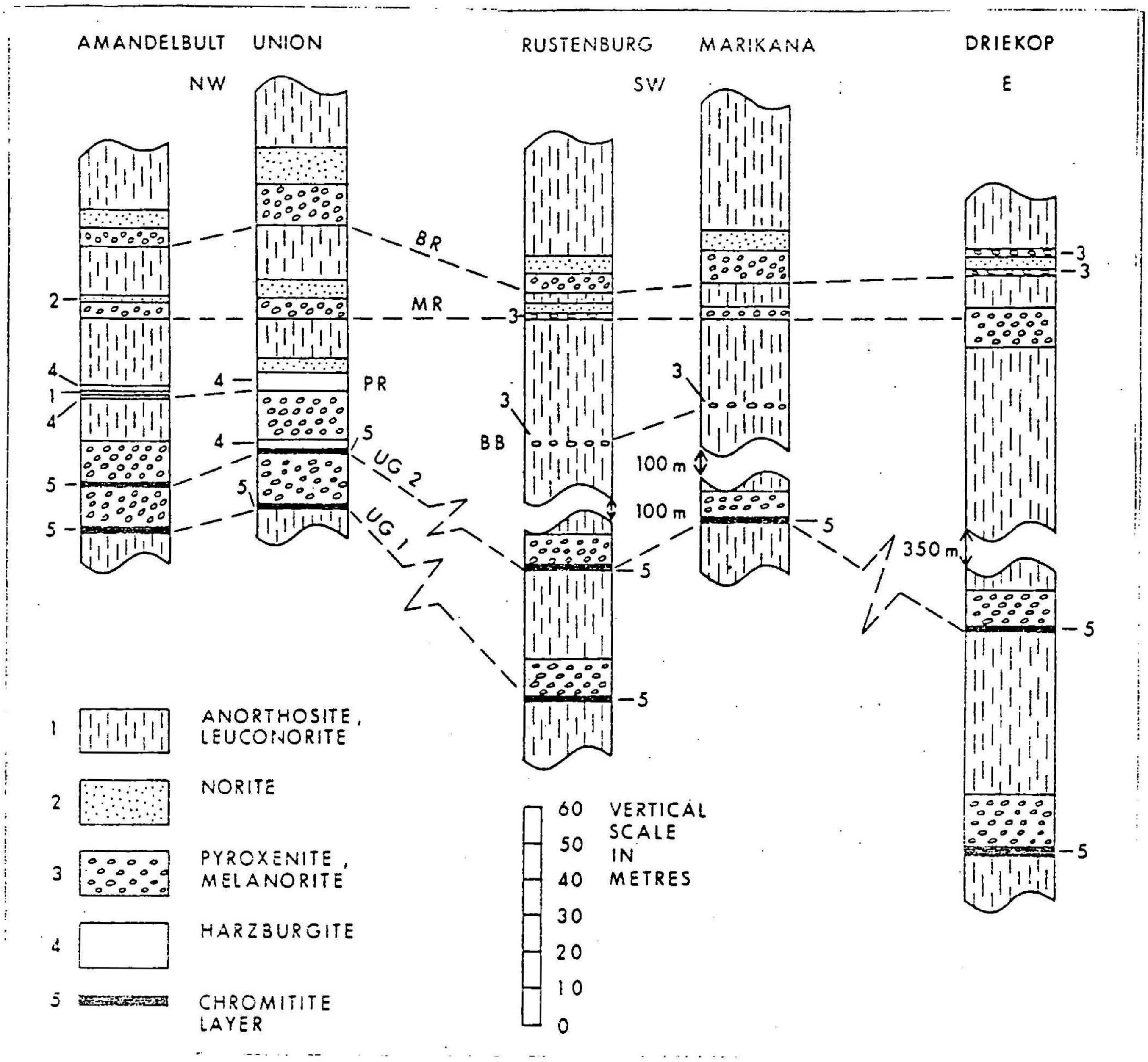

Figure 4. Stratigraphical successions of the Bushveld Complex, in the vicinity of the Bastard Reef (BR), Merensky Reef (MR), Pseudo Reef (PR) and Chromitite Layers Reproduced, with permission, from Naldrett (1981).

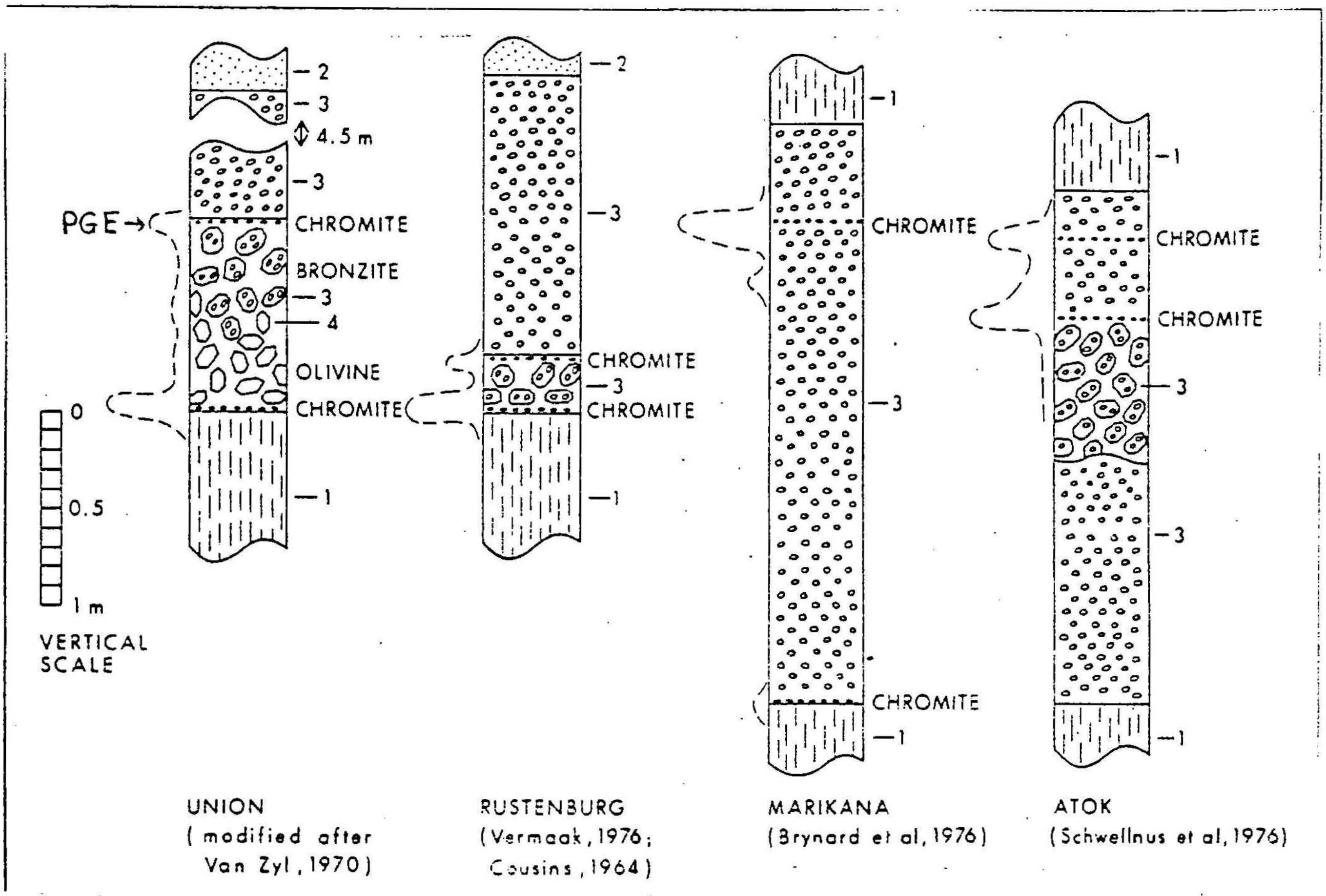

Figure 5. Stratigraphical successions throughout the Bushveld Complex, showing the relationship between PGE rich zones and the pegmatoid (olivine shown as 6 sided symbols, bronzite as 8 sided symbols that contain two open circles) underlying anorthosite, chromite layers and overlying pyroxenite in the vicinity of the Merensky Reef. Legend as for Figure 4. Reproduced, with permission, from Naldrett (1981).

1.1(ii) UG2 Chromitite Layer: This horizon is 30 to 400 m below the Merensky Reef and represents the single largest concentration of PGE in the world. (ore reserves estimated at 5.42×10^9t, see Table 1). Layers of cumulus chromite, designated UG1, UG2, UG3 occur at or near the base of various cyclic units ranging upward from porphyritic pyroxenites or melanorite through norite to anorthosite. Both the UG2 and UG3 contain minor amounts of base metal sulphides with which the PGE are associated. Laurite, braggite, cooperite (Pt S), vysotskite (Pd S) predominate.

1.1(iii) Platreef: Mineralisation occurs on the Potgietersrus limb (northern extension of the Bushveld Complex) and consists of a zone of sulphide blebs and rarer massive stringers within feldspathic pyroxenite and harzburgite over a strike length of 60 km and a thickness of up to 200 m. Mineralisation is close to the floor of the intrusion, with considerable sulphide development resulting from the interaction of the magma and basement ironstones and dolomites. Platinum group minerals include cooperite and sperrylite always in association with sulphides. Grades range from 7 to 27 g/t *total PGE. Pd predominates over Pt and the ore contains a similar proportion of Rh to the other PGE as the Merensky Reef.

1.1(iv) Dunite pipes: Dunite pipes and associated envelopes of olivine-bronzite-plagioclase pegmatoid occur in both the western and eastern sectors of the Bushveld Complex. These pipes which can be of very high grade, up to 2050 g/t total PGE, often consist of a central 20 m diameter zone of hortonolite dunite which tapers downward and is encased within a 100 m diameter zone of olivine dunite. The pipes have been interpreted as the replacement of bronzitite by hot aqueous solutions which leached SiO_2, Al_2O_3, and Na_2O and introduced FeO, TiO_2, V and the PGE.

The mineralogy differs greatly from the Merensky, UG2 chromitite layers in that there are not Bi tellurides, and PGE sulphides are rare. Pt-Fe alloys, sperrylite, geversite (Pt Sb_2), hollingworthite (Rh As S) and irarsite (Ir As S) are prominent.

Figures 4 and 5 show stratigraphic successions of the Merensky Reef and UG2 chromitite layer, and PGE rich zones from different areas of the Bushveld Complex.

1.2 Stillwater Complex

The Stillwater Intrusive Complex of southwestern Montana is a differentiated layered sequence (Sm-Nd age $2.701 \pm 0.008 \times 10^9$ y, De Paolo & Wasserburg, 1979) of mafic-ultramafic rocks which intrudes a Precambrian metamorphic terrain and has subsequently been faulted, uplifted and rotated into its present steep attitude. The surface form of the complex is believed to represent the margin of a much larger saucer shaped body, dipping steeply to the northeast. The complex extends for 48 km along strike and has a maximum exposed thickness of 7.4 km, although considerable thinning has occurred during erosion.

* All g/t units referred to in this review are gm/tonne.

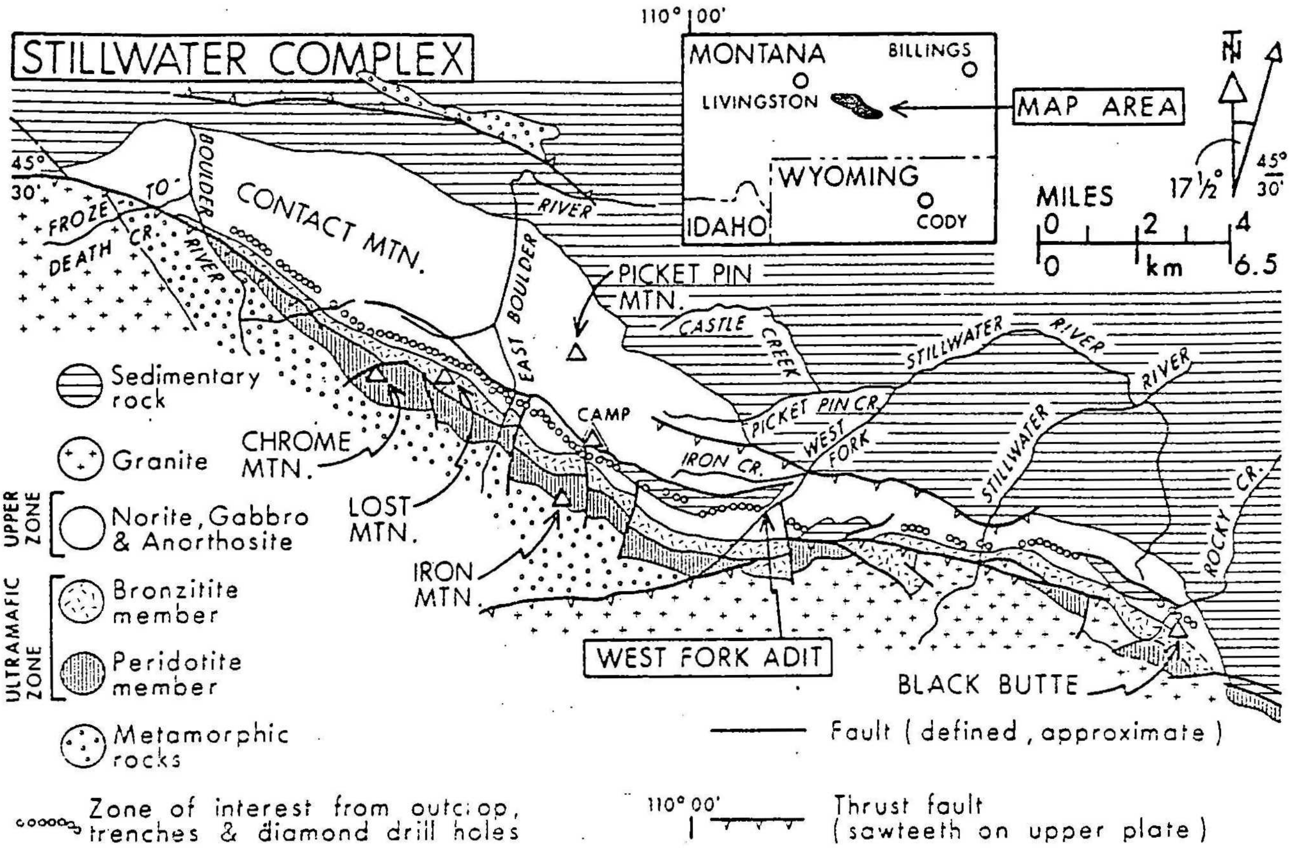

Figure 6. Geology of the Stillwater Complex. Reproduced, with permission, from Conn (1979)

Jones *et al.* (1960) Zone	Thickness (m)	McCallum *et al.* (1980) Zone	Thickness (m)	Characteristics
Upper	2040	Upper Banded	1130	Lower olivine-bearing subzone with a thick upper subzone of gabbro-norite.
		Middle Banded	1750	Dominantly anorthosite with two complex olivine-bearing subzones.
Banded	2255	Lower Banded	1590	Norite and gabbro-norite with minor anorthosite, troctolite and gabbro.
		Bronzite	305	Essentially a single layer of bronzite cumulate.
Ultramafic				
		Peridotite	915	15 cyclical units consisting of dunite, harzburgite and bronzitite, 13 with a chromitite layer near the base.
Basal			60	Noritic rocks; medium grained; variable textures; often rich in sulphide and inclusions of country rocks.

Table 2. Sequences of layered igneous rocks in the Stillwater Complex Reproduced, with permission, from Naldrett (1981)

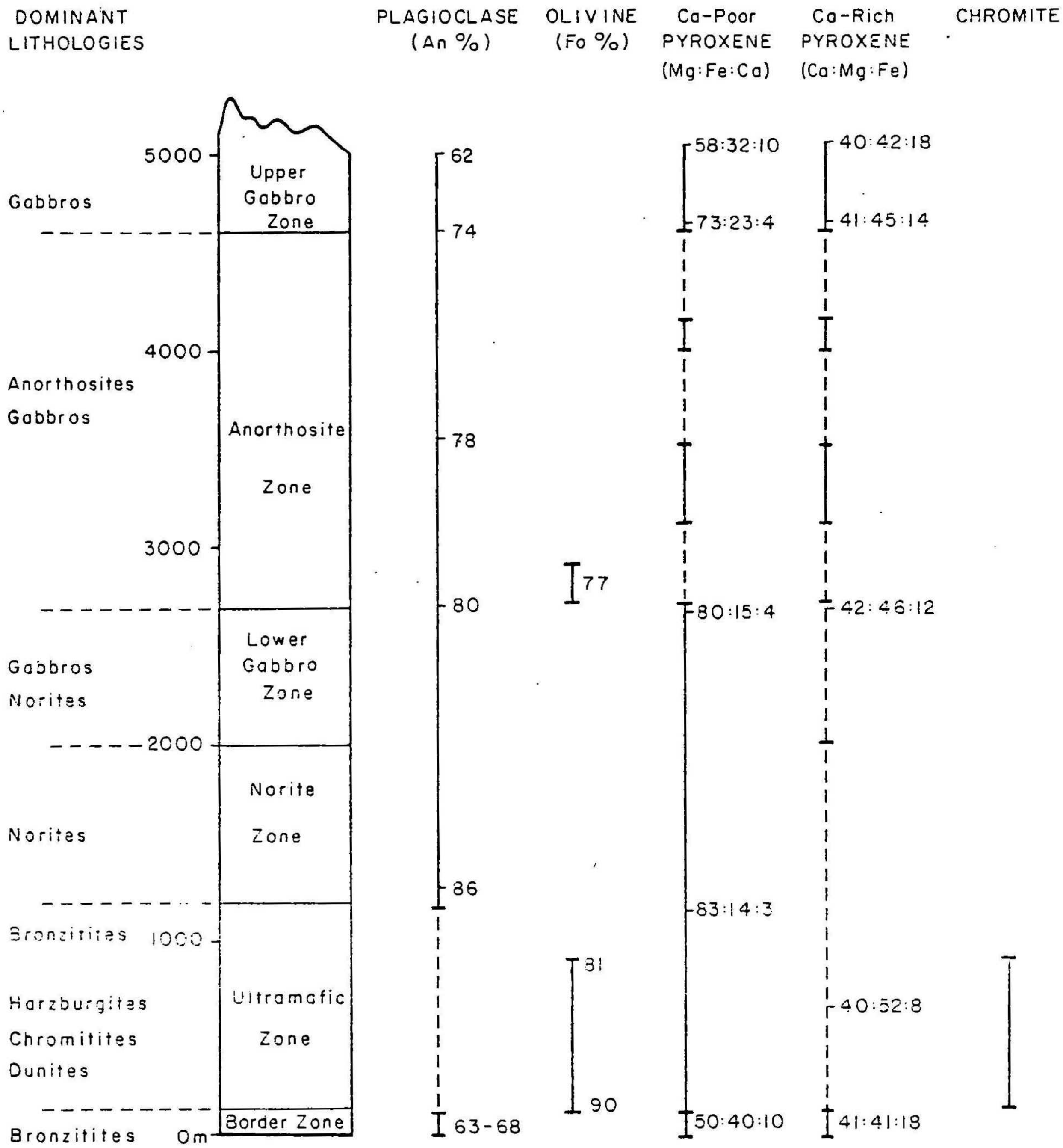

Figure 7 LITHOLOGICAL-CRYPTIC VARIATION OF THE STILLWATER COMPLEX. BROKEN LINES INDICATE INTERCUMULUS PHASES

Modified after Wager and Brown (1968)

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PGE Mineralisation-Stillwater Complex

The mafic-ultramafic succession has been divided into four main zones (i) Basal, (ii) Ultramafic, (iii) Banded and (iv) Upper zones as shown in Table 2. Figure 6 shows location and geology of the Stillwater Complex.

(i) The Basal zone consists of a marginal ophitic chilled gabbro, pyroxene gabbro, norites and feldspathic bronzitites higher in the sequence. Textures are variable and banding is uncommon. Large concentrations of nickel-copper sulphides (minor PGE associated) are prominent in this zone.

(ii) The Ultramafic zone composed of dunites, chromitites and bronzitites has been divided into two subzones, namely:

-a The Peridotite Subzone: This comprises the lower 75 percent of the ultramafic zone and is composed of 15 cyclical units of dunite, harzburgite and bronzitite, 13 of these with a chromitite basal layer. The cyclical units are characterised by basal concentrations of olivine and chromite which pass upward into bronzitite with plagioclase and augite as interstitial phases. PGE concentrations are closely associated (as with Bushveld) with the chromitite horizons, reaching a maximum for the basal horizon (called A zone) and progressively becoming lower tenor up through the chromitite horizons. The thickest chromitite horizons, the G and H zones do not have the highest PGE concentrations, hence chromite abundance does not govern PGE concentration. The A zone averages 0.10 oz/ton ($\simeq$ 3.42 g/t) and attains up to 0.60 oz/ton ($\simeq$ 20.52 g/t) of Pt + Pd + Rh. Stibiopalladinite, sperrylite, cooperite, platinum iron alloys and laurite occur as inclusions in chromite and in interstitial sulphides. Chromium shows the strongest correlation with the PGE, V a moderate correlation, and Ni, Co, Cu a lower correlation. Platinum metals are in greatest concentration where the oxidation ratios of chromite are lowest. (Brobst & Pratt, 1973).

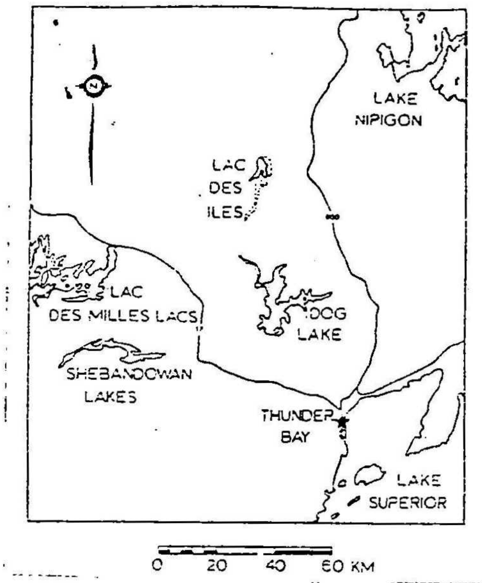
-b The Bronzite Sub Zone: The balance of the ultramafic zone is represented by a single layer of bronzite cumulate, some 305 m thick.

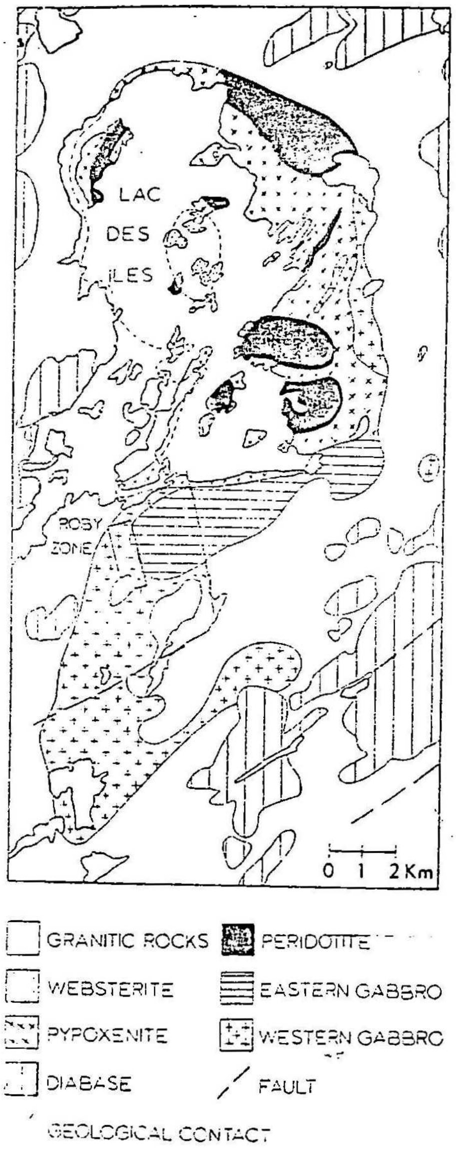
(iii) and (iv) The Banded and Upper zones consist of alternating layers of norite, gabbro-norite, gabbro and anorthosite. Small amounts of PGE have been reported from disseminated sulphide (0.5-1.5%) in gabbroic rocks of the Banded zone. This horizon has been traced over a 39 km strike length, with a width of about 2 m.

1.3 The Lac des Iles Deposit

The Lac des Iles intrusive complex located in Western Ontario differs from the previous two complexes in that it is regarded as Archaean in age and possibly intruded into an unstable tectonic terrain. The complex which has been intruded into granitic and gneissic rocks, consists of three parts: a northern dominantly ultramafic part; peridotite, clinopyroxenite, websterite and gabbro and a southern part composed of a western and an eastern gabbro. The western gabbro is composed

Figure 8 Location of the Lac des Iles Complex





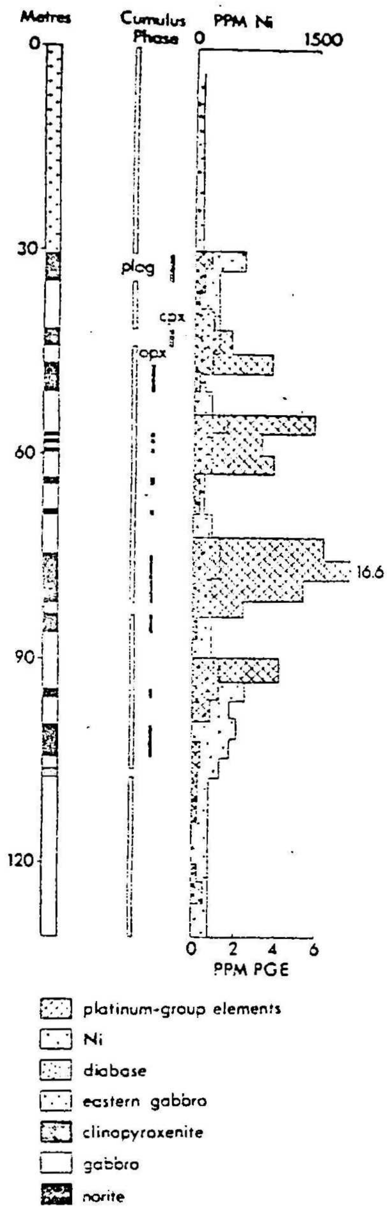


Figure 8 Geology of the Lac des Iles Complex. Figures 8 and 9 reproduced, with permission, from Watkinson and Dunning (1979)

Figure 9 Relationship of rock types, cumulus phases, PGE in DDH P57 (Roby Zone) of steeply dipping (50 to 85° to the east) interlayers of gabbro (70%), norite (20%), clinopyroxenite (10%) and minor anorthosite. Mineralisation consists of disseminated copper-iron-nickel sulphides and platinum group sulphides, arsenides, antimonides and tellurides. The eastern gabbro consisting of norite and gabbo is oxide rich, sulphide poor. The western gabbro is coarser grained and pegmatitic compared to the eastern gabbro. Order of emplacement is western gabbro, eastern gabbro and ultramafic unit.

Figure 8 shows the location and geology of the Lac des Iles complex.

PGE Mineralisation. Lac des Iles Deposit

The PGE are associated with zones of disseminated sulphide within the western gabbro. This is composed of layered plagioclase, orthopyroxene-plagioclase and clinopyroxene cumulates. The plagioclase cumulates contain up to 50% intercumulus augite. Pyrrhotite-pentlandite-chalcopyrite-pyrite are common in the less altered, sulphide rich rocks, although pyrite, millerite and violarite are more common in sheared and altered rocks of the western gabbro.

Nickel values from diamond drill hole P57 which drilled the mineralised Roby Zone (see Fig. 9) shows highest levels up to 600 ppm for noritic and pyroxenitic layers. Noritic layers contain the highest PGE, but high values have also been recorded in sheared altered clinopyroxenite - up to 3.8 g/t PGE. In general high PGE concentrations occur with higher nickel values, although there is no proportional relationship between the two. The correlation of PGE, Ni and pyroxene cumulates is apparent from Figure 9.

Vysotskite (Pd S), kotulskite (Pd Te), merenskyite ($Pd\ Te_2$), sperrylite, moncheite ($Pt\ Te_2$), isomertieite ($Pd_{11}\ Sb_2\ As_2$) and stillwaterite ($Pd_8\ As_3$) are the common PGM species with 0.19% Pd occurring as solid solution in pentlandite. Mineralisation appears to be more similar to Platreef, than the Merensky, UG2 layers of the Bushveld or Banded zone of the Stillwater Complex.

1.4 Some Criteria for Recognising Potential PGE Layered Complexes

Jackson & Thayer (1972) have distinguished three world wide classes of peridotite-gabbro complexes, namely: stratiform, concentric and alpine, based on their geological setting, proportions of rocks, mineralogy, texture, structure and form etc. It is the great stratiform complexes of the world which are the important hosts for magmatic platinum, platinum-chromite deposits, as outlined in the previous section. Although these complexes show in many cases great variability in detail several characteristics which are discussed below, are common to each. They are:

(i) Age: Generally pre 1000 m.y. with the PGE-Cr mineralised complexes of great status, pre 2000 m.y.

Table 3. Principal features of and Differences between Peridotite-Gabbro Complexes. Reproduced with permission from Jackson & Thayer (1972).

	STRATIFORM	CONCENTRIC	ALPINE
CHARACTERISTIC ROCK TYPES	dunite; HARZBURGITE; lherzolite; ORTHOPYROXENITE; WEBSTERITE; troctolite; NORITE; TWO-PYROXENE GABBRO; ANORTHOSITE; granophyre.	DUNITE; WEHRLITE; harzburgite; MAGNETITE-HORNBLENDE PYROXENITE; TWO-PYROXENE GABBRO; TONALITE; diorite; granodiorite.	A. HARZBURGITE SUBTYPE: DUNITE; HARZBURGITE; orthopyroxenite; websterite; GABBRO; troctolite; trondjemite; albite granite. B. LHERZOLITE SUBTYPE: dunite; harzburgite; SPINEL LHERZOLITE; garnet and plagioclase lherzolite; spinel, garnet and plagioclase websterite; garnet clinopyroxenite; troctolite; gabbro.
TEXTURE	CUMULUS TEXTURES; APPOSITION FABRICS, SELDOM LINEATED.	CUMULUS TEXTURES; MUSH FLOW TEXTURES; recrystallization textures; APPOSITION FABRICS, COMMONLY LINEATED; tectonite fabrics.	TECTONITE FABRICS (SOLID-FLOW TEXTURE); RECRYSTALLIZATION TEXTURES; RE-EQUILIBRATION TEXTURES; unmixing textures; cumulus textures rare, relict.
STRUCTURE			
A. GRAIN ORIENTATION	PLANAR LAMINATION; lineate lamination.	LINEATE LAMINATION; planar lamination; foliation.	FOLIATION (commonly crossing layers); LINEATION.
B. LAYERS a. kinds	SEDIMENTARY IN NATURE: MINERAL-GRADED LAYERS; ISOMODAL LAYERS; CHEMICAL GRADED LAYERS; size-graded layers. Dikes rare to absent	SEDIMENTARY, METAMORPHIC, AND IGNEOUS IN NATURE: ISOMODAL LAYERS; mineral-graded layers; SIZE-GRADED LAYERS; MUSH-FLOWAGE LAYERS.	METAMORPHIC AND IGNEOUS IN NATURE: METAMORPHIC DIFFERENTIATION LAYERS; SOLID FLOW LAYERS.
b. concordancy	ALWAYS TABULAR AND PARALLEL.	SUB-PARALLEL TO DISCORDANT; MAY BE CONCENTRICALLY ZONED.	COMMONLY DISCORDANT.
c. continuity	EXTREME.	VARIABLE.	LENTICULAR AND IRREGULAR TO MODERATELY PERSISTENT.
d. repetition	CYCLIC STRATIGRAPHY COMMON TO UBIQUITOUS.	VARIABLE.	IRREGULAR TO ABSENT.
C. CROSS-CUTTING STRUCTURES	RARE. "SANDSTONE" DIKES; scour; crossbeds; slump structures.	COMMON: dunite dikes; werhlite dikes; MAGNETITE-HORNBLENDE PYROXENITE DIKES; websterite dikes; GABBRO DIKES; HORNBLENDE-PLAGIOGLASE PEGMATITE DIKES. BOTH "SANDSTONE" DIKES AND MAGMATIC DIKES PRESENT.	COMMON: HARZBURGITE SUBTYPE: dunite dikes, ORTHOPYROXENITE DIKES; GABBRO AND TROCTOLITE DIKES. LHERZOLITE SUB-TYPE: SPINEL AND GARNET WEBSTERITE DIKES; garnet clinopyroxenite dikes; GABBRO AND TROCTOLITE DIKES.
D. STRUCTURAL SHAPE	FLOORED: TABULAR PARALLEL TO LAYERS; FUNNEL SHAPED.	CYLINDRICAL WITH ROUGHLY CONCENTRIC MAP UNITS; IRREGULAR.	VERY IRREGULAR: LENSOID TECTONIC SLICES; DIAPIRIC CONES.
STRUCTURAL SETTING	INTRUSIVE INTO METAMORPHIC OR BASALTIC TERRANES: COMPLEXES HAVE CHILLED BORDERS. LOCALIZED IN PRECAMBRIAN SHIELDS OR BASALTIC TERRANES OF ANY AGE.	INTRUSIVE INTO METAMORPHIC COUNTRY ROCKS: CHILLED BORDERS RARE TO ABSENT. LOCALIZED IN EUGEOSYNCLINAL OROGENIC BELTS. MAY BE ASSOCIATED WITH GRANODIORITE BATHOLITHS OR ROOTS OF ANDESITIC VOLCANOES.	TECTONIC EMPLACEMENT: FAULT CONTACTS, SERPENTINITE MARGINS, OR BRECCIATED BORDERS. HOT DIAPIRS; RHEID MUSH INTRUSIONS. LOCALIZED IN EUGEOSYNCLINAL OROGENIC BELTS AND ISLAND ARCS. MOST ARE PARTS OF OPHIOLITE SEQUENCES WHERE NOT STRUCTURALLY DISMEMBERED.
THERMAL EFFECTS	VERY STRONG CONTACT METAMORPHISM (PYROXENE HORNFELS FACIES) OVER LARGE DISTANCES. LITTLE ASSOCIATED METASOMATISM.	STRONG CONTACT METAMORPHISM (PYROXENE HORNFELS FACIES) OVER MODERATE DISTANCES. CONSIDERABLE AMPHIBOLE-PLAGIOCLASE CONTACT METASOMATISM.	METAMORPHISM MODERATE (ALMANDINE-AMPHIBOLITE FACIES) TO ABSENT. LITTLE OR NO ASSOCIATED METASOMATISM.
AGE OF EMPLACEMENT	EARLIEST PRECAMBRIAN TO HOLOCENE. MOST ABUNDANT IN 2500-3500 m.y. TERRANES.	PRE-DEVONIAN(?) TO MIDDLE CRETACEOUS.	LATE PRECAMBRIAN TO TERTIARY. ONLY ONE KNOWN OLDER THAN ABOUT 1200 m.y.
MAGMATIC MINERAL DEPOSITS	HIGH-IRON (CHEMICAL GRADE) CHROMITE; high-chromium (metallurgical grade) chromite; TITANIFEROUS MAGNETITE (VANADIUM); COPPER-NICKEL SULFIDES; PLATINUM SULFIDES; native platinum.	TITANIFEROUS MAGNETITE; NATIVE PLATINUM; ~~high-iron~~ (chemical grade) chromite; platinum sulfides.	A. HARZBURGITE SUBTYPE: HIGH-CHROMIUM (METALLURGICAL GRADE) CHROMITE; HIGH-ALUMINUM (REFRACTORY GRADE) CHROMITE B. LHERZOLITE SUBTYPE: NONE.
MINERALOGY A. RELATIVE ABUNDANCE OF MINERALS	VARIABLE: GENERALLY PLAGIOCLASE, ORTHOPYROXENE, OLIVINE, CLINOPYROXENE, CHROMITE.	VARIABLE: GENERALLY CLINOPYROXENE, OLIVINE PLAGIOCLASE, HORNBLENDE, MAGNETITE, ORTHOPYROXENE, CHROMITE.	A. HARZBURGITE TYPE: OLIVINE, ORTHOPYROXENE, PLAGIOCLASE, CLINOPYROXENE, CHROMITE. B. LHERZOLITE TYPE: OLIVINE, CLINOPYROXENE, ORTHOPYROXENE, SPINEL, PLAGIOCLASE, GARNET, PARGASITE, PHLOGOPITE.

B. COMPOSITIONS OF MINERALS	STRATIFORM: ULTRAMAFIC ROCKS (CUMULUS MINERALS ONLY)	STRATIFORM: GABBROIC ROCKS (CUMULUS MINERALS ONLY)	CONCENTRIC: ULTRAMAFIC ROCKS	CONCENTRIC: GABBROIC ROCKS	ALPINE: ULTRAMAFIC ROCKS HZ TYPE	ALPINE: ULTRAMAFIC ROCKS LZ TYPE	ALPINE: GABBROIC ROCKS
1. olivine	Mg 75-94	Mg 0-80	Mg 74-93	Mg 27-82	Mg 88-94	Mg 87-94	Mg 75-88
2. orthopyroxene	Mg 77-92	Mg 45-81	Mg 78-89	Mg 47-77	Mg 89-92	Mg 89-93	Mg 53-83
(Al_2O_2, wt. %)	(1.5-2.0)	(1.5-4.0)	(1.0--4.0)	(1.0-2.5)	(1.0-3.0)	(1.5-8.0)	(3.0-8.0)
3. clinopyroxene	Ca39-42Mg44-51	Ca35-41Mg0-49	Ca40-50Mg38-53	Ca37-48Mg29-53	Ca44-48Mg48-51	Ca40-48Mg46-54	Ca40-48Mg35-53
(Al_2O_3, wt. %)	(1.5-3.0)	(2.0-3.5)	(1.0-7.0)	(1.5-3.5)	(1.0-3.0)	(2.5-10.0)	(3.0-11.0)
4. plagioclase	An 77-86	An 30-88	An 90-93	An 25-93	none	An 60-88	An 37-93
5. hornblende	none	rare	Ca32-34Mg40-52	Ca32-34Mg45-50	none	Ca28-32Mg59-65	rare
(Al_2O_3, wt. %)			(14.5-17.0)	(14.0-15.5)		(10.0-15.0)	
6. garnet	very rare	none	none	none	none	Ca11-15Mg64-70	none
(Al_2O_3, wt. %)						(21.-24.0)	
7. chromite	Mg 30-70	Mg 30-46	Mg 49-66	none	Mg 51-73	Mg 50-95	Mg 44-80
(spinel)	Cr49-77Al19-41	Cr60-65Al20-28	Cr48-63Al17-46		Cr18-87Al11-81	Cr2-19Al76-99	Cr0-7Al52-80
8. magnetite-ilmenite	rare	abundant	abundant	abundant	none	none	moderately abundant
T_1O_2 (wt. %)		(12.0-20.0)	(4.0-11.0)				
V_2O_5 (wt. %)		(0.3-2.1)	(0.5-1.4)				

(ii) Tectonic Setting: Dominantly in stable Precambrian cratonic shields or more rarely in basaltic-ophiolitic terrains of variable age.

(iii) Scale: Typically and significantly, very large in all three dimensions. Stratigraphic thickness of mafic-ultramafic component at least five to six km. Other two dimensions can be up to 400 km, as highlighted by the Bushveld Complex.

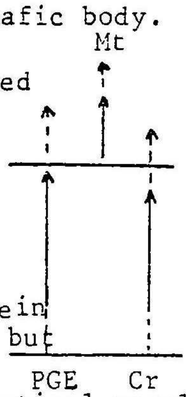
(iv) Form: Generally basinal or lopolithic in profile showing considerable lateral persistence on flanks. Invariably floored with some incorporation of country rock. Attitude of complexes variable, ranging from sub vertical (i.e. Stillwater Complex) to near horizontal (i.e. Bushveld Complex) thus governing different surface geometries.

(v) Deformational Status: Degree of tectonic disruption and dismemberment of complexes variable, ranging from the Bushveld type which displays a paucity of fault-deformational related features to intensely deformed and regionally metamorphosed variants such as the Giles Complex of central Australia, or the Coobina Complex of Western Australia. The chromite deposits of Campa Formosa in Brazil were formerly thought to be isolated blocks, but now they are recognised as a highly faulted layered complex about 18 km long (Evans, 1980).

(iv) Overprinting Features: Contact metamorphism of country rock strongly pronounced. Extensive contact aureoles of pyroxene-horfels facies. Precious and base metal telemagmatic ores may be incorporated within marginal country rock.

(vii) Associated Intrusives: Younger discordant granitic, granophyric and alkaline intrusives are commonly within the mafic-ultramafic body.

(viii) Stratigraphy: A generalized succession is shown at right.



Gabbro-diorites-troctolites
Norites-anorthosites-gabbro-troctolites
Bronzites-norites-anorthosites-chromites
Bronzites-dunites-harzburgites-chromites
Chilled basal rocks, mainly mafic composition

Importantly the sequence is not only differentiated but also layered. The layering is of great vertical regularity and of wide lateral extent. Cumulate fabrics involving pyroxene, olivine, plagioclase, chromite, magnetite dominate certain levels. Rhythmic, cyclic, cryptic trends are common througout.

(ix) P.G.E. Distribution: The platinum group minerals are typically low in the stratigraphy, within the more magnesian members of the mafic-ultramafic pile. PGE generally show a close spatial association with chromite, however they can be associated with nickel-copper sulphides, either in the basal zones, or within gabbroic rocks high in the sequence. Prediction of PGE concentration within the stratigraphic levels appears to be difficult, as shown by the following examples. PGE zones within the Bushveld Complex are generally not associated with the first appearance of any unique rock type, although many PGE horizons are of greatest dimension and continuity, with the first consistent widespread juxtaposition of an olivine cumulate with an overlying plagioclase cumulate. In the Great Dyke of Zimbabwe a concentration of precious metals over 1 to 2 m occurs close to the boundary between feldspathic clinopyroxene rich and orthopyroxene rich cumulates. This horizon, usually present about 10 m from the top of a 160-185 m thick pyroxenite layer, is anomalous in nickel, copper, chromium, palladium, platinum and gold. However, in the case of the Stillwater Complex the favourable zone represents one of cyclic magma introduction, with the PGE-chromitite bands tending to be rather thin and dispersed, thus the whole ultramafic zone, represented by both olivine and pyroxene cumulates would have to be investigated.

1.5 Other Styles of P.G.E. Mineralisation

Apart from the nickel-copper sulphide dominant styled deposits, such as the norite-gabbro Sudbury-Irruptive Complex-Ontario, the tholeiitic intrusive hosted ores of Pechenga-USSR and Lynn Lake-Canada, and the komatiitic associated deposits of Kambalda, Widgiemooltha, Perseverance, Mt Keith, Yakabindie of Western Australia and the Abitibi, Ungava, Manitoba, Dumont belts of Canada, three other forms of PGE mineralisation may also have relevance within the Australian Phanerozoic and Precambrian. These are (i) hydrothermal type depsoits (ii) the boninite precious metal association and (iii) ores associated with intracontinental rifting and intrusive equivalents of flood basalts.

(i) The New Rambler copper and iron sulphide deposits of southeastern Wyoming are known to contain significant concentrations of PGE. The ore occurs as irregular pods in hydrothermally decomposed metadiorite and metagabbro. Pyroxenite and peridotite are known at depth, beneath the ore zones. The main sulphides include: pyrite, chalcopyrite, pyrrhotite, covellite, marcasite with accessory pentlandite and PGE The distribution of the ores, their structural control, the hydrothermal alteration associated with them, their composition and mineralogy collectively suggest the metals have been concentrated by the combined activity of hydrothermal solutions and supergene alteration. There is no evidence that the deposit is the result of the alteration of an original concentration of magmatic sulphides. Similar styled deposits occur in the Waterburg and Messina districts of Transvaal, Hitura-Finland, Monchegorsk-USSR and Noril'sk W. Siberia (McCallum and others, 1976).

It is unlikely that this style of mineralisation is pronounced within the Archaean and Proterozoic of western and central Australia, however the Palaeozoic magmatic provinces of the Tasman Geosyncline with

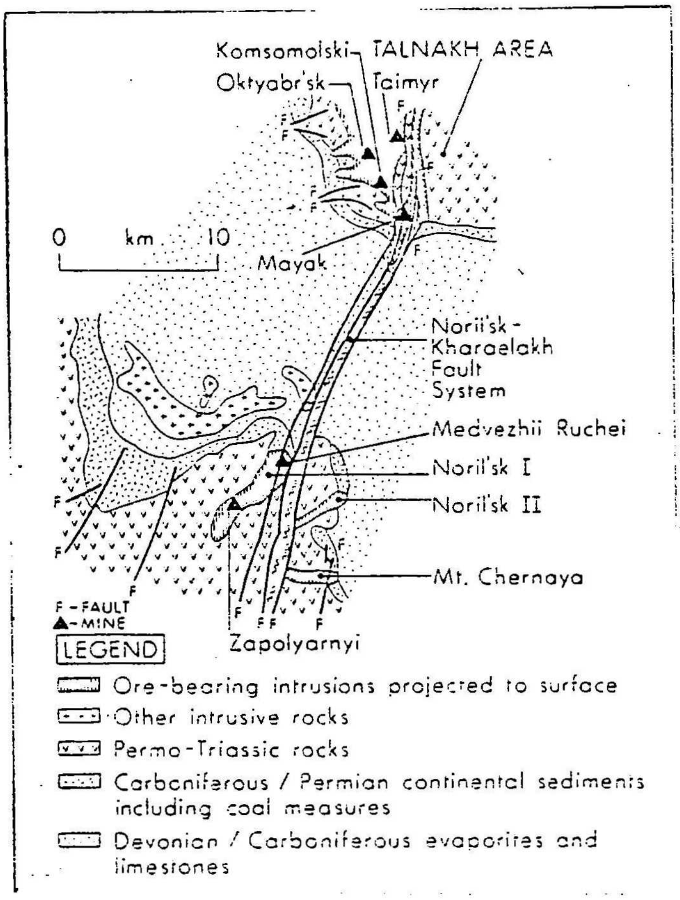


Figure 10. Geology of the Noril'sk-Talnakh Area. Reproduced, with permission from Naldrett (1981)

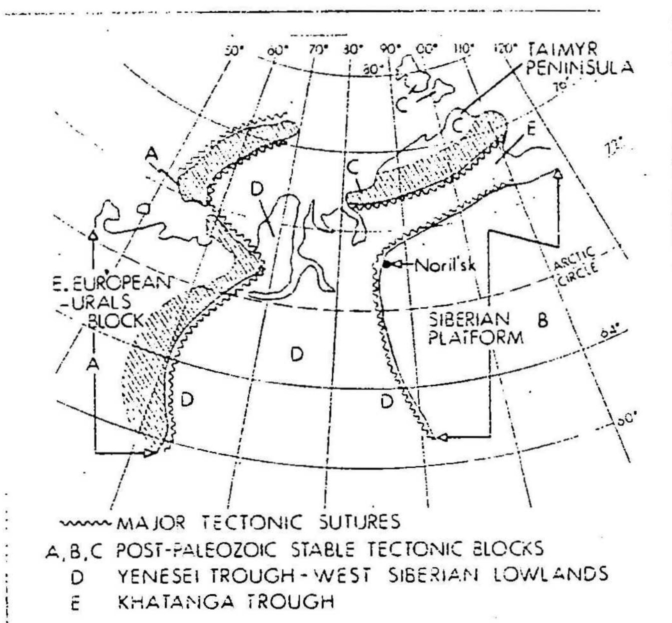


Figure 11. The tectonic setting of the Noril'sk Ni-Cu camp. Reproduced with permission from Naldrett (1981)

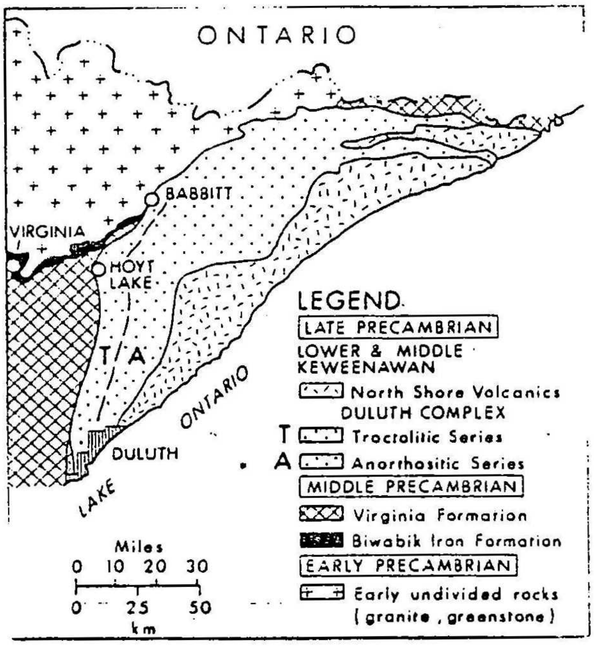


Figure 12. Simplified geological map of the area around the Duluth Complex. Reproduced, with permission from Naldrett (1981).

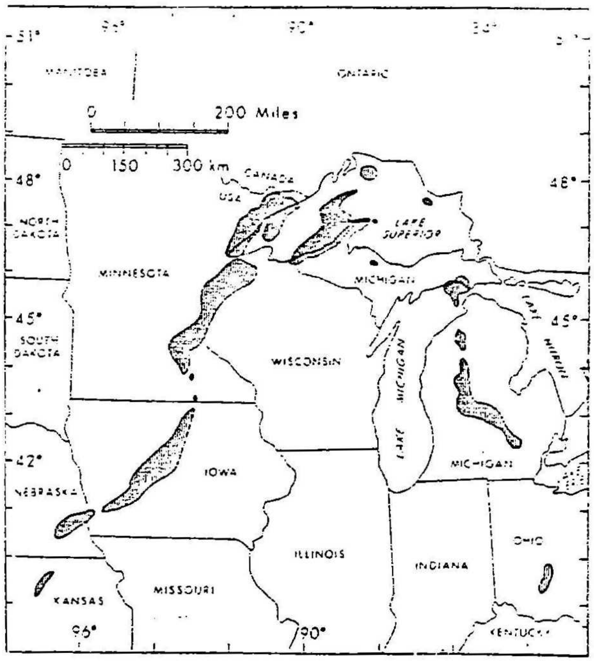


Figure 13. Bouguer gravity-North America. The mid continental rift zone is indicated by the positive gravity (hatched) zone. Reproduced with permission from Naldrett (1981)

associated widespread hydrothermal alteration and mineralisation may offer scope for small tonnage type deposits, in particular where such regimes of hydrothermal activity are spatially close to the ultramafic-platiniferous belts of eastern Australia. Vein type PGE-basemental mineralisation is known from the Thomson River Copper Mine, near Walhalla, Victoria where mineralisation is of veining-disseminations in dykes, and Pt-Au veins at Evans Head, NSW. However the rarity of this type of mineralisation on a world wide scene (although this may be partly due to a lack of recognition) suggests similar type deposits may be restricted to a particular geological setting and/or time period.

(ii) The precious metal potential of boninite type volcanism within Australia is largely unknown since an understanding of these rocktypes has only recently become clearer in the island arc type regions of the western Pacific. However the chemistry and interpreted genesis of these specialized magma types suggests they may be prospective for PGE sulphide hosted mineralization, within rifted oceanic or continental crust terrains.

Boninites are fine grained olivine, orthopyroxene, clinopyroxene bearing, plagioclase poor lavas whose characteristic chemistry: high MgO 9%, high $SiO_2 > 55\%$, low $TiO_2 < 0.3\%$, Ni 70-450 ppm, Cr 200-1800 ppm (Hickey & Frey, 1982) distinguish them from island arc tholeiites and calc alkaline type volcanics. They appear to cover a wide geographic distribution including the Bonin Islands-Japan, both fore arc and trench wall regions of the Marinana Trench, Cape Vogel-Papua New Guinea and the Greenstone Belts of Central Victoria. Boninites are believed to be derived from the peridotite residue of an earlier tholeiitic volcanic phase and because of their late stage sulphur saturation combined with their anomalous metal content, may form important concentrations of precious metals.

(iii) The other main style of PGE mineralisation which appears to have potential in Australia, is that involving intracontinental rifting and flood basic volcanism and is highlighted by the extensive Noril'sk-Talnakh copper-nickel deposits of the Siberian Platform and the Duluth Complex of Minnesota.

(iii)-a The tectonic history of the Noril'sk-Talnakh copper-nickel deposits occurring on the northwestern margin of the Siberian Platform has been a complex one, with various phases of uplift-subsidence, rifting occurring during Phanerozoic times. Large volumes (approx. 1.0 million cubic km) of late Permian and Triassic flood basalt and tuff, known as the Siberian traps mantle Palaeozoic marine argillaceous sediments, carbonates, evaporites and younger lagoonal and continental sediments, see Figures 10, 11. Sill-like tholeiitic intrusions varying in composition from sub-alkaline dolerite to gabbro dolerite were emplaced contemporaneously with, and are feeders to the extrusive activity. It is these Triassic intrusions which are mineralised and represent volcanic conduits radiating outward and upward from intrusive centres and penetrating the sedimentary sequence. The ore-bearing intrusives are differentiated, with picrite and picritic dolerite overlain by more felsic differentiates. Individual sills may attain lengths of 12 km, widths of 2 km and thicknesses of 30 to 350 m. The Cu, Ni, PGE mineralisation forms relatively persistent ore horizons, occurring as disseminated and massive accumulations of pyrrhotite, pentlandite, chalcopyrite in the lower portions of the intrusions and as disseminated zones and massive veins in the adjacent footwall.

Most of the intrusive centres at Noril'sk are associated with prominent block faulting, which is coeval with the igneous activity. Individual faults may be over 500 km in length, with throws of up to 1000 m. Principal fault trends are NNE to NE.

The Noril'sk ores contain a wide variety of PGM species, particularly in the copper rich ores. They include the native metals, Sn and Pb solid solutions with Pd and Pt, intermetallic compounds of Pd with Sn, Pb, Cu, Ni, S, Bi and As, and various arsenides, antimonides, bismuthides, sulphides and tellurides of Pt and Pd. Isotope studies suggest sulphur is not mantle derived but resulted from the assimilation of the evaporites during magmatic emplacement.

(iii)≠b The Duluth Complex consisting of a Troctolite and Anorthosite series of 1.12 Ga intrusive age extends as an arcuate mass for 250 km from Duluth, Minnesota to the Canadian border. Archaean felsic intrusives and volcanics with younger iron formations flank the complex to the northeast while various argillaceous and graphitic sediments and sulphide facies iron formations occur to the north and west, see Figure 12 for the regional geolgoy.

The mineralisation of the Duluth Complex occurs along its western margin, associated with a variety of intrusions, some of which are believed to have been feeders for the Keweenawan flood basalts found along the north shore of Lake Superior. Pyrrhotite-pentlandite-chalcopyrite sulphides are commonly associated with a zone of dunite and with peridotite layers within overlying troctolite. It is believed that the initial olivine rich magma which was contaminated with sulphide bearing country rock, was injected to form the main dunite hosted ore zone which then started to differentiate. Successive influxes of new magma flushed out existing, partially differentiated magma to form the Keweenawan north shore volcanics, and themselves differentiated to give rise to a series of peridotite-troctolite-arothosite cyclical units in which sulphides settled into the basal peridotite members of each of these units.

The mid continental rift zone of North America is indicated by positive gravity, see Figure 13, and both positive and negative magnetic anomalies, with a high proportion of Keweenawan basalts and mafic intrusions occurring within this anomalous geophysical zone. Intracontinental rifting had its greatest development in the Lake Superior area.

In summary these "unusual" types of PGE mineralisation may have Australian anologues since they appear to occur over a wide geological time span, from at least the Mesozoic to Mid-Proterozoic, are located widely on different continents, are intimately associated with flood type doleritic and/or basaltic volcanism, which are possibly characteristic of several Australian Provinces. In addition it is likely that these types of deposits have received very little exposure from private industry and the prospector.

Recognition of: intracontinental rift zones (by utilising geophysics, locating pervasive structural elements and linear regions of intrusive-extrusive activity, etc.), basaltic-doleritic flood volcanism with their associated feeder intrusives, carbonate and/or sulphide bearing country rock for source of sulphur by assimilation, and deep seated fault related structures within complexes such as: the Zamu-Oenpelli Dolerites of the Pine Creek Geosyncline, Woodward and Hart Dolerites of the Kimberley Block, Lower Proterozoic sills of the Bangemall-Hamersley-Naberu-McArthur Basins and even the younger Jurassic dolerite sills of central-eastern Tasmania and flood basalts of western Victoria, may suggest the region is favourable for this unique form of PGE mineralisation.

1.6 Exploration Techniques

Despite the successful use of various geophysical methods, in defining diverse styles of base metal mineralisation, these methods appear to have little application in the investigation of poorly exposed layered complexes. Magnetics may help to define the regional extent and possible gross structures of the intrusive body in a weakly magnetic terrain, however it is unlikely to discriminate thin PGE-sulphide or even at the least, prospective pyrrhotitic sulphide zones, especially at considerable depth. An exception to this may be the definition of the oxide facies, i.e. magnetite gabbros and magnetite bands high in the sequence. Despite the high specific gravities of the PGE and chromite, gravity would be of little use in "narrowing in" on the target due to the thin nature of the PGE lodes and masking by the dense mafic-ultramafic host rocks. Associated sulphide contents are invariably too low and of disseminated nature to provide strong induced polarization responses. Depth of weathering and water table influences in the Archaean-Proterozoic of Australia may also complicate these electrical methods. I.P. responses are coincident with soil platinum geochemistry at the Janet 96W mineralised zone of the Stillwater Complex (Conn, 1979), thus IP may be of use in thinly covered terrains.

The combination of careful field assessment and geochemical methods appears to have greatest application in locating such deposits. The geochemical stability of platinum group elements in the secondary environment, its association with other traceable elements, such as Cr, V, Cu, Fe (Clark & Greenwood, 1972) high specific gravities (12.0 Pd to 22.5 Os) combined with the PGE zones favouring, in many cases particular compositional interfaces in the lower stratigraphical levels, and the lateral continuity of horizons, collectively suggests recognition of crystallisation sequences of favourable stratigraphic successions coupled with reconnaissance heavy mineral stream sediment-rock chip sampling are the most favourable explorative methods.

2. Platinum Group Mineral Resources within Australia

With the exception of the Kambalda nickel-copper sulphide deposit of Western Australia, Australian production has been largely derived from small placers within the Tasman Geosyncline of Eastern Australia. Thin structurally controlled serpentinite bodies of "Alpine intrusive type" are believed to be the source of the PGE.

The majority of Australian platinum has come from New South Wales, while Tasmania has dominated osmiridium production. Total recorded Australian production to the end of 1961 was 595.43 kg of platinum and 909.13 kg of osmiridium (McLeod, 1965). PGE production from eastern Australia since 1961 has been negligible. Recoverable platinum and palladium within Kambalda nickel concentrates amounted to 63.61 kg and 328.24 kg respectively, during 1980 (Pratt, 1980).

The following listing of PGE-Chromium-Vanadium Resources within Australia is largely obtained form the following references: (McLeod, 1965, - BMR Bull No. 72; Knight, 1975, - BMR Mono. 5.; Baxter, 1978, - GSWA Min. Res. Bull. No. 11; Markham & Basden, 1974, - GSNSW Mineral Deposits of New South Wales; Lord, 1975, - GSWA Mem 2; Pratt, 1980, - Australian Mineral Industry - Annual Review; Omer-Cooper & Moeskops 1978, - Amdel No. 23 Bulletin; Parkin, 1969, - Handbook of South Australian Geology, Douglas & Ferguson, 1976 Spec. Publ. No. 5; see appended reference list for details of the above). Figure 14 shows the localities of the PGE-Cr-V occurrences, mentioned in the following three sections. Table 4 lists the deposits according to style-type of mineralisation.

Summary of PGE Occurrences within Australia

2.1 Queensland

Palladium has been recorded within small auriferous quartz veins within fractured diorite at Westwood, near Rockhampton. Platinum and osmiridium has been detected in beach sands along parts of the southern Queensland coast.

2.2 New South Wales

The Fifield alluvial district of central western New South Wales has been by far the largest producer of platinum in Australia. Platinum with gold is found at the Fifield, Platina and Ellenbine Tank alluvial leads, with the source of the metals probably derived from the basic differentiates of the Tout Complex - a Siluro-Devonian basic to ultrabasic body with spatially associated serpentinites. Fifield has accounted for over 96% of eastern Australian platinum production.

Small quantities of platinum, osmiridium, palladium have been obtained as a by product of gold dredging, on the Macquarie River, near Wellington. Total production is less than 6.0 kg of platinum concentrate.

Platinum and gold have been obtained from a small vein at Evans Head, and some platinum from Ballina, both on the north coast.

Small quantities of platinum are associated with serpentinite sills and lenses in the Broken Hill district, notably at Mulga Springs, Mt Darling Creek and Red Hill. The platinum occurs in lenticular veins which are discontinuous and thin. Gold, copper, nickel, cobalt, iridium and rhodium are often associated.

Platinum has been reported in beach sands at Ballina, Black Head, Brunswick River, Byron Bay, Coffs Harbour, Evans Head, Gerringong, Lake Macquarie, Macleay River, Murrumerang, Seal Rock Bay, Shellharbour, Swansea, Ulladulla and Woodburn.

2.3 Victoria

Platinum and palladium occur in association with copper minerals at the Thomson River copper mine, near Walhalla. The copper occurs as sulphide veins and disseminations in a hornblende dyke intruding Silurian sediments. The platinum occurs as sperrylite, while the more prominent palladium species is unknown.

Small quantities of osmiridium are known from beach sands at Waratah Bay - South Gippsland.

2.4 Tasmania

Adamsfield, 80 km west of Hobart has been the largest producer of osmiridium in Tasmania. The osmiridium occurs in both lode and alluvial deposits with the greatest production being related to the latter. The main lode occurs at the northern end of a serpentinite dyke which intrudes conglomerates, quartzites and limetones of the Ordovician Junee Group. The osmiridium averages 45% Os, 41% Ir, 6% Ru, 0.3% Rh with trace Pd, Au. Total production from Adamsfield has been 436.42 kg about 40% of the State's total reocrded output.

Osmium-iridium alloy occurs at Fourteen Mile Creek on the South Gordon track from Maydena, 25km east of Adamsfield.

The Bald Hill-Savage River-Mount Stewart-Wilson River osmiridium alluvial deposits near Waratah in the northwest of the State are derived from small bodies of serpentinized bronzite, peridotite and serpentine. Total production for this district to 1952 was 444.92 kg.

2.5 South Australia

Platinum has been recorded at Mingary, on the Broken Hill railway line, near the New South Wales border.

2.6 Western Australia

PGE values are often associated with sulphide nickel-copper deposits, such as Kambalda (as mentioned earlier) and Windarra, where platinum ranges from 0.15 g/t-0.17 g/t) and palladium 0.77 g/t-2.3 g/t. These sulphide dominated type deposits will not be discussed in any great detail in this review.

Chromite bands from the Panton Sill, a Early Proterozoic disturbed stratiform type complex in the Halls Creek Mobile Zone assay up to 3 g/t platinum.

Chromite bands within the Eastman's Bore-Louisa Downs mafic-ultramafic complex, located 130 km southwest of Halls Creek contain Pt+Pd values up to 7 g/t.

Exploration is currently active at the Yellowdine Platinum Prospect, located 34 km east-southeast of Southern Cross in the Yilgarn Block. Platinum values up to 200 g/t have been obtained in a complex 1.5 km long, consisting of metaperidotite segments flanking a granitic dome.

Alluvial osmiridium and rutheniridosmine grains have been located north of Roebourne, in the west Pilbara.

3. Chromium Resources within Australia

It is important to consider the distributuion and geological setting of chromite (and vanadium) within Australia, since as highlighted by the Bushveld Complex, it often shows a close spatial and tenor association with PGE mineralisation within the layered mafic-ultramafic intrusive complexes.

Australian chromite deposits are geographically and geologically quite diverse; with "Alpine podiform" types occurring within narrow Palaeozoic serpentinite belts of the Tasman Geosyncline and secondly within Archaean-Proterozoic layered peridotite-gabbro intrusives and highly metamorphosed basic to ultrabasic rocks of western and central Australia. Alluvial deposits spatially associated with eastern Australian serpentinites have been intermittently worked.

Total Australian production to the end of 1980 was approximately 80,570 tonnes (Pratt, 1980, and previous Annual Reviews). Recent production has been confined to the Barnes Hill deposit near Beaconsfield, northern Tasmania, where detrital chromite occurs within Tertiary quartzose gravels. New South Wales has been the largest state producer, with deposits near Rockhampton, Qld, and the Coobina Creek deposit of WA also being prominent. All major deposits appear to be associated with serpentinite.

Summary of Chromite Occurrences within Australia

3.1 Queensland

Chromite production (14,024 tonnes) has been prominent in the Rockhampton area; notably, the Princhester-Marlborough-Glen Geddes-Tungamull districts, where separate serpentinite bodies intrude schists and andesites. The serpentinites vary from strongly schistose to massive, with the chromite ore being of both massive and disseminated type. The deposits are of low-grade, with the chromite generally low in chromium.

Several small uneconomic deposits occur on Gray Creek, 112 km west-southwest of Ingham, where chromite pods occur within a serpentinite-gabbro-pyroxenite complex. Coarsely crystalline chromite, probably of cumulate origin and disseminated chromite ore are confined to the serpentinite horizons.

Small chromite occurrences are also known in the Mareeba, Ipswich, Stanthorpe, Clermont, Kilkivan, Mary Valley districts.

3.2 New South Wales

New South Wales has provided over 60% of Australia's total chromite production with some 50,000 tonnes produced prior to 1945. Negligible production has occurred since then. The podiform chromite deposits occur within three north-northwesterly trending serpentinite belts namely:

Gundagi-Coolac-Wallendbeen Belt
- (80 km strike length, total production 32,000^{+} tonnes)

Nundle-Bingara Belt
- (320 km strike length, total production 8,040 tonnes)

Copmanhurst-Fineflower-Gordon Brook Belt
- (32 km strike length, total production 4,895^{+} tonnes)

The dominant rock type within these belts are serpentinized harzburgites, which often show evidence of deepseated deformation and syntectonic recrystallisation. The Coolac Ultramafic Belt also has associated small layered complexes of dunite-wehr lite-clinopyroxenite-gabbro lithologies. The chromitite bodies within the serpentinites are generally lenticular and of variable small dimensions, less than 2000 m^3 generally. Chromite textures are variable throughout the Belts, these being related to cumulus, tectonic, transport, metasomatic and cataclastic processes.

PGE potential throughout the Ultramafic Belts has been investigated by various private companies and appears to be low. Platinum has been reported in these "Chromite Belts" from Nowendoc, Nundle and Crow Mountain of the Nundle-Bingara Belt.

3.3 Victoria

Only chromite production within Victoria has been associated with shear zones in a podiform serpentinite body at Dolodrook River, 45 km north of Heyfield in an Upper Cambrian sediment-greenstone sequence.

Occurrences associated with Cambrian diabases have been recognised at Howqua River (15 km south of Mansfield), Tatong (26 km southeast of Benalla), Dookie (38 km west of Wangaratta), Mount Stavely (42 km south-southwest of Ararat) and the Black Range near Horsham.

A serpentinite chromite association has also been reported at Theile's Creek, 200 km east of Melbourne.

Chromite alluvium is also known in the Heathcote area.

3.4 Tasmania

Minor chromite mineralisation occurs throughout the west and north of Tasmania in association with Cambrian rocks. Chromite is associated with the Adamsfield osmiridium deposits and is present as extensive alluvial deposits at Montague Swamp, northwest Tasmania and at the Barnes Hill-Rifle Range Prospects-Beaconsfield, northern Tasmania. The Tasmanian alluvial deposits are invariably derived from the Cenozoic weathering of Cambrian "Alpine" type serpentinites.

3.5 South Australia

Chrome and nickel mineralisation within the Tomkinson Range in the northwest is the only noted occurrence within the State.

3.6 Western Australia

Sub-economic chromite deposits of the stratiform and disturbed stratiform type occur within the Yilgarn, Pilbara, Albany-Fraser and Kimberley areas of Western Australia. Intrusions within the Musgrave Block of central Australia (includes WA, NT, SA) are also hosts for chromite mineralisation. Complexes are either layered peridotite-gabbro intrusions, i.e. Coobina, Nobs Well, Pear Creek and Bulong or highly metamorphosed basic to ultrabasic rocks, i.e. Imagi Well, Taccabba Well and West Bendering. In the former, the chromite tends to form flat discontinuous sheets at the base of differentiation cycles of no greater than 2 m thickness, while the chromite lenses in the metabasic complexes tend to be concentrated in moderately compact zones parallel to the lithological layering and often disrupted by faulting and granitoid intrusion.

The chromite occurrences of Western Australia will be divided into the various provinces; Yilgarn and Pilbara Blocks, Albany-Fraser and the Kimberleys.

- Yilgarn Block:

The Imagi Well chromite prospect (located near the Mullewa-Gascoyne Junction Rd on Byro Station) consists of discontinuous chromite lenses within a steeply dipping quartz amphibolite, pyroxene amphibolite sequence of upper amphibolite facies. Pospect investigated by E.Z. Co (Aust) Ltd.

Limited drilling information for the Taccabba Well chromite occurrence (located 4 km west of Milly Milly Homestead, 1 km north of Byro Road) indicates a single thin chromite bearing ultramafic unit within a granulite facies, meta-banded felsic and mafic rock sequence. Thin bands of chromite occur within an amphibole Iherzolite member of the mafic-ultramafic West Bendering Complex (located 27 km east of Corrigin). Up to 10% chromite has been reported from this complex, which consists of highly metamorphosed amphibolite-Iherzolite, harzburgite and serpentine layers.

The Bulong chromite occurrence (approx.30 km east of Kalgoorlie) occurs at the base of a norite intrusion with a 15 to 20 cm wide segregated chromite zone persisting along strike for about 1 km.

Other chromite occurrences have been reported on Bronzite Ridge of the Jimberlana Dyke near Norseman, Plumb Ridge near Kalgoorlie, Yamarra east of Leonora and within metapyroxenites south of Bunbury.

With the possible exception of the Taccabba Well prospect all the occurrences described briefly above have been privately investigated for their chromite potential, no reference was made of their PGE potential.

- Pilbara Block: (includes Sylvania Dome)

The Coobina chromite deposit located in the Sylvania Dome, 410 km north-northwest of Meekatharra is the largest chromite deposit in Australia (14,650 tonnes of 42 to 46% Cr_2O_3, total production between 1952 and 1957). The deposit is considered marginally economic. The Coobina Complex, a disturbed stratiform type, is a highly serpentinised and chloritised peridotite-gabbro intrusion with over 200 isolated chromite lenses. Most of these lenses are conformable, but some are discordant to the serpentinite foliation. The chrome ore is fine grained with clearly defined layering and cumulate features. The Coobina serpentinite has been intruded and extensively stoped out by granitoid rocks.

The Nobs Well occurrence, about 6 km southwest of the Bamboo Creek mining centre, is related to a serpentinised peridotite sill which intrudes the Archaean Duffer Formation. Chromite occurs as basal contact pods and fine disseminations throughout the peridotite.

Chromite is concentrated within a serpentinised peridotite which intrudes a fault line separating the Archaean Gorge Creek and Warrawoona Groups at the Pear Creek prospect (5 km south of the Pear Creek-Great Northern Highway Junction). Disseminated chromite also occurs in the ultramafic body.

Chromite float has been reported in the Spinnaways area, north of Marble Bar and in the Pilganguora area, south of Port Hedland.

- Albany-Fraser Province

Discontinuous, irregular chromite lenses occur at the basal levels of a metaperidotite which intrude a high grade gneissic sequence at the Salt Creek occurrence (2.5 km south of Salt Creek). The metaperidotite is intruded by granitic rocks.

- Kimberley Province

The Panton Sill situated 55 km north-northeast of Halls Creek is part of a disturbed stratiform complex of McIntosh Gabbro, Alice Downs Ultrabasics, where chromite occurs as disseminated grains, primary segregated bands and secondary veins. Steeply dipping chromite bands 1.5 m wide occur within a 10 m wide zone which can be traced for over 1.0 km, and veinings of 0.60 x 100 m within the sill. The complex has been extensively folded, faulted and granitoid intruded. The chromite bands carry platinum values.

The Lamboo Homestead occurrence, 45 km southwest of Halls Creek, consists of a number of chromite bands within a 6 m wide zone near the base of a serpentinized peridotite sill. The chromite lenses are up to 50 m long and 10 m wide, and are persistent around the peridotite body.

3.7 Central Australia

Thin (1-2 cm) chromite bands are present within altered olivine gabbros and pyroxenites of the layered Mount Davies intrusion of the Giles Complex.

4. Vanadium Resources within Australia

Vanadiferous titaniferous magnetite concentrations occur widely and almost exclusively throughout the Archaean and Proterozoic of western and central Australia; notably in the Murchison, Eastern Goldfields and southwestern provinces of the Yilgarn Block and in the Pilbara, Musgrave Blocks.

The magnetite bands are commonly at the base of a differentiation cycle but generally the mineralised cycle is not the lowest in the gabbroic-anorthositic complex. Basal magnetite contacts are often sharp while upper contacts are diffuse. Vanadium appears to be concentrated in either ilmenite or magnetite, but it is more common in the latter. Up to 1980 there has been no production of vanadium in Western Australia, with the Barrambie (37.5 Mt @ 0.46% V_2O_5) and Coates (45 Mt @ 0.88% V_2O_5 surface ore and 0.51% V_2O_5 primary ore combined, Pratt, 1980) deposits being the subject of feasibility and treatment studies.

Vanadium enrichment associated with lead deposits (i.e. Braeside near Marble Bar) uranium ore bodies (i.e. Yeelirrie-north Yilgarn Block), or basemetal veinings, lateritic, oil shale, phosphatic, beach sand associations will not be discussed in this review. Discussion will be confined to the vanadiferous magnetite deposits of layered intrusives since this may give some insight into the PGE potential of the lower stratigraphic levels of the complexes, which may be unexposed.

The following vanadium occurrences are divided according to the following provinces: Murchison and Eastern Goldfields, Southwestern, Pilbara and Musgrave.

Summary of Vanadium Occurrences within Australia

4.1 Western Australia

Murchison and Eastern Goldfields Province

Vanadium mineralisation at the Barrambie Prospect, located 450 km east-northeast of Geraldton, occurs within an anorthositic gabbro which intrudes Archaean metamorphics and is in turn intruded by Archaean granitoids and Proterozoic dolerite dykes. The layered intrusion of alternating anorthositic-gabbro lithologies is 500 to 1700 m thick and exposed over 80 km strike length. Titaniferous magnetite bands are best developed within the anorthosites, which display cumulate, intercumulate fabrics with the plagioclase. The vanadium is combined in solid solution with martite and to a lesser degree with residual magnetite and ilmenite.

The Gabanintha vanadium prospect (8.56 Mt @ 1.24% V_2O_5, 15.5% TiO_2 Baxter (1978) located 46.5 km south of Meekatharra, consists of a series of titaniferous magnetite bands in a moderately dipping anorthositic gabbro. The complex intrudes Archaean country rock. The magnetite, as with most of these deposits, is concentrated in the anorthositic gabbro, rather than the gabbro. The intrusion has been extensively faulted, causing fragmentation of the magnetie rich zone into eight distinct areas.

Located to the north of Gabanintha, the Yarrabubba deposit (inferred reserves 1.98 Mt @ 1.3% V_2O_5 Baxter (1978) consists of a single titaniferous magnetite band 1 to 3 m wide, 2 km long within an anorthositic gabbro. The complex has been intruded by granites, dolerite and minor quartz veins. The magnetite being microcrystalline and massive is parallel to the gabbro foliation.

The Windimurra prospect which occurs within the large Windimurra Intrusion contains both gabbroic and anorthositic bands. The magnetite bands are lenticular generally less than 130 m long, 3 m wide wide and aprallel to the gabbro strike.

The Buddadoo Gabbro Complex located 50 km southwest of Yalgoo consists of a basal gabbro-anorthosite-pyroxenite zone followed by an oxide zone of martite-anorthosite-and gabbro, a mixed zone of dolerite-gabbro-anorthosite-pyroxenite and finally an upper zone of doleritic granophyre. Layering and cumulate textures are prominent in the lower two zones and lower half of the mixed zone. Cyclic vanadiferous magnetite bands varying from 0.3 to 4 m thick occur within the oxide zone, which can be traced over a 4.6 km strike length and vary from 1 to 190 m wide.

The Bremer Range Prospect located about 5 km south of Lake Metcalf, lies within a pyroxenite leucogabbro layered intrusion of the Maggie Hays Formation. The titaniferous magnetite is concentrated at the base of a pyroxenite phase of the layered intrusion.

Southwestern Province

The Coates vanadium deposit, 3.5 km east-northeast of Wundowie, occurs as lenticular magnetite lenses at the core of the layered Coates Gabbro. The Complex, 1 km long and 600 m wide, is composed of three main layers; a leucogabbro, a magnetite gabbro and a gabbro; with lithological contacts being sharp. Magnetite is concentrated in lenticular layers within the magnetite gabbro, which can obtain up to 80% oxide mineral. Pyrite, pyrrhotite, chalcopyrite, and pentlandite have been noted in the gabbros. Lateritic surface enrichment of vanadium is pronounced at Coates. Magnetite bands also occur in the Tallanalla Gabbro.

Pilbara Block

The Balla Balla deposits, situated 11 km north of Whim Creek, are confined to a metagabbro sequence in which there is variation from leucogabbro to anorthosite. The magnetite bands are generally less than 50 cm thick and consist of an intimate mixture of ilmenite and magnetite with feldspar.

The Andover deposits are about 20 km south of Roebourne, with the host rocks being saussuritized metagabbro which contains both cumulus and intercumulus magnetite. The host gabbro has been intruded by barren gabbro and aplitic veins. The magnetite lenses are discontinuous, less than 200 m long and 2 to 5 m wide. The deposits are of only marginal economic interest in relation to vanadium.

Musgrave Block

The Jameson Range and Blackstone Range Gabbroic intrusions of the Giles Complex are known to contain bands of vanadiferous titaniferous magnetite. Vanadium within the Jameson Range Gabbro (120 km east-northeast of Warburton Mission) is confined to Zone 2 of the Complex which consists of olivine gabbro and pyroxene gabbro and Zone 4, a suite of troctolite-gabbro-anorthsite. The magnetite bands are up to 3 m thick and can be traced over 37 km strike length.

Southeast of Jameson Range (10 km west of Mount Elliot) thin titaniferous magnetite horizons occur in a suite of gabbro-anorthosite and olivine rocks, which are correlated with Zone 4, mentioned above. Bands averaging 0.3 m width have been traced for 20 km.

The deposits in the Blackstone Range Gabbro are thin and discontinuous and are confined to the northern side of Bell Rock Range. Logistics (remoteness) of these vanadium occurrences suggests they are prohibitive for economic mining.

Legend For Fig. 14. Table 4 Platinum-Chromium Vanadium Occurrences-Australia

▲ Platinum Group Metals - Various Lode Types and/or Alluvials

1. Westwood
2. Fifield
3. Macquarie River
4. Ballina
5. Broken Hill
6. Thompson River
7. Adamsfield - Maydena
8. Bald Hill - Savage River-Mount Stewart-Wilson River-Nineteen Mile Creek Corinna
9. Mingary
10. Panton Sill
11. Louisa Downs
12. Yellowdine
13. Roebourne-Wickham

Chromium ○ "Alpine Serpentinite Lode" Types and/or Alluvials

1. Princhester-Marlborough-Glen Geddes
2. Tungamull.
3. Gray Creek
4. Gundagi District
5. Bingara District
6. Fineflower District
7. Dolodrook River
8. Adamsfield
9. Montague Swamp
10. Beaconsfield

⊙ Layered Metamorphosed Basic-Ultrabasic Complexes

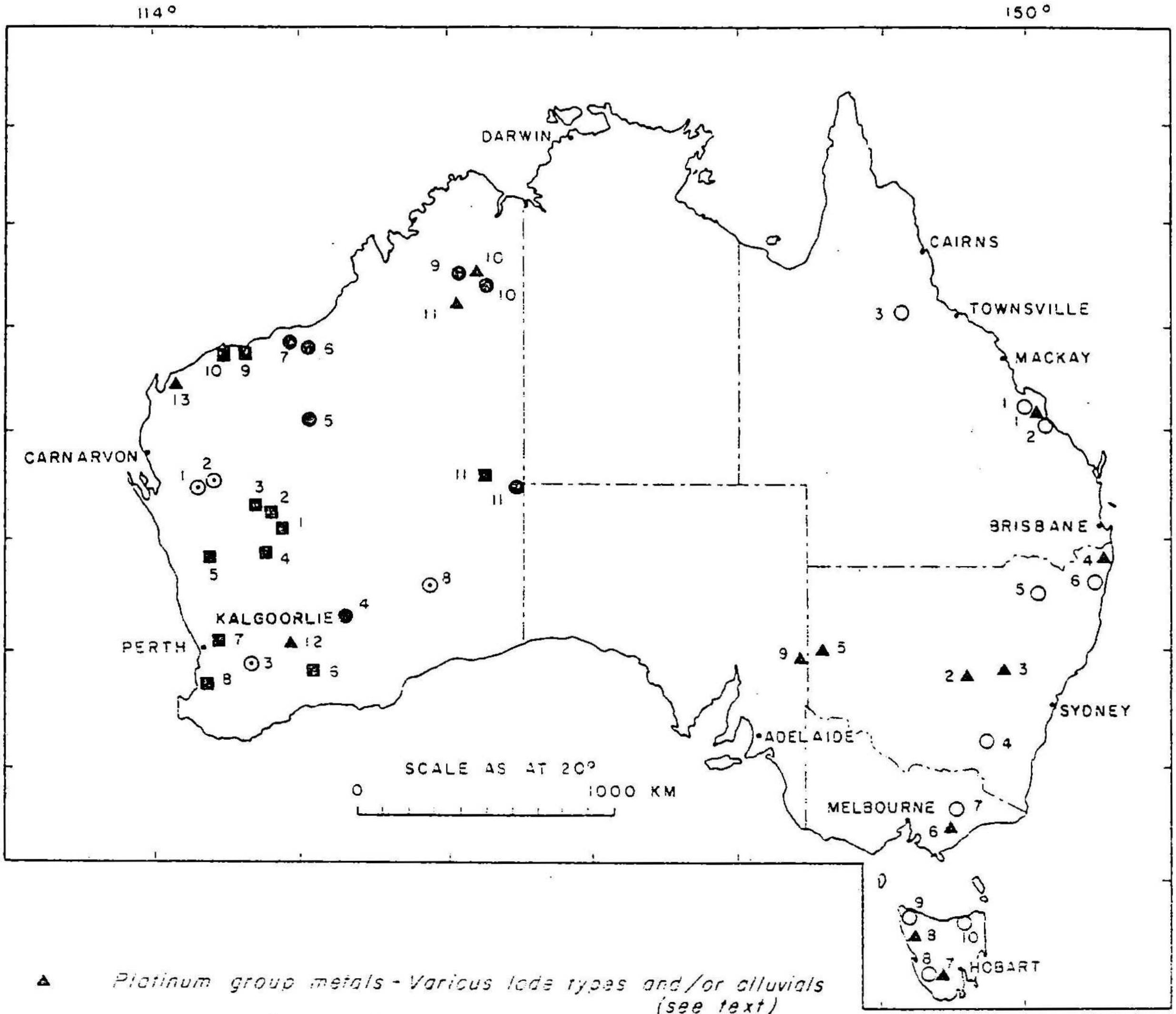
● Layered Peridotite-Gabbro Complexes.

1. Imagi Well
2. Taccabba Well
3. West Bendering
4. Bulong
5. Coobina
6. Nob's Well
7. Pear Creek
8. Salt Creek
9. Panton Sill
10. Lamboo Hstd.
11. Mount Davies

Table 4 - continued.

Vanadium - Gabbro-Anorthosite Complexes

1. Barrambie
2. Gabanintha
3. Yarrabubba
4. Windimurra
5. Buddadoo
6. Bremer Range
7. Coates
8. Tallanulla
9. Balla Balla
10. Andover
11. Jameson Range



▲ *Platinum group metals - Various lode types and/or alluvials (see text)*

○ *Chromium - "Alpine" serpentinite lodes and/or alluvials*

⊙ *Chromium - Layered high grade basic/ultrabasic complexes*

● *Chromium - Layered peridotite-gabbro complexes*

■ *Vanadium - Vanadiferous magnetite with gabbro - anorthositic complexes*

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Figure 14 PLATINUM, CHROMIUM, VANADIUM RESOURCES IN AUSTRALIA.

5. Layered Mafic-Ultramafic Complexes within Australia

Platinum potential within Australia appears to largely exist within three distinct geological settings, namely:

- the north-northwest trending Palaeozoic serpentinite belts of the Tasman Geosynclins.
- layered mafic-ultramafic complexes of stable Archaean and Proterozoic blocks
- and tectonically dismembered layered complexes of mobile Proterozoic zones.

Of the three terrains the Palaeozoic alpine podiform type of eastern Australia is believed to hold the least potential, for the following reasons:

(a) The PGE mineralisation is genetically and therefore spatially related to thin structurally controlled serpentinite bodies, which form well defined geographical belts, thus the host rocks have a high degree of predictability about their likely distribution.

(b) Recognition of these platiniferous bodies has been invariably related to the initial identification of an associated placer deposit, thus the favourable drainage systems of eastern Australia has facilitated the recognition of alluvial and subsequent lode deposits on a regional scale.

(c) Since the host rocks are strongly fault controlled and form thin steeply dipping resistant bodies, they generally form exposed topographical highs which have received extensive investigation from the prospector and private mining companies.

(d) Scale, Australian alpine lode deposits are generally of low tonnage status.

Layered mafic-ultramafic complexes are prominent in the Archaean and Proterozoic of western and central Australia, however this is not exclusive since small Palaeozoic complexes are known, i.e. the Tout and Honeybugle Complexes of central New South Wales, Gray Creek-Greenvale, and Somerset Dam, both Qld, and overseas the Tertiary Skaergaard Intrusion of Greenland, and the post-Permian Dufek Intrusion of Antarctica are prominent. However, bearing in mind that most large platinum layered deposits are pre 1000 m.y. (The Råna deposit of Norway of Phanerozoic age is a noted exception) this search should be restricted to the Archaean-Proterozoic terrains of Australia.

Layered mafic-ultramafic complexes are scattered throughout the Yilgarn-Pilbara Archaean Blocks, Proterozoic Halls Creek Mobile Zone and Musgrave Block of central Australia. Although most intrusions are pre-metamorphic in age, good preservation, particularly in the core of the complexes of primary textures and mineralogy exists. The intrusions are not confined to any particular country rock sequence and intrude mafic, ultramafic, felsic, sedimentary or metasedimentary lithologies.

Most Archaean layered mafic-ultramafic bodies are elongate to ovoid in plan and often display concordant relationships with folded structures. Areal extent is variable from a few square km to over a couple of thousand square km, and thicknesses up to 6000 m for both Archaean and Proterozoic examples. Lithologies display variable grainsizes from fine grained chilled zones to pegmatoidal phases, fabrics include cumulate horizons, phase, cryptic and rhythmic layering, although the latter does not appear to be well developed in the Archaean complexes. Differentiation may be simple, ranging from basal dunite, harzburgites, through orthopyroxenite-bronzite layers to upper norites, gabbros, dolerites, granophyre layers, to complex, involving repetition of particular horizons or the complete absence of cumulate phases.

Chemically two main types predominate, high Mg and tholeiitic types. The high Mg types (MgO of 15-17%) typical of the Eastern Goldfields Province Sills, (see Fig. 25) characteristically have a greater ultramafic component, with gabbros and granophyres weakly developed, they are often spatially associated with magnesian basalts and discrete podiform ultramafic rocks, are thin, averaging 200 to 400 m and of upper amphibolite to granulite metamorphic facies. Greater potential exists in these high Mg complexes for nickel-copper sulphides with accessory platinum group minerals rather than platinum group dominant. Tholeiitic layered complexes such as that occurring on the Challa-Barrambie-Yarrabubba trend, Roebourne district of the Pilbara Block and the Musgrave Block are larger in all three dimensions, have poorly developed ultramafic horizons with gabbros and anorthosites volumentrically significant. Vanadiferous-titaniferous magnetite segregations are often common within the anorthositic layers, with chromite layers localised within certain peridotite-gabbro complexes. Despite the smaller ultramafic component these layered intrusions are believed to hold greater potential for PGE, especially in view of their greater stratigraphic thickness, which is believed to be critical. Overprinting metamorphic and tectonic fabrics may preclude the recognition of certain complexes as being of large scale layered type, hence mafic bodies within the King Leopold-Halls Creek Mobile Zone, which are known locally to be platinum and chrome bearing, should also be considered.

The following listing, Table 5 to Table 14, is of "layered complexes", either the high Mg type (particularly where the ultramafic stratigraphic component is considerable) and tholeiitic types of Archaean and Proterozoic age throughout Australia. Proterozoic dolerite sill complexes are also discussed, especially in view of the Noril'sk-Talnakh, Duluth model. Locations are shown on Figure 15 which also indicates various Archaean-Proterozoic terrains.

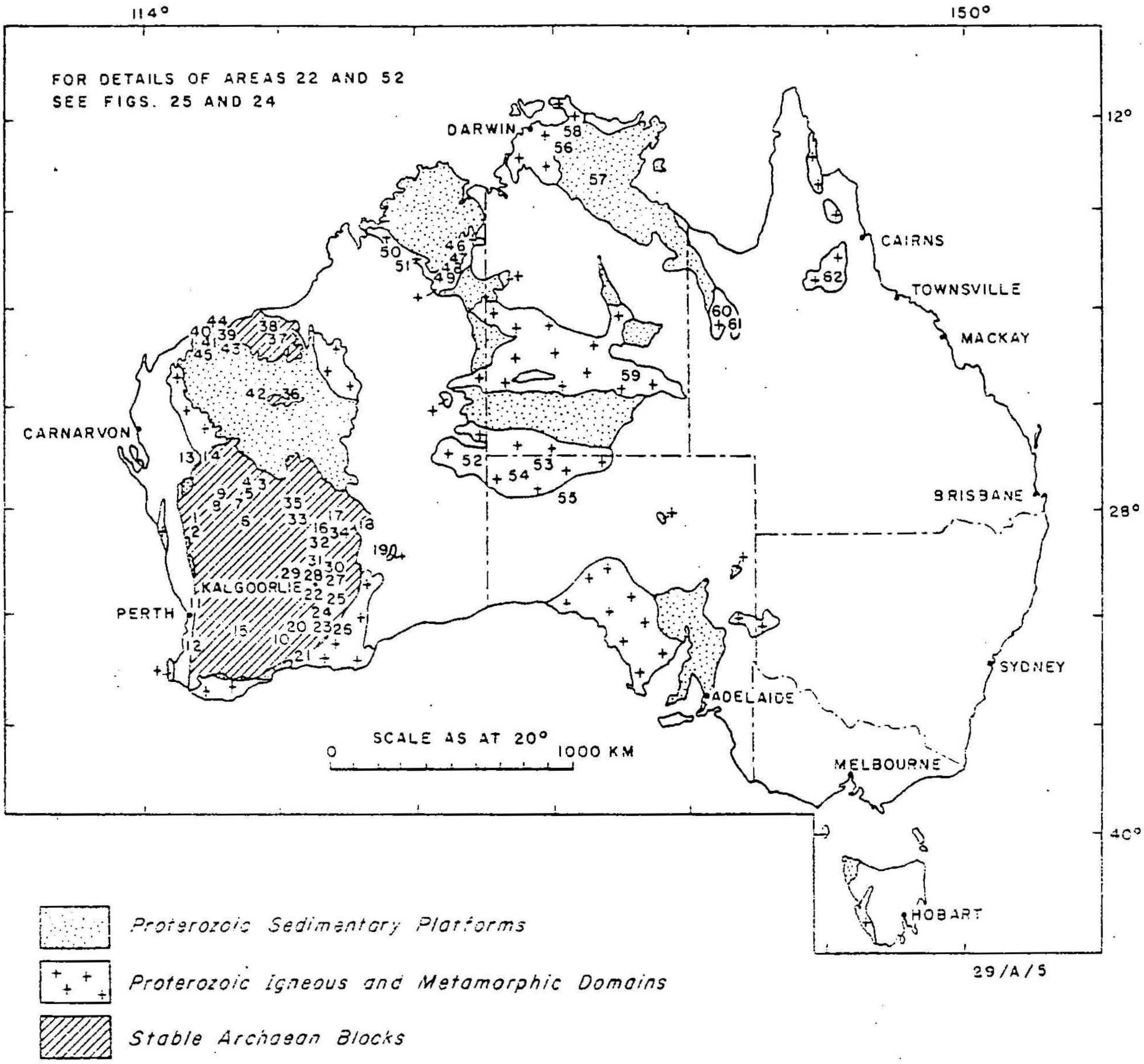

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Figure 15 MAFIC-ULTRAMAFIC COMPLEXES OF AUSTRALIA OF ARCHAEAN, PROTEROZOIC AGE

Legend for Lithologies - Tables 5 to 14

Mt	-	Magnetite
GG	-	Granophyre
T	-	Troctolite
LT	-	Leucotroctolite
DD	-	Diorite
QDD	-	Qtz Diorite
D	-	Dolerite
OD	-	Olivine Dolerite
ND	-	Norite
AN	-	Anorthosite
ANN	-	Anorthositic Norite
ANG	-	Anorthositic Gabbro
OAN	-	Olivine Anorthosite
QA	-	Qtz Amphibolite
PxA	-	Pyroxene Amphibolite
N	-	Norite
NG	-	Norite Gabbro
ON	-	Olivine Norite
G	-	Gabbro
QG	-	Qtz Gabbro
HG	-	Hypersthene Gabbro
OHG	-	Olivine Hypersthene Gabbro
OG	-	Olivine Gabbro
ANPx	-	Anorthositic Pyroxenite
AOG	-	Anorthositic Olivine Gabbro
LG	-	Leucogabbro
MG	-	Melagabbro
MOG	-	Olivine Melagabbro
B	-	Bronzitite
W	-	Websterite
OOPx	-	Olivine Orthopyroxenite
Px	-	Pyroxenite
OPx	-	Orthopyroxenite
CPx	-	Clinopyroxenite
LH	-	Lherzolite
H	-	Harzburgite
P	-	Peridotite
S	-	Serpentinite
Du	-	Dunite

TABLE 5

State	Province/Block-Age	Intrusive Complex	Areal Extent (km)	Thickness (m)	Form-Orientation	Dom. Lithologies	Layering/Fabrics	Mineralisation	Comments	Ref.
W.A.	Yilgarn - Arch									
	1.	Wadgingarra Gabbro 96 km E of Yalgoo	8 x 3	1300	Folded sill into S plunging syncline	GG (top) - G, QG, QDD, AN, N → P (base)	Well banded	Cu-qtz veins in adjacent shales , metagabbro	Shearing confining to centre of complex	Yalgoo SH/50-2
	2.	Buddadoo Complex Lat: 28°42'19"S Long: 116°28'63"E	8.6 x 2.5	2400	Sill trending N-NW	D,GG (top) → G, AN, Px → Oxide Zone; AN, G → G, AN Px (bottom)	Rhythmic Layering Cumulate features	Vanadiferous titaniferous magnetite in oxide zone. Oxide zone can be traced for 4.6 km and varies from 1-190 m wide	Also small gabbro and gabbro-pyroxenite peridotite (Abe, Abd, Abg) complexes showing weak layering,occur to the NE, NW, of Yalgoo	" + Bull 11-GSWA
	3.	Barrambie Intrusion Lat: 27°25'S Long: 119°07'E	21 x 0.4 Dcts.along strike for 80 km	500 to 1700	Vertical sill trending largely NW	A,G, Mt G.	Layered, Cumulates	Vanadiferous-titaniferous magnetite occurs in both G, An. Ore reserves of 37.5 Mt @ 0.46% V_2O_5	-V potential investigated by Greenstone Investments Pty Ltd and Ferrovanadium Corp. N.L. -Believed to be genetically similar to complexes at Youanmi, Wyemandoo Yarrabubba and Gabanintha	Bull 11-GSWA
	4.	Gabanintha Intrusion Lat: 26°56'S Long: 118°38'E			Gabbro strikes N-NE dipping 50-60°W	Coarse grained ANG, G	Cumulates	V-magnetite concentrated in ANG. Ore reserves of 8.56 Mt @ 1.24% V_2O_5 15/5% TiO_2	-Drilled by Mangore (Aust) Pty Ltd,? presently held by Garrick Agnew Pty Ltd -G is poorly exposed between Mt bands -Complex extensively faulted resulting in fragmentation of Mt rich zones.	"
	5.	Yarrabubba Intrusion Lat: 27°02'S Long: 118°41'E			Gabbro foliation dips 50-80°E	ANG	Foliated	Single band of V-magnetite 2.0 km long x 1 to 3 m wide. Inferred reserves of 1.98 Mt @ 1.3% V_2O_5	-Drilled by Mangore (Aust) Pty Ltd ?presently held by Garrick Agnew Pty Ltd -Complex intruded by granite, dolerite dykes and qtz veins	"
	6.	Windimurra Intrusion Lat: 28°23'S Long: 118°33'E	Large 85 x 35	3.5 to 5 km	Steep sided, fault bounded tabular body	Large gabbroic intrusion with anorthositic bands	Banded	At least six lenticular magnetite bands, less than 130 m long and 3 m wide	-V potential reviewed by Mangore (Aust) Pty Ltd -Being investigated by Anaconda and several other companies	" + Ahmat 1983
	7.	Windimurra Gabbro Nulyercamyer Hill; SE corner of sheet	150 km^2 Extends further S to Gabanintha Complex		Large intrusive body	Meta G with AN bands	Differentiated	Au in metagabbro		Cue SG/50-15
	8.	Dalgaranga Gabbro Dalgaranga Hill SW corner of sheet	12+ x 3		Two or more sills	Meta G	Coarse grained pegmatoidal in places. Differentiated from ultrabasic base to acidic pegmatoid top			"
	9.	Dalgaranga Gabbro Mount Charles SW corner of sheet	14 x 2			Meta G	Differentiated	Disseminated pyrite up to 2 cm size and minor chalcopyrite	-Associated pegmatite bodies in gabbro which are possibly related to nearby granites -Also several serpentinized peridotite sills (after dunite and/or peridotite intrusives or volcanics) throughout sheet area, ie; at Moyagee Siding, Scott Bore (DDH - minor Ni-sulp) Lake Austin, Lennonville, Wattagee Well and a large (area) body at Cullculli Hill	

TABLE 6

State	Province/Block - Age	Intrusive Complex	Areal Extent (km)	Thickness (m)	Form-Orientation	Dom. Lithologies	Layering/Fabrics	Mineralisation	Comments	Ref.
	10.	Bremer Range Lat: 32°32'31"S Long: 120°40'47"E	8 x 4		Moderately dipping sill complex trending NW	LG, Px	Layered	Discontinuous magnetite containing between 0.23-0.54% V_2O_5 occurs at the base of a pyroxenite phase.	-Drilled by Unimin Laporte J.V. -See also Lake Medcalf Complex which is nearby	Bull 11 GSWA
	11.	Coates Gabbro Lat: 31°44'30"S Long: 116°24'03E	1 x 0.6		Gabbro strikes 120° dipping 70°SW	Three layers; LG, MtG, G	Layered, Cumulates	Lenticular magnetite lenses at core of gabbro. Pyrite, pyrrhotite, pentlandite associated with minor chalcopyrite. Ore reserves of 45 Mt @ 0.51% V_2O_5 - primary ore, + 0.88% V_2O_5 - surface ore Lateritic V_2O_5	-Drilled by Mangore (Aust) Pty. Ltd. -Gabbro poorly exposed.	"
	12.	Tallanalla Lat: 33°09'S Long: 116°08'E			Gabbro strikes 130° dipping 50-60°SW	G		Lenticular magnetite bands up to 500 x 2m contain 1.12% V_2O_5 19.8% TiO_2 within gabbro	Poor surface exposure of complex.	"
	13.	Imagi Well Complex Lat: 26°11'53"S Long: 116°12'33"E			Regional strike of sequence is 020°, dipping at 80-85°W	Varied from QA to PxA - amphibolite facies		Discontinuous chromite lenses in both amphibolites	-Prospect investigated by Ez.Co. Aust. Ltd. who indicated chromite reserves were too small to warrant detailed drilling. -High grade metamorphosed basic-ultrabasic type rather than layered mafic-ultramafic type	Bull 11 GSWA
	14.	Taccabba Well Complex Lat: 26°05'27"S Long: 116°37'57"E			NE strike with steep westerly dip	Banded sequence of felsic and mafic rocks of granulite facies	Banded	Chromite occurs in one thin ultramafic unit	-Investigated by Pacminex Pty. Ltd. who stated reserves were too small to warrant further exploration for chromite -No surface expression of this meta basic-ultrabasic type; masked by 20m of Murchison River alluvium, ∴ surface geochemistry of no use.	"
	15.	West Bendering Complex Lat: 32°23'27"S Long: 118°08'55"E				LH, H, S (after Dunite)	Layered	Chromite bands in the amphibolite-lherzolite member, Cr up to 10%	-Drilled by E.Z. Co Aust. Ltd -High grade metamorphosed complex	
	16.	"Red Knob Complex" (2 km W of Red Knob)	3 x 2		Sill of near equant plan form	Varied from Px to LG	Layered		-Also folded ultramafic-gabbro complex at Benalla Hill displays some layering	Laverton SH/51-2
	17.	"Mt Weld Complex" (Two bodies; 3 km NE and 6 km E of Mt Weld)	4 x 2.5		Sills	Px to LG	Layered			"

TABLE 7

State	Province/Block-Age	Intrusive Complex	Areal Extent (km)	Thickness (m)	Form-Orientation	Dom. Lithologies	Layering/Fabrics	Mineralisation	Comments	Ref.
	18.	Mt Venn Complex	12 x 4		Arcuate S plunging synformal sill structure	LG, W, N, G (no ol. bearing rocks)	Rhythmic layering Gravity stratification of minerals	Cu-Pb in qtz veins in mafic rocks	-Transition from ultramafic rocks at northern end of complex to leucogabbros at southern end -Younger discordant granites, faulting common	Rason SH/51-3
	?Prot 19.	Salt Creek Complex Lat: 29°32'36"S Long: 124°55'04"E	Small, < 1 km²		Dips steeply SE Facings W :• overturned	Meta P	Layered on a 1-2cm scale	Discontinuous irregular chromite lenses occur in basal levels of P	-P intrudes high grade gneissic sequence -Also called the Datum Prospect -Chromite tested by Mineral Search and Devel Ltd.	Bull 11 GSWA Plumridge SH/51-8
	Arch 20.	Lake Medcalf (5 km S of Lake Medcalf)	(not indicated on sheet - due to laterite)		Intrusive sill at southern end of N plunging Gordon anticline. East facing	Ranges from LG to ol rich ultramafics	Layered, magnetite concentrations	Magnetite Lorizon (Amk) went Ti-24%, V-0.54% Cr-145 ppm, Ni-127ppm Cu-243ppm	-One of the lowest units of the Maggie Hays Fm. -Apart from magnetite rich horizons complex marked by lateritic cover	Lake Johnston SI/SI-1
	21.	"Desmond Ultramafic" (to the E of Desmond)	17 x 2	Approx 1600	Conformable sills, flows, plunging synformally towards SE	P,S	Spinifex, porphyritic pillow basalts skeletal amygdaloidal, dendritic	Cu, Ag, Au, Magnesite	-Not of layered type, high grade. Altered volcanic hosted.	Ravensthorpe SI/51-5
	Eastern Goldfields Province									
	22.	Ora Banda	23 x 2	≃ 2000	Sill	G, N,G N, OPx, P	Phase and cryptic layering is well developed in most intrusions but rhythmic layering is only present in the larger intrusions. ie. Ora Banda, Mt Monger, Mission	-Most if not all sills envisaged as high level injections contemporaneous with volcanics		Williams + Hallberg (1972)
		Mt Hunt	> 2 x 0.5	400	"	G, NG, OPx, P				
		Yilmia West	3 x 0.8	750	"	G, NG, N, OPx, P				
		Yilmia East	> 2 x 0.5	> 500	"	OPx, N, NG				
		Carowlyme 1	2.4 x	280	"	OPx, N, G				
		Carowlyme 2	2.1 x	280	"	NG, G,				
		Carowlyme 3	> 3.2 x	> 150	"	OPx, NG, G,				
		Carowlyme 4	> 0.8 x	≃ 240	"	OPx, NG, G,				
		Carowlyme 5	≃ 0.5 x	≃ 90	"	, NG,				
		Carowlyme 6	≃ 1.1 x	≃ 210	"	N, NG,				
		Carowlyme 7	> 0.5 x	> 300	"	G, NG, N, OPx, P	Cumulate textures are well developed and adcumulus growth is the dominant form of postcumulus enlargement			"
		Mt Monger	4.2 x 0.8	920	"	G, NG, N, OPx, P				
		Mt Monger Nth	1.6 x	400	"	NG, N, OPx, P				
		Mt Monger Sth	1.6 x	750	"	OPx, N, NG				
		Turkey Dam 1	1.1 x	300	"	N, NG				
							Igneous lamination is weakly developed throughout the sills			"
		Turkey Dam 2	1.1 x	90	Sill	N, NG				Williams + Halberg (1972)
		Peter's Dam 1	4.5 x	900	"	G, NG, N, OPx, P				
		Peter's Dam 2	0.6 x	300	"	N, NG				
		Seabrook	3.7 x 0.8	430	"	G, NG, N, OPx, P				
		Seabrook East	> 2.1 x	210	"	OPx, N				
		Mission	>10.0 x 2.0	?1900	"	G, NG, N, OPx, P				
	23.	Mt Thirsty	20.0 x ?2.5	Thin	"	Serpentinized dunite + H (base) grading through N, G, to GG (top)			-Differentiation may be structural repetitions rather than multiple intrusions	Norseman SI/51-2

TABLE 8

State	Province/Block-Age	Intrusive Complex	Areal Extent (km)	Thickness (m)	Form-Orientation	Dom. Lithologies	Layering/Fabrics	Mineralisation	Comments	Ref.
	?Prot 24.	Killaloe Hill (2 km N-NE of Killaloe Hill on northern edge of sheet)	Small, < 2 km^2	600	Sill	OPx, G,	Differentiated with basal OPx layer		-Several smaller (in area) sills throughout northern edge of sheet	Norseman SI/51-2
	Prot 25.	Gnama South (90 km NE of Norseman)	1.5 x 0.7	500	Steeply dipping lenticular bodies	P, H, through to ANPx, ANN	Trace (<1%) disseminated pyrrhotite - pentlandite chalcopyrite	-Drilling by Newmont Prop. Ltd. -Numerous other N-P, N-G complexes in Gnama-Yardilla District		BMR Mono. 5 pp405-408
	L. Prot 26.	Jimberlana Norite (Extending from west of Lake Johnston to east of Norseman)	200 x 0.5 to 2.5	1100	Thin E W trending "canoe" shaped intrusive complex	Du, H, B, N, NG, G,	Layered, Cumulates	Potential for Ni,Cu, Cr precious metals, but sections of intrusion been extensively explored, particularly by W.M.C. Ltd.	Close similarities between the uppermost pyroxenite layer of the Great Dyke Zimbabwe and the equivalent horizon in the Jimberlana Intrusion suggested potential for precious metals. In the Great Dyke, a concentration pf precious metals over 1-2m occurs close to the boundary between feldspathic cpx rich and opx cumulates. This horizon is usually present about 10m from the top of a 160-185m thick pyroxenite layer which is anomalous in Ni, Cu, Cr, Pd, Pt and Au Drilling is the Dundas Hills area tested the equivalent horizon but Pt, Pd were low, rarely exceeding 0.1g/tonne. Drilling at Bronzite Ridge for Cr seams at the base of the dunite-pyroxenite cycles revealed only minor chromite concentrations	Norseman SI/51-2 + BMR Mono. 5 pp75-78
	L. Prot 27.	Widgiemooltha Dyke Swarm	Numerous thin linear features discontinuous over large strike distances		Dykes/Sills Common strike 070°	Variable Px to GG with QG dominant	Layering generally rare, but has been observed → Ballona Dyke S of Stoney Dam	Cu sulphides at Gindalbie Station	-Dyke on Gindalbie Station one of the largest at 4 x 0.5 km -Dykes of this group are ubiquitous throughout the Province	Kurnalpi SH/51-10 + Southern Cross SH/50-16
	Arch 28.	Bulong Complex Lat: 30°46'11"S Long: 121°50'17"E	37 x 4	4,600	?Multiple intrusion canoe shaped form, consists of a number of sills	Serpentinized P Du, Px through to G, D, with N intrusions	Layering pronounced. Cumulates, "Cross Bedded" features	Chromite occurs at the base of N intrusions, with Cr zone, 15-20 cm wide by 1 km along strike. Cr associated with serpentine	Complex locally bifurcates along strike -Complex sounds prospective for platinoid investigation	" + Bull 11 GSWA

TABLE 9

State Province/Block-Age	Intrusive Complex	Areal Extent (km)	Thickness	Form-Orientation	Dom. Lithologies	Layering/Fabrics	Mineralisation	Comments	Ref.
29.	Hampton Complex (4 km W of Bulong Complex)	42 x 1	600-900	Steeply dipping? sills	Serpentinized P, Du. Not as differentiated as much as the Bulong Complex			-Follows N/S lineament, probably genetically related to Bulong Complex which is 4 km further to the east	Kurnalpi SH/51-10
30.	Several small complexes in Morelands Fm (A1j) and Malgabbie Fm (A2j) on Kurnalpi Sheet	Largest with Carr Boyd and Bulong-Hampton Complexes		Sills	Variable Px to GG	Layered in most examples		-Areally too small to be of interest	"
31.	Carr Boyd Complex Lat: 30°04'S Long: 121°38'E	75km^2	2,900 (at mine)	Lobate intrusion	T, O-An, D, B, H, N,	Layered, cyclic	Ni-Cu sulphides/Carr Boyd Mine 1.3 Mt@ 1.65% Ni (1969) 0.57% Cu	-Bronzite and norite pegmatoids cut the complex. See final chapter for details	BMR Mono. 5 pp125-128 (1969) + Purvis etal (1972)
32.	Mount Kilkenny (Nth edge of sheet)	8 x 5	600	Asymmetric syncline sill, plunging gently S-SW	G,T,D, serpentinized G	-Simply layered cumulate textured -Igneous lamination, no cyclic layering		-Duck Hill (2x2 km), Mt. Boyce (3x0.5) are smaller layered complexes in sheet area -Complex at Pyke Hill (4x2) containing G, D, S is not layered -L. Jacques did Honours on Mount Kilkenny	Edjudina SH/51-6 + Jacques (1976) Pers. Comm. Jacques BMR
33.	Numerous thin mafic, ultramafic sills occur on Leonora Sheet	Largest - Agnew Bluff (6x3km) and 10 km to the east, Mt Adamson which is the SE strike extension of Agnew Bluff	Thin	Folded sills	P, Px, D (Aup) Px (Aux) G, Px (Ad)	Some cumulate features, layering not pronounced	Local Au	Too small with the exception of the Agnew Bluff - Mt Adamson trend to warrant Pt investigation	Leonora SH/51-1
34.	Windarra Complex Lat: 28°29'S Long: 122°14'E	Thin (<1km) with long strike length of Greenstone Belt	<20-700+	Series of sills or near surface intrusives along N-NW trending synclinal-anti-clinal greenstone belt	Completely altered metamorphosed serpentinized sequence probably after inhomogenous Du, P, Px	Metamorphic textures dominate	Windarra Ni sulphide deposit, reserves of 5.4 Mt@ 2.18% Ni 0.2% Cu	-Some Pt/Pd associated with Ni mineralization, namely Pt (0.15-0.17 g/tonne Pd (0.77-2.3 g/tonne) from the A shoot -Amphibolite facies meta basic ultrabasic type	BMR Mono. 5 pp129-143
35.	Preserverance Lat: 27°49'S Long: 120°42'E	Thin (<1.5 km) part of Leonora-Wiluna Green-stone Belt	Preseverance U/M horizon 20-700m	Lens	Preseverance U/M is a body of Du+S surrounding a core of Du	Metamorphic textures	Preseverance Ni sulphide deposit, reserves of, 33 Mt @ 2.2% Ni	-Meta basic-ultrabasic type typical of the greenstone belts of the Eastern Goldfields Province	" pp149-155

TABLE 10

State	Province/Block-Age	Intrusive Complex	Areal Extent (km)	Thickness (m)	Form-Orientation	Dom. Lithologies	Layering/Fabrics	Mineralisation	Comments	Ref.
	Pilbara-Arch 36.	Coobina Complex Lat: 23°29'45"S Long: 120°16'35"E	Complex forms a ridge 10 km long with equant mass 4 km^2 at western end, and 300 m dyke feature at eastern end		Irregular, tectonically dismembered intrusion Foliation strikes N and NE, dipping E and SE at 40°, 70° respectively	Meta S, serpentinized P, AN	Most textures of metamorphic or deformational-shearing origin. Some cumulate (Cr) features evident Pseudomorphs after cumulate ol, cpx, ?opx also present	200+ lenses (5-150m long 1-6m wide) of chromite occurs in the serpentinite. Coobina production 14,650 t @ 42 to 46% Cr_2O_3	-Largest known chromite deposit (Coobina) in Australia considered only marginally economic. Grade, discontinuity of chromite bands, logistics inhibits marketing -All production by BHP Prop. Co. Ltd. and Mr L. Ives between 1952-1957 -Coobina ultramafic represents basal portion of large stratiform body, since overturned, with upper levels originally being eroded off	Bull 11 GSWA pp 205-206
	37.	Nobs Well Intrusion Lat: 20°50'S Long: 120°11'40"E			Sill	Serpentinized P		Chromite pods near basal contact, with disseminated Cr throughout peridotite up to 3.1% Cr	-Sill intrudes Archaean Duffer Fm.	Bull 11 GSWA
	38.	Pear Creek Intrusion Lat: 20°53'S Long: 119°31'E				Serpentinized P		Chromite displays local concentration and dissemination in peridotite	-Deposit has been drilled -Serpentinite intrudes a fault line separating the Archaean George Creek and Warra Woona Groups	"
	39.	Balla Balla Complex Lat: 20°48'S Long: 117°47'E			Sequence strikes 080-100° dipping 25-30°N	Saussuritized meta G sequence, ranging from LG to AN		Ore reserves estimated at 1.94 Mt @ 0.75% V_2O_5 with V contained in numerous thin (0.5m) magnetite bands	-Deposit reviewed by Mangore (Aust) Pty. Ltd. ?currently held by Garrick Agnew Pty. Ltd. Deposits individually are small	"
	40.	Andover Complex Lat: 20°51'S Long: 117°04'E			Foliation strikes 080° dipping 50-65°N	Saussuritized meta G	Cumulates	17 lenses (200x2m) of titaniferous (V) magnetite, are of marginal economic interest -Disseminated py in G	-Deposit reviewed by Mangore (Aust) Pty. Ltd. and Garrick Agnew Pty. Ltd. -West end of Roebourne South Complex	"
	41.	George Sherlock Lat: 20°50'S Long: 117°28'E	6 x 1		Elongated E-NE trending? sill	N, G, S	Layered, Cumulates	Trace chalcopyrite, pyrrhotite, pyrite in norite	-No exposure, complex masked by 50m alluvium:· surface geochemistry of no use -Sherlock Bay Ni-Cu deposit of similar setting (but exposed) is located 6km further to the east.	BMR Mono. 5 pp 169-171
	42.	"Praire Downs" Gabbro (32km E-NE of Praire Downs Hstd)	5 x 3		Fairly equant in plan. Lineations 46°	Meta G	Moderately uniform.		Fault bounded on southern margin -Serpentinite lenses in vicinity of complex	Newman SF/50-16
	43.	Mt Langenbeck-Mt Satirist Complex Lat: 21°2'S Long: 118°10'E	17 x 15* (from p59-Mono 5)	350?	Elliptical domal sill structure	OPx, G, D overlying P	Layered	Mons Cupri and Whim Creek Cu-Zn deposits, 30km to the NW	-Potential V, Cr, Ni in magnetite rich rocks -Ultramafic rocks intruded penecontemporaneously during sedimentation *SF/50-3 shows complex to be largely masked by alluvium cf pp 59 of Mono. 5 -Large in area Proterozoic dolerites (Pdc), some layering; are common on SF/50-7. Potential for Noril'sk type PGE mineralisation??	BMR Mono. 5 pp59-61 + Pyramid SF/50-7

TABLE 11

State	Province/Block-Age	Intrusive Complex	Areal Extent (km)	Thickness (m)	Form-Orientation	Dom. Lithologies	Layering/Fabrics	Mineralisation	Comments	Ref.
	44.	"Roebourne South Ultrabasic Complex"	20 x 5	2000	Folded dissected sills	S, G, AN, P, Du Amphibolite	Cyclicity of 100-200m Du, P, Px, G, AN	Andover V deposits is located at western end of complex	Also Radio Hill, Gidley Gabbro-Granophyre, Mt Sholl complexes of Roebourne district	Roebourne SF/50-3 + Bull 127 GSWA
	45.	Munni Munni Complex Lat: 21°7'S Long: 116°45'E	11 x 10+	3500m-feld G 2000M-M-U/M	Tilted basinal sill, ellipsoidal NE-SW in plan Dips 20-35° internally	P, G, CPx, S	Layered Rhythmic + Cryptic Lamination cumulus and "slump" textures	Whundo Cu-Zn deposit, 10km and along a NE strike from the complex	-Similarities to Bushveld Stillwater complexes -The complex has a strong magnetic signature which extends for 16km under Proterozoic cover :· larger than indicated at surface -Granite intruded	Yarraloola SF/50-6
Halls Creek Mobile Zone	L. Prot ? 46.	Lamboo Complex; Panton Sill Lat: 17°47'43"S Long: 127°48'34"E	11 x 3.2	1000	Southerly plunging syncline with 50° dip-western flank 70° dip-eastern flank	Alice Down Ultra-basics and McIntosh Gabbro. Broadly layered and consists of altered P and tremolite-chlorite schist at base, which grades into alternating bands of uralitized G and LG at top	Banding Ranges from 30 to 90m thick	Peridotites contain disseminated chromite,(with Pt values of 3g/tonne), primary segregated bands 15cm over 1.5km and secondary veins. The chromite is euhedral, generally pentagonal, rarely embayed. Also Ni, Cu, values with the Cr-Pt	-Alice Downs Ultrabasics are probably differentiates of the McIntosh Gabbro	Dixon Range SE/52-6 + BMR Bull 107
	47.	McIntosh Sill (60km NNE of Halls Creek)	14.5 x 5	1500	Sill folded into a basin, with dips 10-75° inwards	Hypersthene Troctolite, ON (top) pass to G, OG, which pass to OG(at base)	Layering poorly preserved, some rhythmic layering indicated by single or cumulative layers of olivine		-Best preserved example of a differentiated basic intrusion in the Lamboo Complex -Large Toby Sill to the west of Panton Sill -Several large McIntosh Gabbro complexes exist NE of Halls Creek on the Dixon Range sheet, but few have associated Alice Downs U/B, which appear critical for Pt, Cr mineralisation. Also present on Gordon Downs Sheet SE/52-10 and Lissadel Sheet SE/52-2.	Dixon Range SE/52-6 + BMR Bull. 107
	48.	Armanda Sill (28km NNE of Halls Creek)	10 x 3.2		Elliptical composite sill of anticlinal structure with gabbro dipping 25°E	Uralitized G, D, no ultrabasics	Rhythmic banding defined by MG, and LG		-An, P, G occur along the western margin (steep) and at the southern end of the McIntosh sill	Pers.comm. H. Davies BMR
	49.	-Lamboo Homestead Complex Lat: 18°27'57"S Long: 127°19'30"E	10 x 6.5		Elliptical sill with southern margin dipping 60°S	Alice Downs Ultrabasic with McIntosh Gabbro surrounding. Ultrabasic now composed of decussate serpentine after ol, px	Rhythmic banding marked by chromite rich (15cm x 50m), chromite poor bands	Cr	-Deposit (as probably with Panton Sill) too small, and low in grade, and contains too high a proportion of iron to be a source of chrominium on its own, ie. needs associated precious metals. -Also 3 large (in area) - of McIntosh Gabbro probably same complex; 11x6, 18x4, 11x5km, respectively 34, 40 and 54km NW of Louisa Downs Hstd.	BMR Bull 107 + Mount Ramsay SE/52-9

TABLE 12

State	Province/Block-Age	Intrusive Complex	Areal Extent (km)	Thickness (m)	Form-Orientation	Dom. Lithologies	Layering/Fabrics	Mineralisation	Comments	Ref.
King Leopold Mobile Zone	50.	Wombarella Quartz Gabbro	7 x 3	655	Layered lopolith with 45-55° inward dips	OPx, and biotite-qtz G, and qtz.N with basic tonalite	Large and small scale banding		-Part of Lamboo Complex, probably comagmatic with McIntosh Gabbro and Alice Downs Ultrabasics -Qtz gabbro and tonalite show evidence of two magma relationships -Chemistry of lithologies appears to be unfavourable for Pt investigation	Lennard River SE/51/8
Kimberley Block	Low Prot? 51.	Hart, Woodward Dolerite	Hart extensive over Kimberley Block (160,000 km^2±) Woodward more confined to E/W parts of Mobile Zone	Woodward Dol. less than 600m Hart Dolerite generally less than 100m, one exception being 900m on northern flank of Mobile Zone, which has a granophyric top (pers. comm. K.A. Plumb, BMR)		Hart-Tholeiitic G, GG, D	See comments		The Hart and Woodward Dolerites which occur frequently throughout the Kimberley Block are not prospective (layered complex type) for platinoids, since they are largely homogenous, ie. showing weak differentiation features, and thin; the Hart Dolerite being less than 100m thick and Woodward dolerite sills, no greater than 600m thick. However scope may exist for the Noril'sk styled mineralisation.	
W.A./NT/SA Musgrave Block	Mid Prot. 52.	Giles Complex			Most intrusions of the Giles Complex form large lopolithic sheets, some of synclinal structure, ie. Hinkley. The intrusions cover an area of at least 12,000km^2 and display a prounced east-west alignment		Layering is common and includes; cryptic, rhythmic, and igneous lamination. Rhythmic layering is common on both large and small scale. Layers up to 30m thick by several kms. Small scale (cms) is common also with "sedimentary" type structures, ie. graded bedding, cut and fill, ripple corrugations, slump structures etc. A mylonite layering is locally prominent There is also a depth stratification developed between intrusions, those in the western portion of the complex being emplaced at a higher level than those of the central zone, which were intruded into the lower crust.			
		Bell Rock	33 x 8	6000	70-80°SW	OAN, T				Copper SE/52-10
		Blackstone	35 x 4	4000	70-80°S	OAN, T, HypT, ON		V in magnetite	Base exposed	
		Cavenagh	18 x 18	1800	0-15°SE	OAN, T				Scott SE/52-6 Nesbitt and Talbot (1966)
		Claude Hills	18 x 0.5		?steep	Px		Ni. ochres		
		N. Mt Davies	6 x 2	2000	80°N	OMG		Cr in OG, Px	Folded	
		S. Mt Davies	15 x 4	4200	70-80°N	Px, OG, AN			Overturned, top exposed	
		Ewarara	4 x 2	300	20-30°S	OOPx, OPx			Base exposed, top removed	Nesbitt and others (1970)
		Gosse Pile	6 x 2		60°S	OOPx, OPx, H				
		Hinkley	23 x 4	3000	var.	OG, ON, OHG		Nickeliferous ochres		
		Jameson	19 x 4	5500	30°SW	OG, LH, T, HG, AN,		Several titaniferous-vanadiferous magnetite bands		
		Michael Hills	22 x 6	6400	var. low.	LG, HG, AN, Px			Folded	
		Morgan	6 x 4		?	ANOG			No layering observed	
		Murray	6 x 4		var, steep	G				
		Walker Hill	8 x 4	?6000	80°NE	OG, Px, H,				
		Wingellina	16 x 2	1700	60°	Px		Nickeliferous ochres 60Mt@ 1.32% Ni	Also called N. Hinkley	
		Mount West	6 x 2	1500	45°W	CPx, OG			Resembles Critical Zone of South Davies	

TABLE 13

State	Province/Block-Age	Complex-Intrusion	Areal Extent (km)	Thickness (m)	Form-Orientation	Dom. Lithologies	Layering/Fabrics	Mineralisation	Comments	Ref.
	53.	Musgrave Complex: Eastern Extention of Giles Complex Mount Woodroffe Norite	215km^2	3650+	Layered sill dipping 35°SE	N, minor DD AN, Px, ON	Macroscopic layering due to difference in grainsize and px content well developed No "sedimentary" structures like Giles Complex	Trace chalcopyrite at Trudinger Pass in Norite S.A.D.M. carried out a stream sediment program over the norite intrusions and tested for Cu, Pb, Zn, Co, Ni, Cr, V, Mn, Pt, Os, Ir, with no anomalous results	-Some intrusions covered by alluvium at Caroline, see below, which have been defined by gravity-magnetics-drilling -Probable equivalent to Giles Complex -Area under Aboriginal Reserve status	Woodroffe SG/52-12
	54.	Cardine Complex (near Palpat -jaranya)	18 x 8		Concordant non-exposed intrusion of Giles Complex rocks	AN, LT, N	Layered		-Drilled by SADM -Also three small N intrusions (plug, sill, dyke) in the Lungley Gully sub area, and three phases of thin dolerite dykes throughout sheet	
	55.	Gabbroic Dykes (No Name)	4 x thin	100	Near vertical thin dykes	Massive G, ON, D	Massive		-Northwest trending dyke swarm postdates Giles Complex -No potential for PGE	Everard SE/53-13
N.T.	Pine Creek Geosyncline -L. Prot 56.	Zamu Dolerite } Zamu Complex }	15+ x 4	300	Conformable intrusive tabular bodies, often striking NW-SE	D, G, DD, Qtz-DD Amphibolites, Syenites	Minor Differentiation	Minor Pb	-Most? post folding of sediments but pregranite intrusion. Metamorphosed to amphibolite facies. -Also some small bodies occur on the Alligator sheet with larger Pdo (Oenpelli) gabbro bodies	Mt Evelyn SD/53-5 Alligator River SD/53-1 + Ferguson + Needham (1978)
	Mid to L. Prot 57.	No Name (several linear-equant Pdl bodies)	15 x 15 (largest)	60-300	Flat lying concordant sills and lenses	D	Uniform composition but variable texture		-Intrude upper part of Roper Group and extend into Urapunga, Mt Young Roper River Sheets. On Urapunga they are ubiquitous with sills totalling 300m thickness and covering areas of 15 x 15km. On Roper River sheet they are less than 75cm thick	Hodgson Downs SD/53-14 + Roper River SD/53-11 + Urapunga SD/53-10 + Mount Young SD/53-15

TABLE 14

State	Province/Block-Age	Complex Intrusion	Areal Extent (km)	Thickness (m)	Form-Orientation	Dom. Lithologies	Layering/Fabrics	Mineralisation	Comments	Ref.
	58.	Oenpelli Dolerite	35 x 15	250	Basinal like ellipsoidal lopoliths, some thin vertical dykes. At least five sheets	OD, G, Qtz-D, Granophyric D, Syenite	Symmetrically differentiated layers of OD, Minor felsic types and cross cutting gabbroic pegmatites. Minor rhythmic layering in thicker OD of cumulate ol+ plag.		-Extend over 20,000km^2 -Similar to Jurassic sills of Tasmania, which are tholeiitic -Noril'sk (USSR) type PGE mineralisation may be valid within these dolerites	Alligator River SD/53-1 Stuart-Smith + Ferguson (1978)
	Arunta Block (? Archaean) 59.	No Name (several small bodies near Jervois Range)	5 x 2 (largest)		Linear sills	O G		Cu in quartz veins	-Intrude PE metamorphic but older than PE granites of area -Probably similar to the gabbroic intrusions of the Davenport Ranges which lack internal differentiation and are fairly massive and thin. These carry qtz veined Cu and Au mineralisation but don't appear to be prospective for platinoid mineralisation	Huckitta SF/53-11
Qld	Mt Isa Inlier L. Prot 60.	No Name	15 x 3		Swarms of dykes, sills of radial-irregular form	Meta D, G Amphibolite	?Weakly differentiated		Gabbroic complex showing ?weak differentiation features, are present around Mount U10 - Selwyn, SE of Mount Isa	BMR Bull 51 + Pers. Comm. D.H. Blake BMR
	Prot 61.	Lunch Creek Gabbro		1500+	Layered sills	G, DD	Some layering, fractionated		Gabbro contains rare olivine, abundant orthopyroxene, clinopyroxene, biotite, plagioclase and represents a subalkaline hydrous tholeiitic calc-alkaline type magma, fractionated from picrite to coarse pegmatoidal gabbro	Marraba 1:100,000 GSQ + BMR + BMR Mono 5 pp 239
	Georgetown Inlier Prot 62.	Sandalwood	$< 2km^2$		Lenticular	S, G		?Ni, Au	-Occurs along narrow belt, 115km long near the eastern faulted margin of the Georgetown Inlier -Also at Gunnawarra Hstd, on A Atherton Sheet, slightly larger at 4km^2 -These occurrences probably present Alpine-pod like type intrusions of older age than the more ubiquitous Palaeozoic intrusions of serpentinite. The Gray Creek Complex, near Greenvale (190km w of Townsville) is a Siluro-Devonian Complex of gabbro-tonalite through amphibolite clinopyroxenite, wehrlite and lower peridotites, serpentinites. Geology is similar to parts to the Sandalwood and Boiler Gully Complexes	Einasleigh SE/55-9 + Atherton SE/55-5

6. Potential PGE Complexes within Australia

The following discusion gives a brief description of the Archaean-Proterozoic mafic-ultramafic complexes considered favourable for PGE mineralisation, throughout Australia.

Styles of mineralisation discussed include:

(i) Stratiform Bushveld-Stillwater-Lac des Iles type.

(ii) Tectonically disturbed type (i).

(iii) Noril'sk-Talnakh-Duluth-intracontinental rifting-flood volcanism type.

(iv) Discordant bronzite pegmatoidal pipes.

Australian complexes described are: (listing is not in order of priority).

Munni-Munni Complex	- WA, Pilbara Block
Oenpelli Dolerite	- NT, Pine Creek Geosyncline
Zamu Dolerite	- NT, Pine Creek Geosyncline
Roper River-Urapunga-Mount Marumba Dolerite	- NT, McArthur Basin
Woodward and Hart Dolerites	- WA, Halls Creek Mobile Zone
McIntosh Gabbro-Alice Downs Ultrabasics	- WA, Halls Creek Mobile Zone
Giles Complex	- WA, NT, SA, Musgrave Block
Windimurra Complex	- WA, Yilgarn Block
Carr Boyd Rocks Complex	- WA, Yilgarn Block
Bulong Complex	- WA, Yilgarn Block

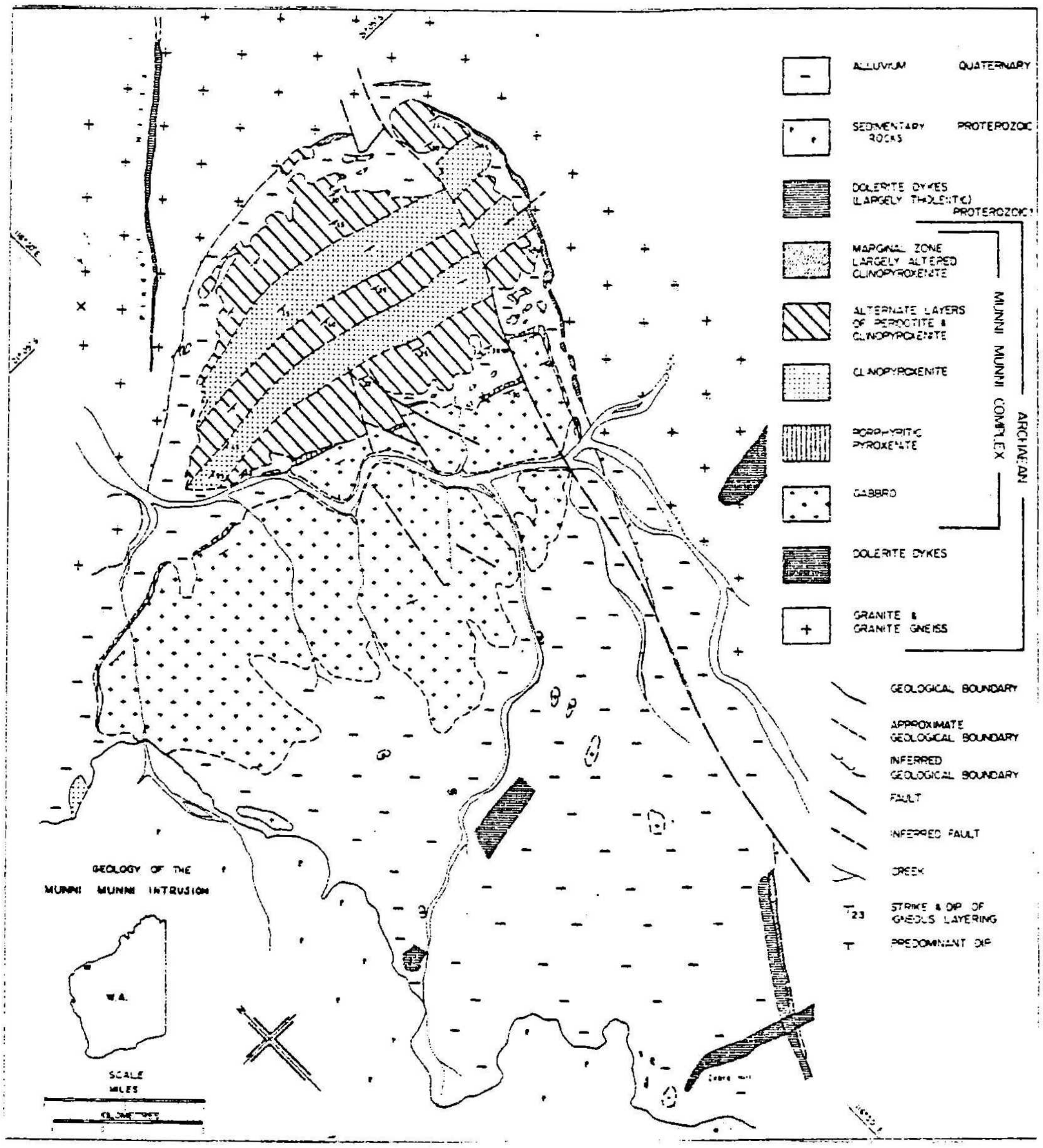


Figure 16. Geological map of the Munni Munni Complex
Reproduced, with permission from Donaldson (1974)

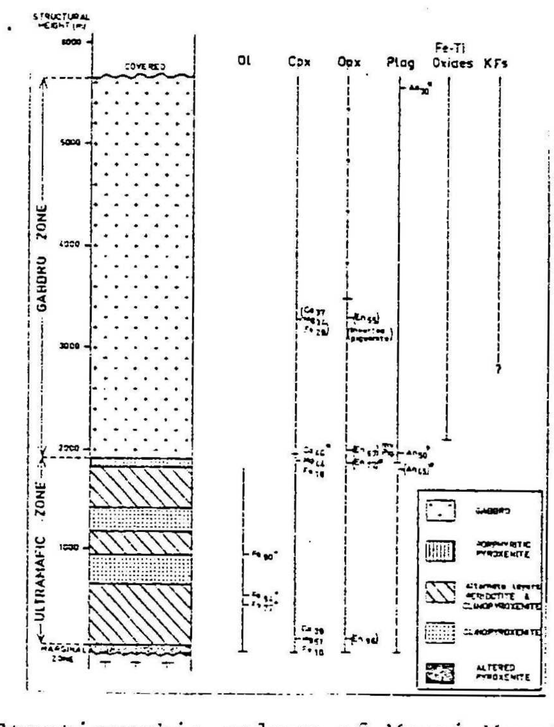


Figure 17. Stratigraphic column of Munni Munni Complex
Reproduced, with permission, from Donaldson, (1974).

N/B. Major source references are indicated in brackets after each Complex title.

Pilbara Block

6.1 Munni-Munni Complex (Donaldson, 1974)

The Munni-Munni intrusive complex located 48 km southwest of Roebourne within the Archaean Pilbara Block is a layered sequence of clinopyroxenite, peridotite and gabbro. Aeromagnetics suggests the complex extends in total for 26 x 9 km with only the northern one third (40 km^2) being exposed. The southern extremity is masked by flat-lying Proterozoic Fortescue Group sediments. The intrusion has been tilted 35-50^o to the southwest, exposing some 2000 m of layered ultramafic rocks overlain by at least 3500 m of gabbroic rocks. Pilbara System Granites dated at 3000 m.y. intrude the complex on the western flank (contact relationships of northern and eastern margins are uncertain) thus the intrusion has been tentatively assigned as Archaean in age. The geology of the Munni-Munni is shown in Figure 16.

The stratigraphy has been divided by Donaldson into three zones, a Marginal Zone, an Ultramafic and a Gabbro Zone, see Figure 17.

Marginal Zone: a narrow zone of altered pyroxenite in contact with granitic gneiss. Generally grades into unaltered pyroxenite within 10 to 20 m of the contact.

Ultramafic Zone: a composite 2000 m zone of alternating layers of clinopyroxenite and serpentinized peridotite. Layers are laterally continuous for over 6 km, with both steep and gradational conformable contacts. Over forty "cyclic" layers have been recognised within the Zone. A cyclic unit consists of basal olivine rich rocks grading into clinopyroxenites at the top. Fine scale (2 mm to 20 cm) layering is developed within pyroxenite layers and mineralogical grading at this scale is common, with either an olivine rich layer grading upwards with increasing pyroxene content or vice versa - scour and fill, and crossbedding "pseudo sedimentary" structures are present.

Gabbro Zone: a 3500 m zone of dominant plagioclase rich rocks. The lower contact with the Ultramafic Zone is sharp. Rhythmic layering is absent with a pronounced plagioclase lamination parallel to the ultramafic layering the dominant fabric. Basal slumping features of 2 m thick banded gabbros occur throughout.

Donaldson notes that the chemical variation in the intrusion with an increasing Fe:Mg ratio and alkali content up the sequence is very similar to the chemical trends in large tholeiitic intrusions such as Skaergaard, Bushveld and Stillwater. Layered fabrics, such as rhythmic and cryptic, igneous lamination, slump structures and cumulus textures and stratigraphic thicknesses are comparable to the overseas complexes. Mineralogical features of the Munni Munni shows some deviation however in the paucity of cumulate orthopyroxene.

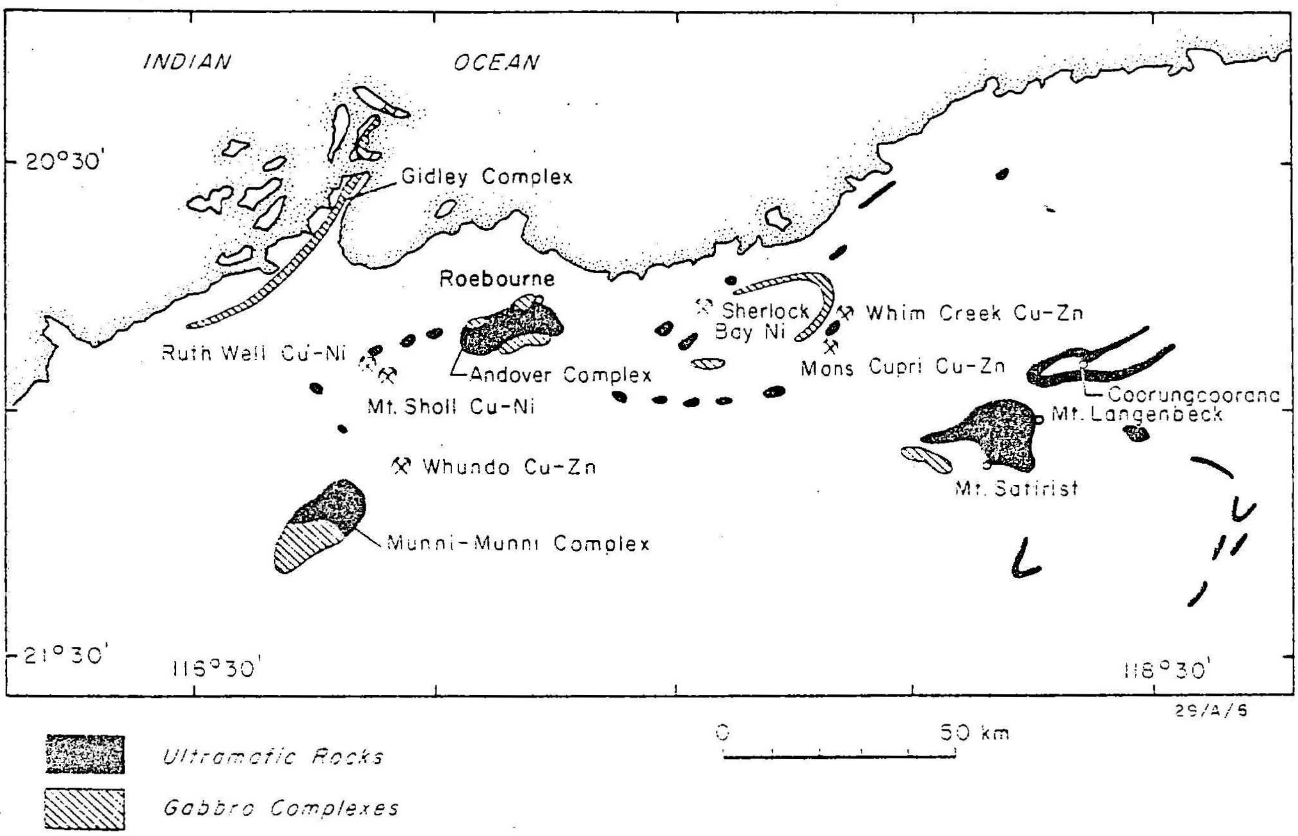


Figure 18 MAFIC-ULTRAMAFIC COMPLEXES AND MAJOR MINERAL DEPOSITS OF THE ROEBOURNE DISTRICT, WEST PILBARA

Apart from some drilling (Source unknown, which intersected disseminated and minor massive nickel-copper sulphides near the basal contact, no other mineralisation is known within the complex. The Munni-Munni Intrusion is believed to be prospective for PGE mineralisation, since it displays several features relating to scale, setting, form, fabrics and mineral-chemical trends to the Bushveld-Stillwater models. PGE and associated chromite mineralisation investigation should be directed towards the cyclical units within the peridotite phases of the Ultramafic Zone (Stillwater type) and also the interface of the Gabbro-Ultramafic Zones which represents the first appearance of extensive cumulus plagioclase in the intrusion and the disappearance of olivine (Bushveld type).

In addition to the Munni-Munni Complex,other layered intrusions occur within the Roebourne district. Vanadiferous magnetite occurs in anorthosite-gabbro complexes at Balla Balla and Andover (see Table 13) with several copper zinc, nickel deposits at Whim Creek, Mons Cupri, Sherlock Bay and Whundo (see Fig. 18), thus the region is weakly but widely mineralised. Large potential PGE complexes may also exist at Mt Lagenbeck-Mt Satirist, 100 km east-southeast of Roebourne and Coorungcoorana, immediately to the northeast of Mt Langenbeck. These complexes are shown in Figure 18. Lower Proterozoic doleritic sills are prominent in the Roebourne area which may be prospective for Noril'sk-Duluth type PGE mineralisation (see section 1.5).

Halls Creek Mobile Zone, Pine Creek Geosyncline and McArthur Basin: Noril'sk-Talnakh-Duluth Model

Greatest potential for the Noril'sk-Talnakh-Duluth type of mineralisation (i.e. intrusive equivalents of flood volcanism, associated with continental rifting) appears to exist within the Proterozoic Orogenic Domains of Pine Creek, Halls Creek and parts of the McArthur Basin.

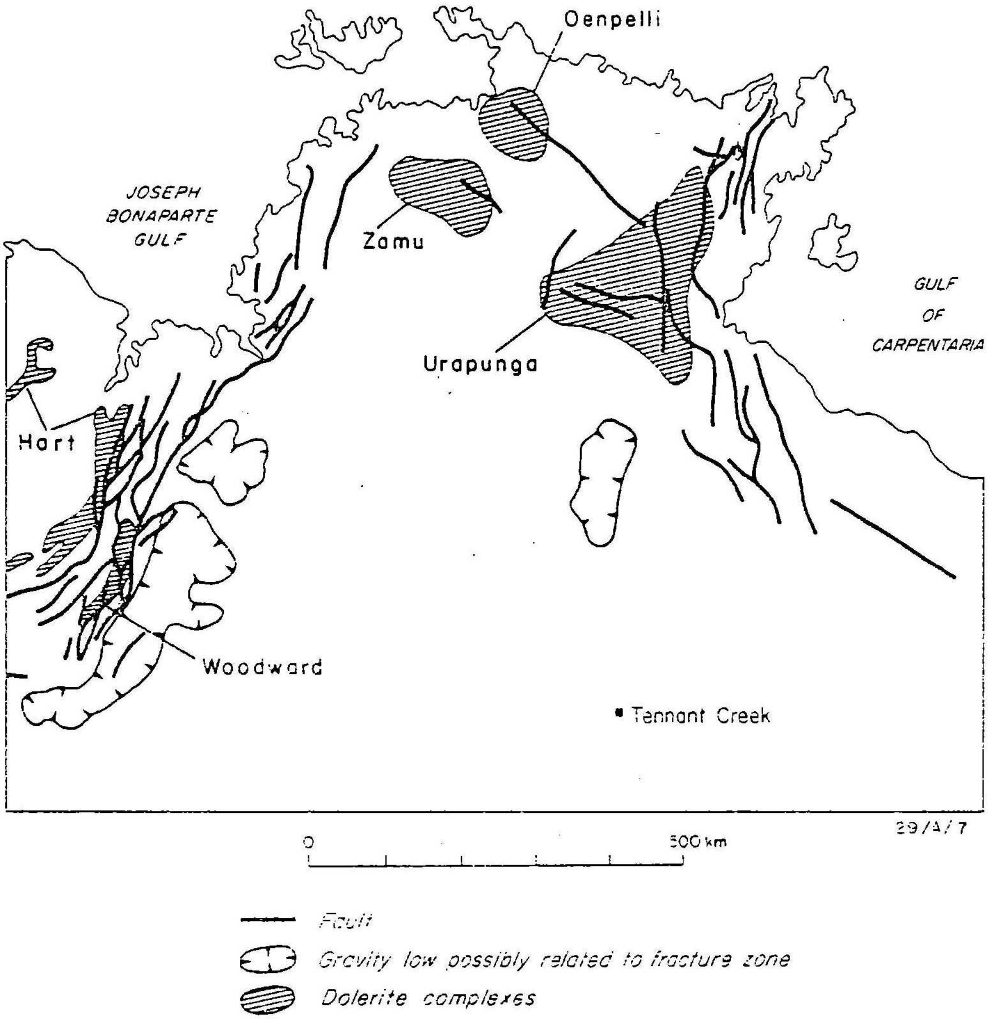
Recognition of Intracontinental Rift Zones

Rossiter & Ferguson (1980) have recognised several major intracontinental rift zones within northern Australia. Evidence for these are:

(i) presence of Archaean rocks within the Pine Creek area (i.e. Rum Jungle, Waterhouse, Nanambu, Litchfield-granitic rocks only). These occurrences are believed to represent translated Archaean fragments, which have moved some 500 km to the northeast along two major fault systems that border the "Arnhem Land Region", see Figure 20;

(ii) various fault-fracture zones display many of the characteristics of extensive strike slippage, although the amount of displacement is unknown. The Halls Creek Fault in particular stands out;

(iii) the parallel northeast-southwest trend of the eastern and western margins of the "Arnhem Land Region", and when extrapolated to the southwest its coincidence with (ii);



Reproduced, with permission, from Rossiter & Ferguson (1980)

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Figure 19 DISTRIBUTION OF MAJOR DOLERITE COMPLEXES, FRACTURE ZONES, GRAVITY LOWS IN NORTHERN AUSTRALIA

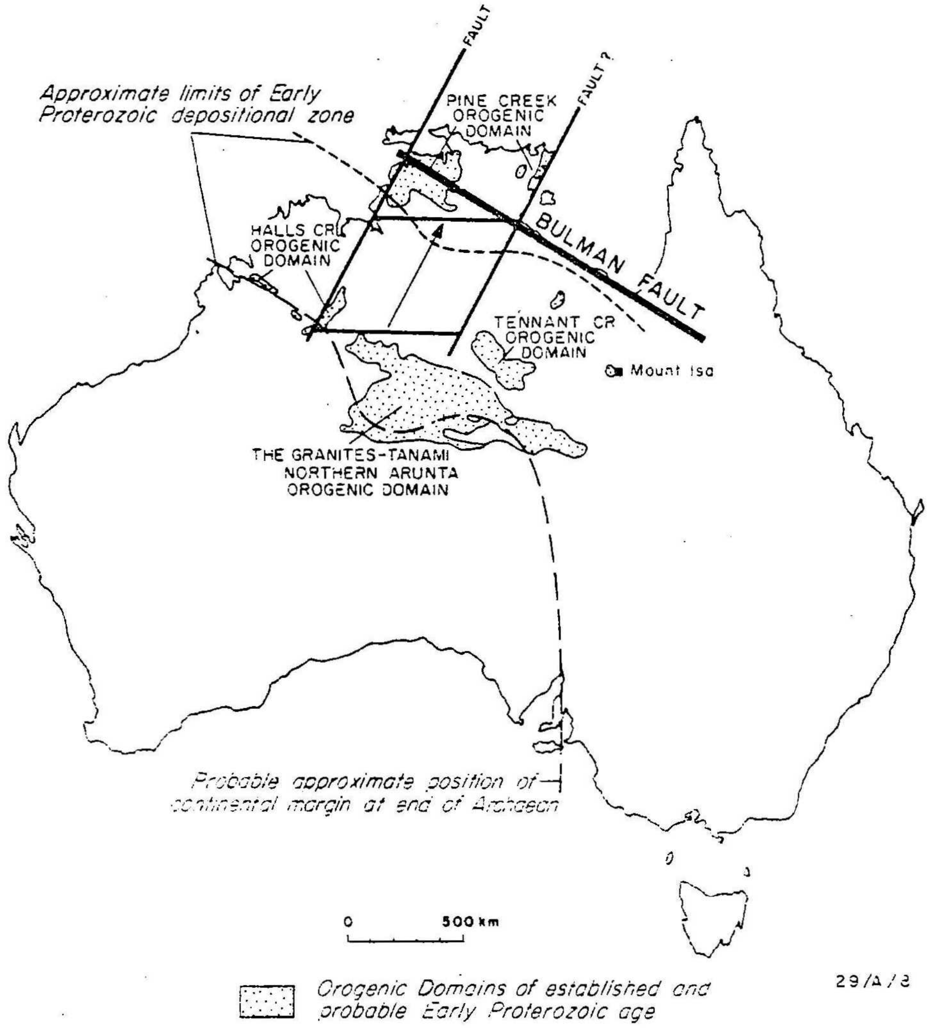

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Figure 20 EARLY PROTEROZOIC (~ 2400 - 1800 m.y.) GEOLOGY AND TECTONIC MODEL FOR NORTHERN AUSTRALIA

(iv) anomalous gravity low trends associated with (ii) and (iii), see Figure 19.

Intracontinental rifting is usually characterised by extensive mafic igneous activity which is reflected by positive gravity features, i.e. as for North America, see Figure 13. This is not observed for the postulated rift systems of Northern Territory, however the authors maintain that preliminary gravity modelling has shown that the lack of a positive gravity response can be attributed to masking by thick low density basinal sedimentary sequences and the presence of high density oceanic crust within about 15 km of the surface. Despite the paucity of known regional igneous activity along these fault zones, several extensive "doleritic" complexes, such as the Oenpelli, Zamu, Roper River-Urapunga-Mount Marumba, Woodward and Hart, maybe genetically linked with the rifting episodes and therefore maybe prospective for Noril'sk type PGE mineralisation.

Physical and chemical features of these complexes will now be briefly discussed.

6.2 Oenpelli Dolerite (Stuart-Smith & Ferguson, 1978)

The Oenpelli Dolerites of 1718 ± 65 m.y. intrusive age extend over a 20,000 km^2 region within the northeast corner of the Pine Creek Geosyncline (240 km east of Darwin). The dolerites consist of at least four major ellipsoidal lopoliths of 100 to 250 m thickness and near flat orientation (5-15^{o}), see Figure 21 for the geology of the region. Intrusive level was shallow at 1 to 2 km depth within amphibolite facies Lower Proterozoic sediments.

The post-metamorphic intrusions (regional phase at 1800 m.y.) are symmetrically differentiated with porphyritic marginal olivine dolerites which grade into a central weakly rhythmic layered ophitic olivine dolerite. The layering which is more prominent in the thicker intrusions is due to olivine, plagioclase cumulate concentrations. Thin discontinuous lenses of granophyric dolerite and minor quartz dolerite differentiates also occur within the central olivine dolerite. Rare gabbroic pegmatite pods and veins occur near the upper chilled margin. See Figure 22 for a section through a dyke.

Normative orthopyroxene and low total alkali to silica ratios, indicate a subalkaline character for the Oenpelli Dolerites, while the ratios K/Rb, K/Ba, Nb/Zr and Ce/Y conforms to a continental mafic tholeiitic trend. Tholeiitic trends whithin the bodies are displayed by the increase of Ba, La, Nb, V, Zr and Ce with differentiation.

6.3 Zamu Dolerite (Ferguson & Needham, 1978)

The Zamu Dolerites located near the eastern margin of the Pine Creek Geosyncline (150 km southeast of Darwin) are older than the Oenpelli Dolerites since they predate the regional metamorphism. The metamorphic overprinting phase of 1800 m.y. has transformed most dykes to amphibolite, although unaltered dolerite is known locally. Figure 23 shows the generalised geology of the Zamu Dolerite.

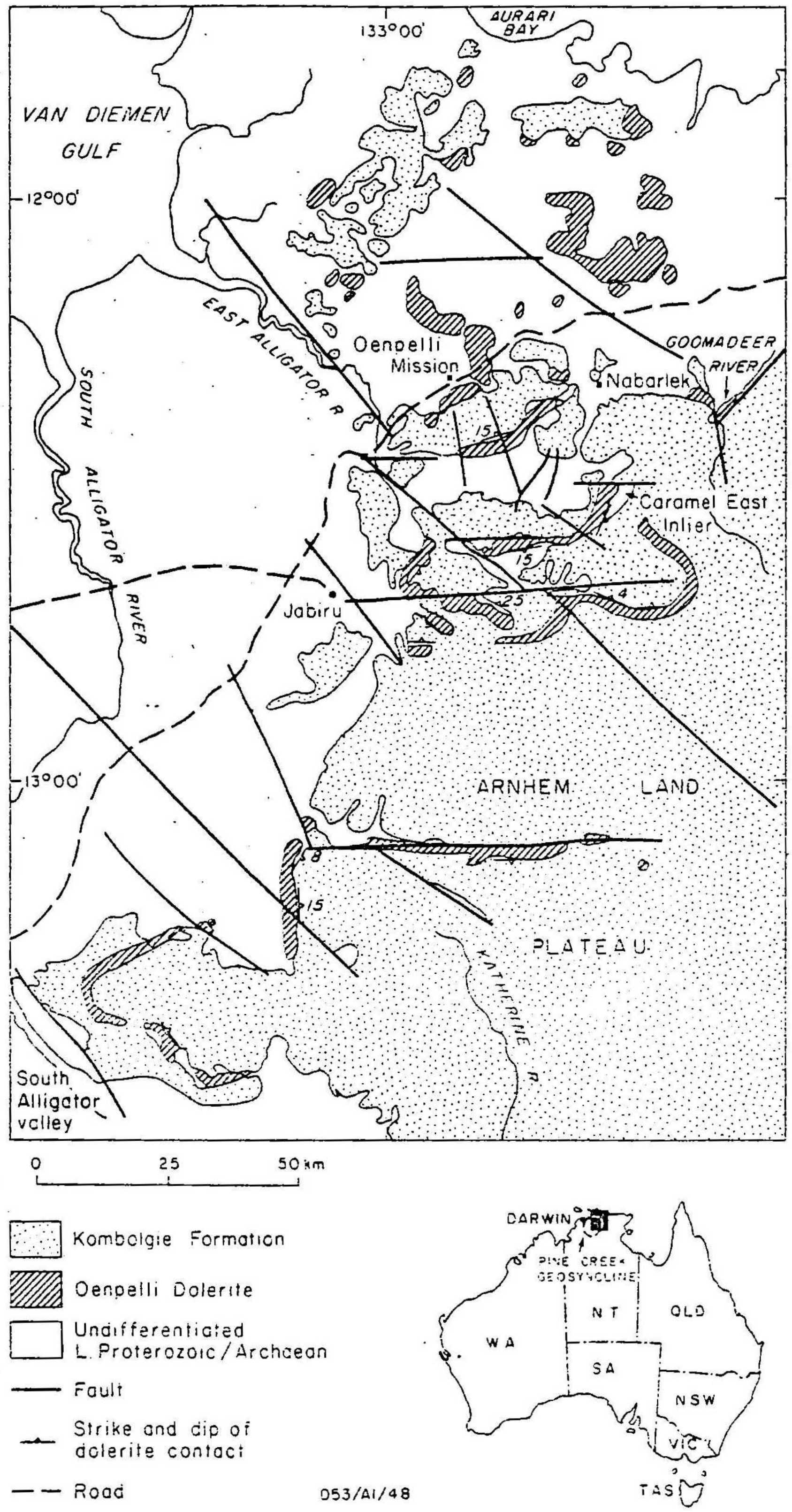

Figure 21. Geology of Oenpelli Dolerite Region. Reproduced, with permission from Stuart-Smith & Ferguson (1978).

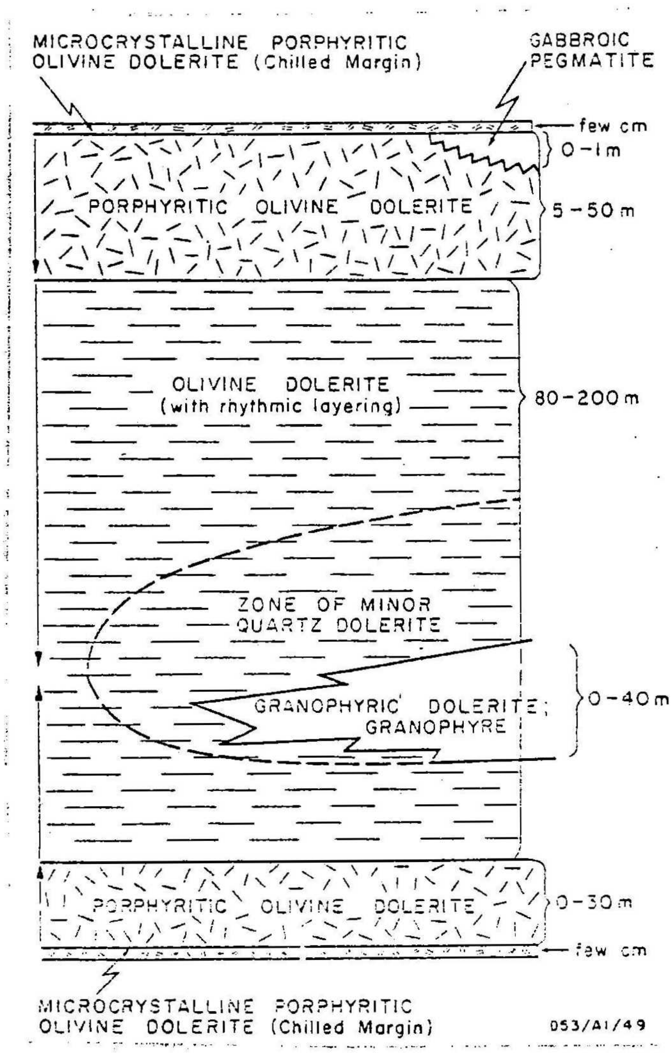

Figure 22. Schematic diagram of the internal structure of the Oenpelli Dolerite. Reproduced, with permission from Stuart-Smith & Ferguson (1978)

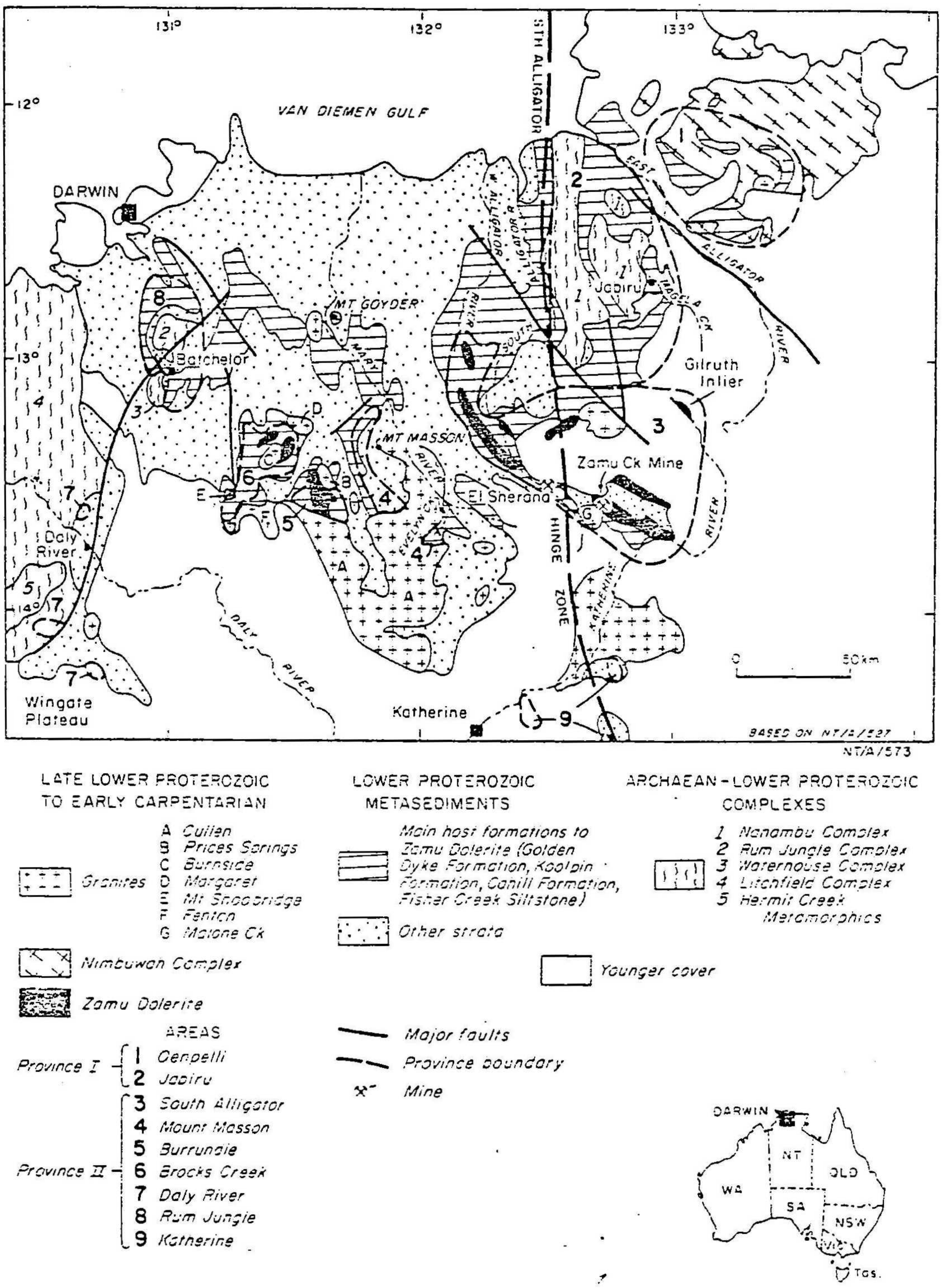

Figure 23. Generalized geology of the Pine Creek Geosyncline. Reproduced, with permission from Ferguson, & Needham, (1978)

This Lower Proterozoic mafic suite generally forms conformable intrusive tabular bodies, often folded and up to 300 m in thickness. The meta-dolerites, amphibolites are generally massive, with some thin (4 mm) lecocratic segregations, and an increase in grainsize of the thicker units towards the centre of the body. Amphibolites with relict ophitic texture grade into unmetamorphosed dolerite which are medium grained and consists of augite ± bronzite (En_{82}), plagioclase (An_{59-72}) ± hornblende, ilmenite, interstitial quartz, biotite and secondary chlorite. Minor pyrite and chalcopyrite is often present as disseminations in areas of alteration. Unlike the Oenpelli Dolerites differentiation appears to be less pronounced.

As with the Oenpelli, the Zamu subalkaline character is reflected by the low total alkalies versus silica, high normative orthopyroxene, and continental tholeiitic basalt compositions.

6.4 Roper River-Urapunga-Mount Marumba Dolerite Swarm (Roper River, Urapunga Mount Marumba BMR 1:250 000 Geological Series Commentaries)

Extensive dolerite development occurs centrally within the McArthur Basin near the junction of the Bulman Fault and the regional northeast trending faults mentioned earlier, see Figure 20.

These Mid to Lower Proterozoic dolerites which intrude the Upper part of the Roper Group, form near flat lying concordant sills and folded lenses up to 15 x 15 km in area and thickness generally less than 300 m. Dolerite lithologies generally show uniform composition but variable textures.

Greatest intrusive activity appears to be in the Urapunga area where five different sills are of aggregate 300 m thickness and of extensive distribution. The mineralogy is fairly consistent with pigeonite, labradorite-andesine plagioclase and some interstitial quartz dominant phases. Texture of the top sill is fine grained basaltic, sill below ranging from fine to coarse grained, and the lower sills are consistently medium grained, showing very little range within themselves or from sill to sill. The intrusions appear to antedate the major fault movements of the Proterozoic and are unconformably overlain by the Lower Cambrian Antrim Plateau Volcanics.

6.5 Woodward and Hart Dolerites (Dow & Gemuts, 1969; Gemuts 1971; Plumb & Gemuts, 1976; Plumb and others, 1981)

The Woodward Dolerite of Lower Proterozoic age comprises numerous basic and ultrabasic sills, dykes which intrude the Halls Creek Group (maximum age of 2,240 m.y.). Their distribution is extensive, covering much of the Halls Creek Mobile Zone, in particular southwest of Halls Creek. The sills are long and narrow, folded, but showing concordancy with the Halls Creek Group. Individual sills range from hundreds of metres to 20 km in length, and from 15 to 600 m in thickness. The thickest sills are concentrated to the west of the Halls Creek Fault near Ruby Plains Homestead where the sills are of domal shape. The texture of the sills ranges from fine grained and massive at the margin to vesicular, coarse grained and porphyritic towards the centre. Most of the sills have been intensely uralitized with little preservation of original minerals and textures. Phases of actinolite, tremolite, albite, epidote, quartz. ilmenite, sphene are prominent. The Alice Downs Ultrabasics (locally platiniferous-chromiferous) and McIntosh Gabbro intrusives are believed to be comagmatic with the Woodward Dolerites.

Sills and dykes of the Hart Dolerite (1800 m.y. age) are of great regional extent, underlying the whole 160,000 km^2 of the Kimberley Basin. Where upturned in the Mobile Zones, a composite thickness of up to 3000 m of dolerite is exposed in several sills, but the thickness beneath the main basin is unknown. Individual sills are up to 1800 m thick, but are commonly composite. Compositions range from olivine dolerite and gabbro through tholeiitic dolerite, quartz dolerite and granophyre. Thus sills show some differentiation trends despite their fairly massive character. Flat lying sheets of granophyre up to 250 m thick are found at the top of the thickest sills, with metasomatic alteration of contact arkoses.

Summary of Noril'sk-Talnakh-Duluth Type PGE Mineralisation and Northern Australian Dyke Swarms

Lower Proterozoic Dolerite intrusions are prominent within both orogenic and stable basinal environments of northern Australia. Complexes such as the Oenpelli, Zamu, Roper River-Urapunga-Mount Marumba, Woodward and Hart Dolerites display a remarkable similarity in compositions, scale and form, with greatest differences relating to degree of fractionation, tectonic setting and temporal relationship of intrusive and major regional metamorphic event. The distribution of the Oenpelli, Zamu, Woodward and Roper River-Urapunga-Mount Marumba dolerites in particular show a spatial relationship with regional strike slip faults, see Figure 19, suggesting their origin may be related to deep seated zones of rifting. The Hart Dolerites which are the msot extensive regionally, occur largely on the northern margin of the Halls Creek Mobile Zone and more widely throughout the Kimberley Basin. Their distribution is largely masked by younger Proterozoic sediments and volcanics thus their origin is more obscure.

Most of the Northern Australian dolerites show similarities to the Noril'sk-Talnakh mineralised intrusions in that they are continental tholeiitic types (of subalkaline character) with gabbro-dolerites forming the dominant lithologies with associated felsic differentiates. Scale of intrusions in all three dimensions is of similar magnitude and their close association with prominent faulting is in accord with the West Siberian deposits. However in all Australian examples with the possible exception of the Hart Dolerites, there is no evidence of extensive flood volcanism associated with the intrusive activity, a characteristic feature of the overseas provinces. In the Kimberley Basin, the Carson Volcanics - a Early Proterozoic tholeiitic flood basalt with interbedded arkose, volcaniclastic sediments are spatially near and may be comagmatic with the Hart Dolerites.

Of the four complexes outlined above, the Oenpelli Dolerites appear to be the most favourable for Noril'sk-Talnakh-Duluth type PGE mineralsiation since they display the greatest degree of fractionation and some layering features. The Zamu, Woodward and Hart Dolerites are weakly differentiated, more massive and generally of a higher metamorphic grade (the mobility of PGE during amphibolite or higher metamorphic facies is unknown). A feature apparently significant for mineralisation within these feeder intrusives is the assimilation of sulphur bearing country rocks (as opposed to a magmatic sulphur source) during magmatic activity at depth, since sulphides are critical as collectors-concentrators of PGE from the melt. In this respect the Woodward and Hart Dolerites fall short in that they largely intrude turbidite sediments, metasediments, volcanics, and volcaniclastic sediments. However in the Pine Creek Inlier the Oenpelli-Zamu Dolerites intrude various pyritic black shales, haematitic siltstones, banded iron formations (South Alligator Group) or pyritic, carbonate-evaporite facies of older Group Formations (Namoona,?Batchelor Groups).

The Roper River-Urapunga-Mount Marumba Dolerites intrude black shales, carbonate ironstones of the Roper and Malay Road Groups, and potentially could intrude subgroups of the McArthur Group which are strongly evaporitic, carbonaceous and pyritic in places (i.e. host to McArthur River HYC basemetal deposits).

Due to the apparent wide age span of the continental rifting-flood volcanism type PGE mineralisation, several other provinces throughout Australia may be also prospective, for example:

- the dolerites southeast of Roebourne, WA of Lower Proterozoic age (although the Archaean tectonic setting suggests deep seated rift zones are not likely to be prominent).
- the extensive Lower Cambrian Antrim Plateau flood basalts flanking the Halls Creek Mobile Zone
- the Jurassic tholeiitic sills of central, eastern Tasmania
- Quaternary basalt flood volcanism of western Victoria.

Halls Creek-King Leopold Mobile Zone

6.6 McIntosh Gabbro and Alice Downs Ultrabasic Bodies (Gemuts 1971; Dow & Gemuts, 1969)

Mafic-ultramafic intrusive magmatic activity is prominent within parts of the Halls Creek-King Leopold Mobile zones. The intrusions fall into two main groups; the dolerite-gabbro sills and dykes of the Woodward-Hart Dolerites (see Section 6.5) and the competent, broadly warped thick sills, represented by the Wombarella Quartz Gabbro, the McIntosh Gabbro and its differentiated phase the Alice Downs Ultrabasics. Most of the complexes are metamorphosed, foliated, altered and tectonically disturbed. The latter feature which may preclude easy appraisal of favourable intrusions, their size and form, degree of differentiation and presence of platinum, chromite mineralization namely at Panton Sill, Lamboo Homestead, Eastman's Bore, collectively suggests this Lower Proterozoic Mobile Zone is prospective for tectonically dismembered layer type PGE mineralisation.

The Panton Sill, Lamboo Homestead Prospects suggest that the close spatial association of McIntosh Gabbro with basal Alice Downs Ultrabasics is significant for PGE-Cr mineralisation. McIntosh Gabbro intrusions are ubiquitous within the Mobile Zone, thus PGE investigations should be directed at locating associated ultrabasic horizons, which due to their differentiated relationship, form subordinate marginal phases to the more extensive Gabbro bodies. The McIntosh Gabbro forms large circular or elliptical sill like bodies which are generally folded into shallow synclines or basins. Individual complexes are up to 32 km across and consist of interlayered olivine gabbro, leucogabbro, norite, hypersthene troctolite, anorthosite and dolerite, up to 1500 m in thickness. Rhythmic layering is generally poorly developed. Most complexes have been partly or completely altered by metamorphism, shearing or granite intrusion. The peridotes and pyroxenites of the Alice Downs Ultrabasics are believed to represent the basal differentiate phase of the McIntosh Gabbro. Greatest expression of the ultrabasics occurs at Panton Sill, (55 km NNE of Halls Creek) where broadly layered basal peridotites and schists grade up into alternating uralitized and leucogabbros, forming a southerly plunging syncline. Other ultrabasic occurrences are known at Lamboo Homestead, western and southern margins of the McIntosh Sill, and south of Tickalara Bore.

The Panton Sill mineralisation would have encouraged intensive investigation of nearby Toby, McIntosh, Armanda Sills, however it is uncertain how much exposure other complexes have received from the exploration companies. The difficulty of recognizing-predicting lode type PGE mineralisation and the emphasis on gold within the Halls Creek region suggests the old prospector played a minor role in the location of PGE. Several complexes throughout the Mobile belt appear to be favourable, notably an extensive (20^{+} x 15 km) McIntosh Gabbro occurrence at Mt Fairbairn (Lat $18^{o}35'$, Long $126^{o}20'$) which has been centrally intruded by the Bow River Granite (suggesting maybe a basinal configuration to the basic rocks) and numerous smaller ?disturbed Gabbro complexes in the Turkey Creek and Sringvale Homestead region.

Musgrave Block-

6.7 Giles Complex (Nesbitt & Talbot, 1966; Nesbitt and others, 1979; Daniels 1974).

The following discussion is generalised; for individual descriptions of intrusions, see Daniels (1974).

The Giles Complex is a series of deformed mafic-ultramafic sheets which occur as isolated east-west trending intrusions scattered over 25 000 km^2 in the Musgrave Block of central Australia. Characteristics and distribution of the major intrusions are shown on Table 12 and Figures 24 and 26.

The intrusions of approximately 1,100 m.y. intrude a similar aged Proterozoic complex of granulites, acid intrusives and younger volcanics and sedimentary rocks of the Bentley Supergroup. Depth of crustal emplacement was variable with the western intrusions being of much shallower (based on various petrological evidence) origin and with less deformation than the central intrusions.

The whole complex is characterised by plagioclase rich lithologies and the deficiency of ultramafic rocks. Olivine gabbros, olivine norite, troctolites and anorthosites comprise approximately 90% of the complex, with the remainder olivine bearing or absent orthopyroxenite, clinopyroxenite and rare peridotites, such as at north Mt Davies, and transgressive harzburgites which occur as layers or small plugs as at Ewara east. All of the sheets display features which are characteristic of layered intrusions. Rhythmic, phase, cryptic and igneous lamination and "pseudo sedimentary" structures are prominent within the less deformed portions of the sheets. Fractionation and deformational intensity are related to the depth of emplacement, with the structurally higher intrusions being less deformed and more highly fractionated. The Tollu acid and basic volcanics, located above the Blackstone Complex, are believed to be contemporaneous with the intrusive activity and may represent the final fractionated phase of the magma.

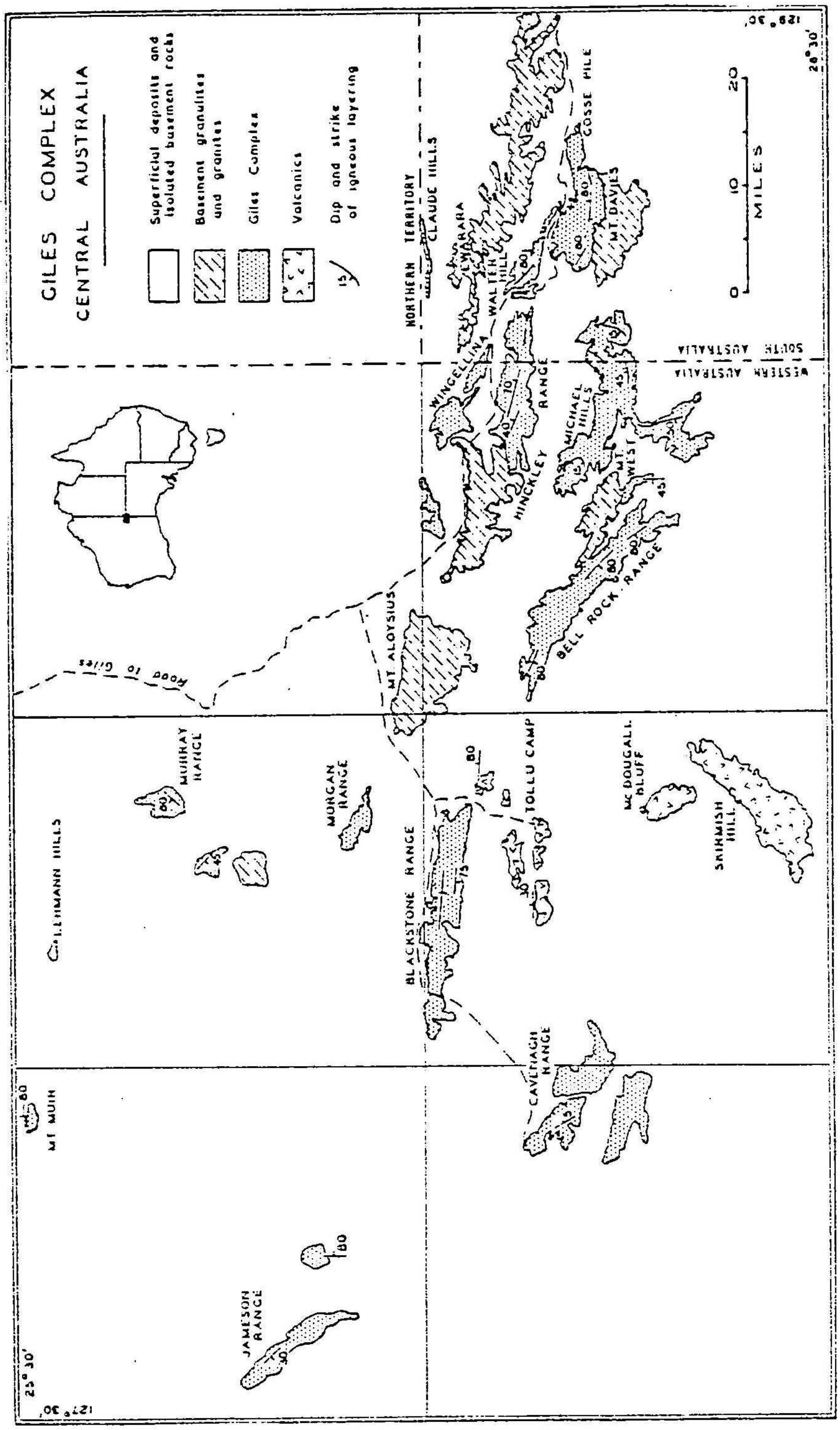

Figure 24. Simplified geological map of the Giles Complex.
Reproduced, with permission from Nesbitt & Talbot (1968).

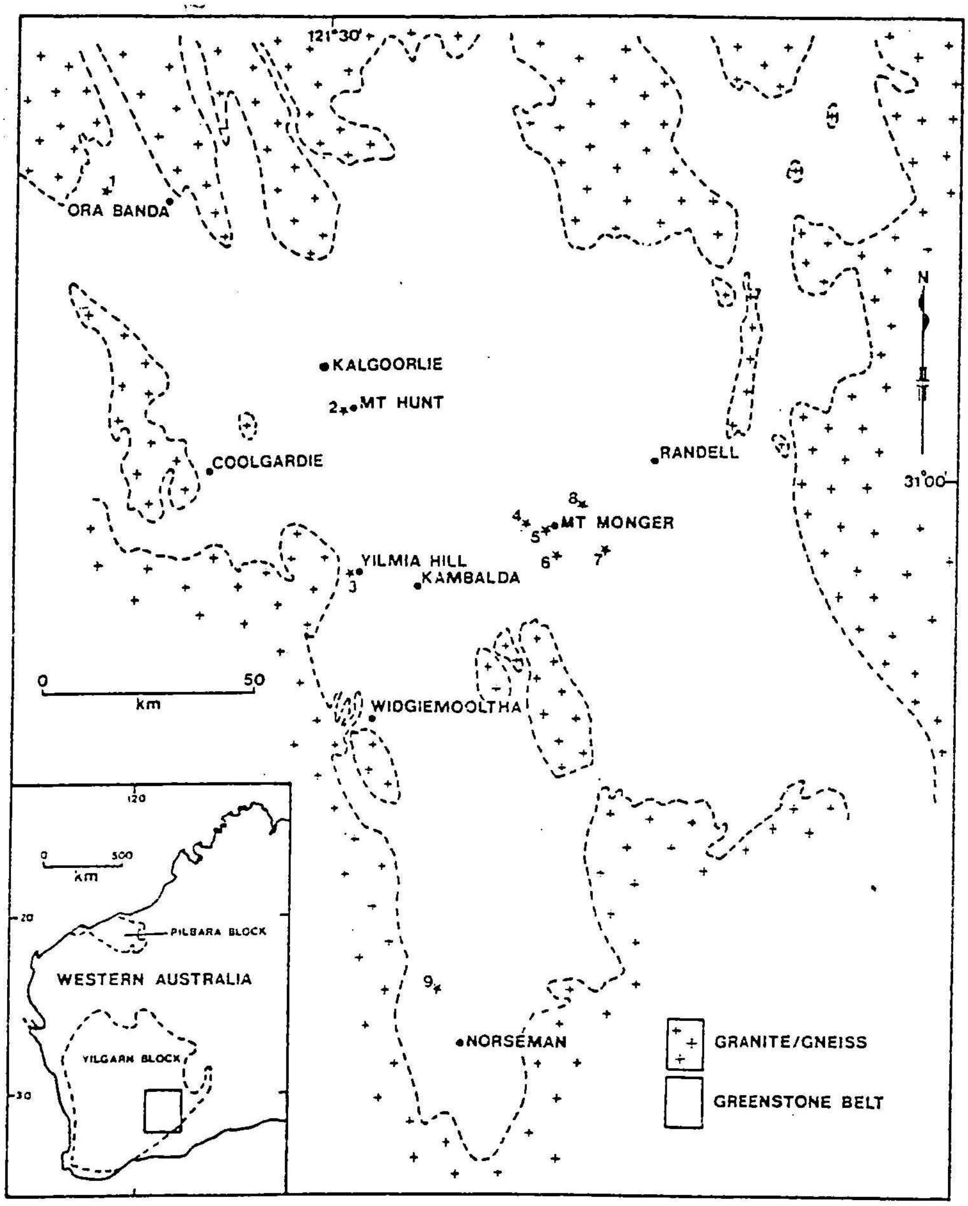

Figure 25. Location and outline of the greenstone belt around Kalgoorlie. Layered intrusions are. 1 Ora Banda Sill;. 2. Mt Hunt Sill, 3. Yilmia Hill Sills (2); 4. Carowlyme Hill and Government Dam Sills (7); 5.,Mt Monger Sills (3); 6. Turkey Dam Sills (2); 7. Peter's Dam Sills (2) 8. Seabrook Sills (2); 9. Mission Sill. Reproduced, with permission from Williams & Hallberg (1972).

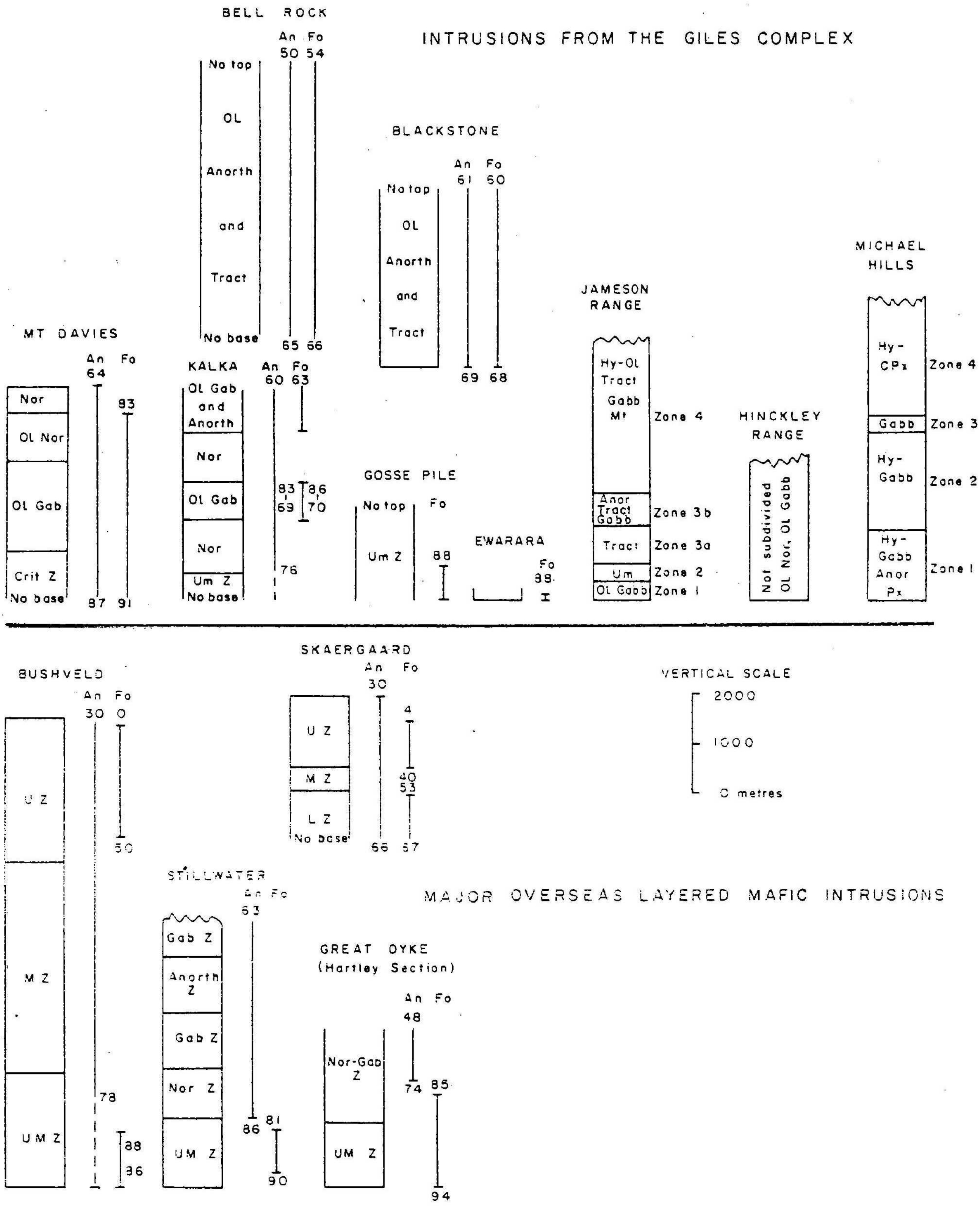

Figure 26 STRATIGRAPHIC SEQUENCES OF THE GILES COMPLEX AND MAJOR OVERSEAS LAYERED MAFIC INTRUSIONS

Reproduced, with permission from Nesbitt and others (1970) and Daniels, (1974) Chilled margins do not represent in all examples the true initial bulk composition of the magma due to contamination effects, alteration from shearing events, and the movement of partially fractionated liquids from lower to higher emplacement levels.

Mineralisation within the Giles Complex is restricted to lateritic nickel and vanadiferous-titaniferous magnetite. No platinum minerals have been recorded from the intrusive complex. The intrusions have attracted considerable investigation from private companies, in particular, Southwestern Mining Company Limited, Westfield Minerals N.L. in conjunction with other companies, and both the Geological Survey of WA and Mines Department of SA. The SADM carried out a stream sediment program over the noritic intrusions of the Mount Woodroffe area (eastern end of Giles Complex) and tested for Cu, Pb, Zn, Co, Ni, Cr, V, Mn, Pt, Os, Ir, with no anomalous results recorded. Lateritic nickel profiles over transgressive serpentinites after picrite are developed at Wingellina in the North Hinckley intrusion (reserves of 61 mt @ 1.32% Ni) and at Claude Hills. Vanadiferous titaniferous magnetite bands occur in both the Jameson and Blackstone Range Gabbros as sheets or conformable lenses within the banded host. The high structural position and well developed chemical fractionation of the Jameson Range sheet are believed to be of significant parameters for the occurrence of these deposits. In contrast the South Australian magnetite occurrences of various intrusions are small pod like bodies in shear zones, carrying negligible vanadium. Features of these vanadium occurrences are described in Chapter 4, and detailed by Daniels pp221-231, 1974; Baxter pp102-105, 1978.

No extensive deposits of chromite are known throughout the Complex. The only reported occurrence, by Coates, (see Moeskops, 1978) is a 1.5 cm chromite seam in pyroxenite cumulates of the Mt Davies Sill. Nesbitt and others (1970) believe the absence of chromite in the basal zones of the magnesium rich central intrusions may be attributed to low oxygen fugacities as reflected by the paucity/absence of magnetite, and under high crystallisation pressures and the absence of an oxide phase to take up the chromium, the chromium instead is entering the clinopyroxene structure producing chrome diopside. The authors believe that, if this is the operating mechanism, chromite mineralisation would not be expected in the structurally higher intrusions i.e. western end of complex since the chromium would have been extracted by fractionation before those differentiated magmas were emplaced.

Nickel within the Complex appears to be confined to the silicates, in particular olivine, as revealed by the lateritic-nickel profiles. Nickel sulphide mineralisation of any scale is unknown. This may be attributed to the initial low sulphur concentration of the parent magma, resulting in the partitioning of nickel within the silicates. If this is the case, PGE values if present will be likely to be low and dispersed, since the magmatic sulphide content is important as a concentrating mechanism. Despite these shortfalls and other problems relating to logistics, intensity of past exploration by State Surveys, and private enterprise and Aboriginal Reserve land status, some scope exists for PGE mineralisation of the layered complex type, near compositional interfaces i.e. feldspathic clinopyroxenite with orthopyroxenite cumulates and/or anorthosite with olivine cumulates of the thicker, higher pressure central intrusions, such as Michael Hills, Bell Rock Walter Hill and Mt Davies.

Yilgarn Block

6.8 Windimurra Complex (Ahmat, 1983)

The Windimurra anorthosite-gabbro complex, located 80 km southeast of Mt Magnet represents the largest single body (85 x 35 km) of gabbroic rocks in the Yilgarn Block. Rb-Sr isotopic ages suggest the intrusion is at least 2.67 Ga, and preliminary Sm-Nd data indicate it may have intruded as long as 3.05 Ga ago. Surface expression of the complex is poor with exposure less than 7 percent of the total complex. Gravity and field data indicate that the intrusive mass is a steep sided, fault bounded tabular body of average 3.5 to 5.0 km thickness. An elongated, deeper central zone appears to be present. The complex has been tectonically disrupted (margins characterised by major shear zones up to 1 km wide), intruded by several Proterozoic-Archaean dykes and experienced in part, greenschist facies metamorphism.

The Windimurra Intrusion is characterised by a high proportion of fresh rocks, rhythmic layering, differentiation, paucity of ultramafics, limited systematic fractionation and a strong anorthositic affinity (25% Al_2O_3). Despite the various tectonic-metamorphic overprinting events, dominant minerals of unaltered state are ubiquitous and include plagioclase (An_{85-58}), Ca-pyroxene (Fe/Fe + Mg = 18-46%), Ca poor pyroxene (Fe/Fe + Mg = 22-48%) and olivine Fa_{20-68}). Magnetite is accessory, with chromite (32% Cr_2O_3), ferrichromite confined to rare ultramafic lithologies as fine disseminated grains. Layering is prominent throughout the complex and defines a basinal shape body with increasing dip angles towards the margin. The measured stratigraphical thickness is up to approximately 8.5 km, which places it as the thickest complex either Proterozoic or Archaean in age, within Australia. The internal structure of the Complex is complicated by shear zones and large areas of discordancy.

Ahmat (1983) has subdivided the stratigraphy according to the presence or absence of either olivine or Ca-poor pyroxene, as follows:

Upper Zone	:	Pl ($\simeq An_{58}$), CPX, Ol(Fa_{63-68}), Mt
Middle Zone	:	Pl ($\simeq An_{58}$), CPX, Opx (inv. pigeonite), Mt
Lower Zone	:	Pl (An_{85-69}), CPX, OPX, Ol(Fa_{20-50})

The Upper and Middle Zones are not extensive in area with the Lower Zone comprising approximately 90 percent of the exposed complex. Olivine is locally absent within the Lower Zone, and where present rarely exceeds 8% volume.

The Windimurra Gabbroid displays many features common to the overseas mineralised stratiform complexes that were discussed in Chapter 1. In particular the scale of this intrusion is very impressive, both areally, and the stratigraphic thickness cf = 8.5 km, exceeds Stillwater and approaches that of Bushveld. Significantly, the Windimurra Complex is one of the few intrusions throughout Australia which contains both extensive vanadiferous titaniferous magnetites (up to 1.2% V_2O_5) and some chromitites, a feature characteristic of the Bushveld. Greatest deviation from the overseas layered complexes appears to relate to Windimurra's anorthositic character and older age. Ahmat (1983) considers the Complex shows closer affinity to the low PGM bearing Fiskenaesset type, of West Greenland.

Yilgarn Block

Eastern Goldfields Province

Small, thin pre-metamorphic sill intrusions of Archaean age are widespread throughout the Eastern Goldfields Province of Western Australia. These layered concordant intrusions have been emplaced within thin sediment layers, high Mg basalts, or tholeiitic basalts as sheeted sills. Lopolithic development is not prominent. Metamorphic overprinting in all examples is of low greenschist facies. Differentiation has produced a diverse sequence of felsic-mafic-ultramafic rocks, ranging from dunites, peridotites, pyroxenites, norites to gabbros, granophyres and anorthosites. Differentiation appears to have followed a tholeiitic trend, with an increasing Fe/Mg ratio and an increase in total alkalies. This sill differentiation is prominent despite their small areal extent and limited thickness - Ora Banda being one of the thickest intrusions at 2000 m, see Table 7, Figure 25. Phase and cryptic layerig are well developed but rhythmic, cyclic, and igneous lamination features are weakly developed.

Due to their limited magma volume, thin sill like form, paucity of rhythmic-cyclic features and absence of major chromite-vanadium-PGE mineralisation, the layered intrusions of the Eastern Goldfields Province are not believed to be highly prospective for stratiform PGE mineralisation of the Bushveld-Stillwater type. However other "unique" styles of PGE mineralisation may exist within certain complexes. The Carr Boyd Rocks and Bulong Complexes which dispaly a greater mafic-ultramafic component and have associated mineralisation will now be briefly discussed.

6.9 Carr Boyd Rocks Complex (Purvis and others, 1972, Knight, 1975)

The Carr Boyd Rocks Complex is a small layered mafic to ultramafic intrusion of Archaean age, located 80 km north-northeast of Kalgoorlie. It is the only layered intrusion within the Kalgoorlie region which contains significant nickel mineralisation (2 m.t @ 1.4% Ni, 0.5% Cu).

The Complex which intrudes basic volcanics-sediments of the Morelands Formation and is intruded by Archaean granites on the northern side, is lobate in outline and extends over 75 km^2. The western, southern and eastern lobes are occupied by ultramafic rocks, while the centre and north are characterised by overlying mafic and minor ultramafic units. See Figures 27, 28 for regional and local geology. The stratigraphy has been subdivided into five units (I to V) of which three are ultramafic and two mafic. Systematic repetition (cyclic layering) is recognised in most of the units (except Unit IV). Most lithologies have been partly or completely altered, with serpentinite, tremolite and actinolite being the main alteration products.

The subdivision is as follows:

Unit	Rock Type	Approx. Thickness
V	Troctolite Olivine anorthosite Norite Minor dunite, bronzitite, augite-norite	1000 m^+
IV	Dunite	250 m

Unit	Rock Type	Approx. Thickness
III	Dunite-harzburgite-bronzitite	200 m
	Dunite	50 m
	Bronzitite	?200 m^+
II	Norite, augite norite, olivine norite harzburgite, and dunite	200-800 m
I	Dunite-harzburgite-bronzitite	50 m
	Bronzitite	150 m
	Dunite-harzburgite-bronzitite	50 m
	Bronzitite	150 m

Intrusive rocks of various lithologies are discordant to the layered series. Bronzite pegmatoids and sulphide bearing noritic pegmatoids are associated with the important bronzite-sulphide pegmatoids (ore hosts) with most of the latter types confined to the base of Unit V. Other intrusions of micronorite, olivine-augite micronorite, andesite and micro granodiorite are common. The various pegmatoids occur in a east-northeast trending zone (see Figure 28), bisecting the intersection of two major faults and are confined to Unit V, indicating both a structural and stratigraphic control.

The sulphide bearing bodies are pipe like breccia intrusions 20-60 m across and up to 300 m deep. They plunge westerly and are cut by north-northwest trending faults. The pegmatoidal phases include bronzite (Fs_{24}), olivine (Fa_{16}), clinopyroxene, hornblende, biotite, plagioclase (An_{62}), chrome titanomagnetite (6-18% Cr_2O_3, 0.3-1.5% V_2O_5) and both massive to disseminated type sulphides (25-30% mono-pyrrhotite, pentlandite, pyrite, chalcopyrite, cubanite). Xenolithic material up to 3 m in size amounts to 30% of the pipes and includes unmineralised troctolite-anorthosite fragments, similar to those of Unit V. The ore host pegmatoidal bodies and barren bronzitite pipes appear to have formed from residual liquids from crystallisation, derived from the Unit V rocks and subsequently been forcefully emplaced during a period of quiet deformation.

The Carr Boyd Rock Intrusion is also characterised by its complex structural setting, intricate cyclic layering, absence of cryptic layering, and the presence of high pressure crystallisation features (crystallisation depth estimated at 23-26 km). The layered sequence is believed to be derived from a tholeiitic magma which progressively became richer in normative plagioclase and poorer in normative orthopyroxene.

The Carr Boyd mineralised pegmatoids show similarities to the envelopes of olivine-bronzite-plagioclase pegmatoids that encase the high grade PGE dunite pipes of the Bushveld Complex (see section 1.1(iv). In the Onverwacht region of the East Bushveld, the pipes consist of a central 20 m diameter zone of hortonolite dunite (Fo_{22}) which taper downward and is encased within a 100 m diameter zone of olivine dunite (Fo_{80-92}). The scale, geometry, pegmatoidal character, mineralogy and envelope olivine compositions appear to be similar in both complexes. Genetic interpretations however appear to differ with the Bushveld pipes resulting from replacement of bronzitite by hot aqueous leaching solutions. Another possible connection with the Bushveld Complex is that the pegmatoids from the Vlakfontein district

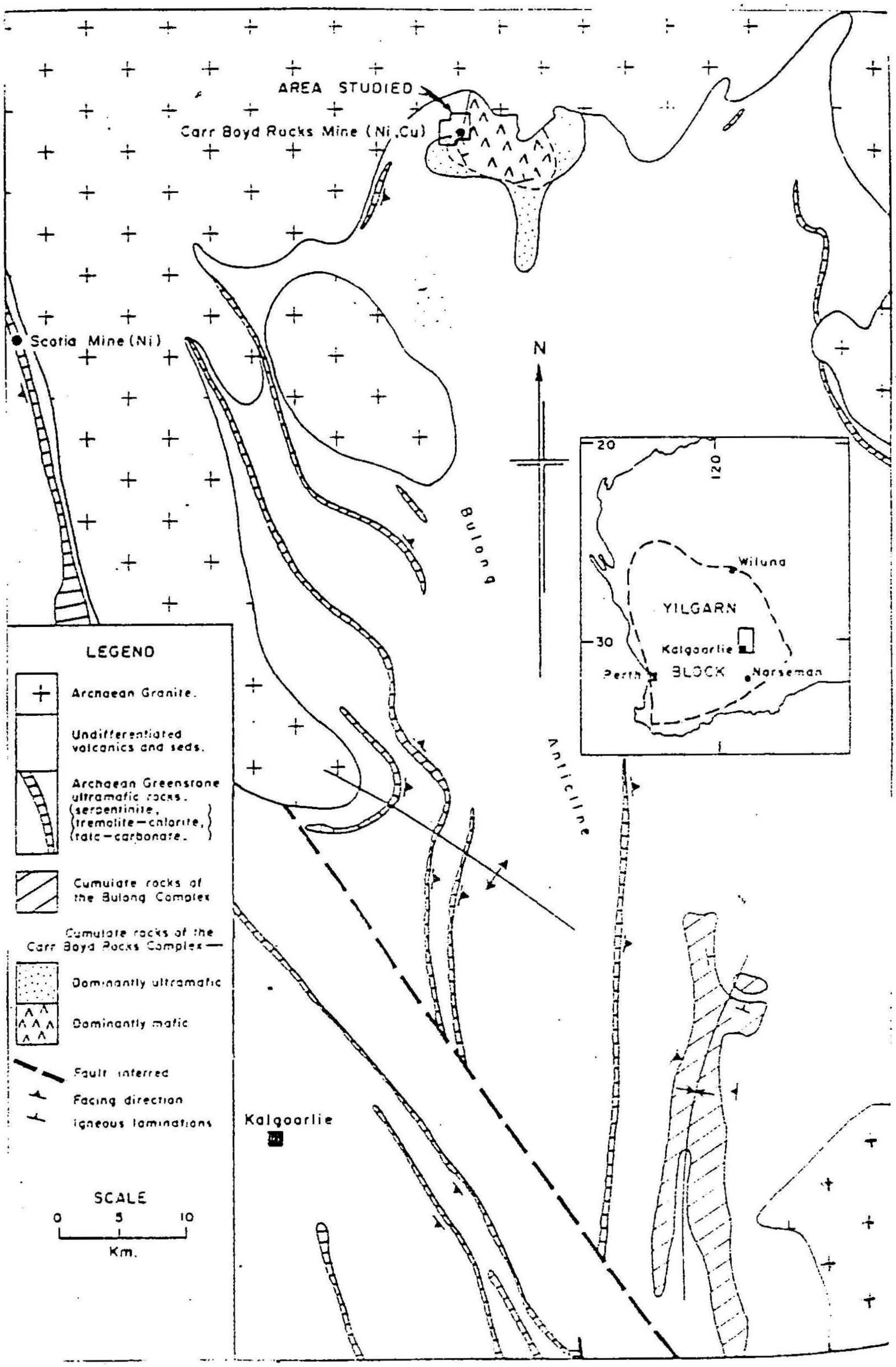

Figure 27. General geology of the area between Kalgoorlie and Carr Boyd Rocks. Reproduced, with permission from Purvis and others (1972).

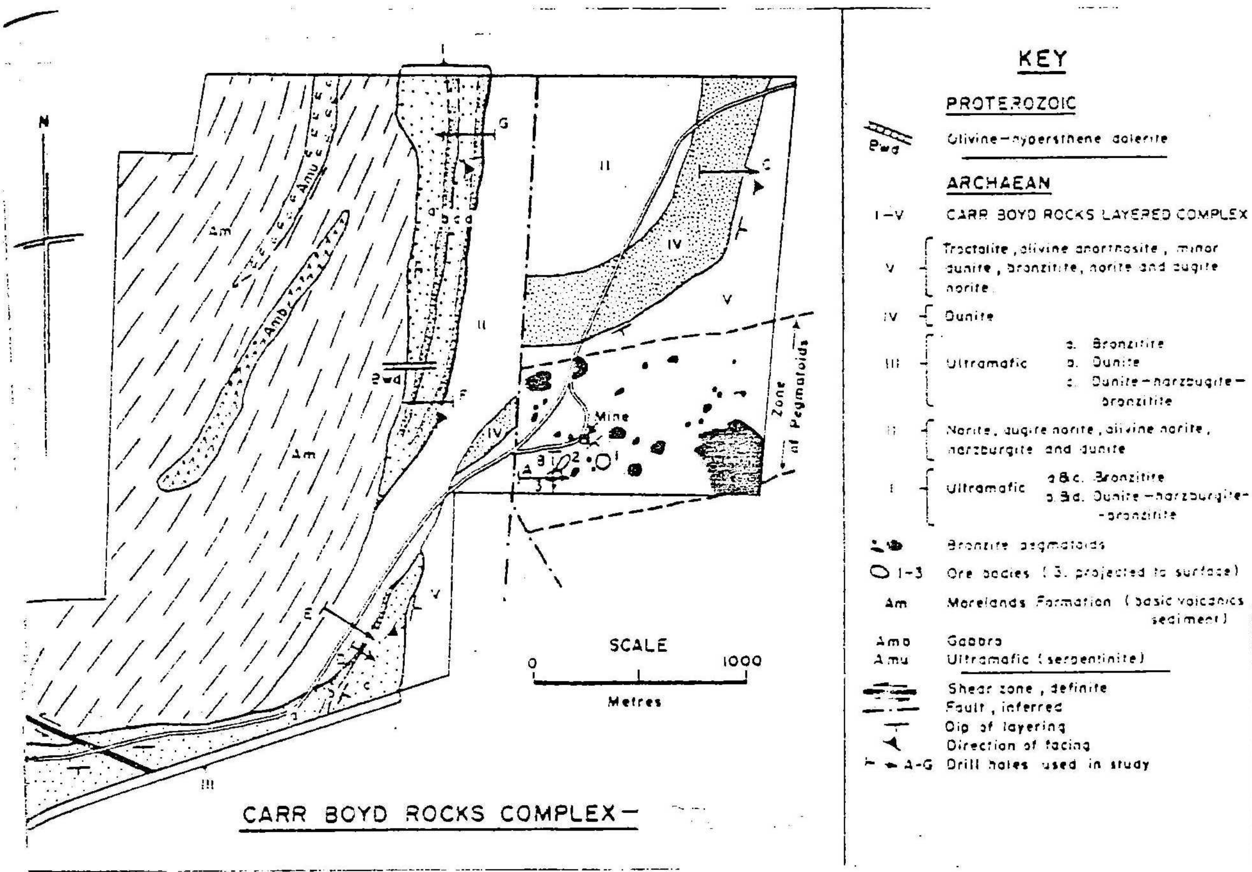

Figure 28. Geology of protion of the Carr Boyd Rocks Complex. Reproduced, with permission from Purvis and others (1972).

are structurally similar, with the ore bodies also being associated with norite-pyroxenite pegmatoids. Similarly the Cu/Cu + Ni ratios are comparable for both regions, 0.2 for Carr Boyd and 0.217 for Vlakfontein for nickel grades less than 3%.

Despite the broad setting of the Carr Boyd Rocks Complex showing deviations from the Bushveld type model, i.e. age, scale, tectonics, absence of extensive gabbroic type rocks, the "unique" form of PGE mineralisation associated with bronzite pegmatoidal pipes, among other styles should be investigated at the Carr Boyd Mine and within the faulted pegmatoidal zone, further to the east.

6.10 Bulong Complex (Williams, 1970: Baxter, 1978)

The Bulong Complex is a long linear zone of mafic-ultramafic rocks, located 30 km east of Kalgoorlie. This north-south trending complex extends over 37 km along strike, from 6.5 km northwest of Mt Monger Homestead to the Unknown Mine on Hampton Hill Station (see Figure 27 and Kurnalpi 1:250 000 Geological BMR-GSWA Sheet). The Complex intrudes both the Morelands (basic volcanic association) and Gindalbie (acid volcanic-clastic association) Formations of Archaean age.

The shape of the Bulong Intrusion is believed to be largely controlled by the regional foliation of host rocks in the north and the Mount Monger Fault to the south. The eastern side is sheared. The Complex often bifurcates along strike into various limbs. Williams considers it to be a multiple intrusion with a boat shaped form, consisting of a number of sills intruded either simultaneously or consecutively. Thickness is believed to be in the order of 4,600 m. The composition of the bodies range from serpentinized peridotite, dunite, pyroxenite, through to gabbro and diorite. There is a pronounced layering within individual intrusions and cumulus textures are present. Cross bedded textures indicate a west facing for the eastern limb of the Complex.

Chromite mineralisation (Lat. 30°46'11"S, Long. 121°50'17"E) occurs at the base of a norite intrusion, and consists of a zone 15 to 20 cm wide, traceable over 1 km along strike. The chromite is accompanied by serpentine.

The Hampton Complex located 4 km west of the similar Bulong Intrusion is discontinuous over 47 km strike length and follows a prominent north-south lineament. The Hampton Complex does differ from the Bulong in that it is largely serpentinised peridotite and dunite of 1000 m thickness. The two bodies are believed to be genetically related.

6.11 Other Potential Complexes within the Yilgarn

Other layered mafic-ultramafic complexes which are believed to hole some potential for stratiform type PGE mineralisation, include:

- Mt Venn Complex (north edge of Rason SH/51-3 sheet) - Although absence of olivine dominant lithologies downgrades this prospect.
- Cullculli Hill (Cue SG/50-15 Sheet).
- Lake Medcalf (Ravensthorpe SI/51-5 Sheet)
- Barrambie-Gabanintha trend (Sandstone SG/50-16).

CONCLUSIONS

Platinum Group production within Australia has been confined largely to the Palaeozoic ultramafic belts of the Tasman Geosyncline, of Eastern Australia. Thin structurally emplaced serpentinite, serpentinised peridotite bodies of Alpine Podiform type, define a tight geographical distribution from southwest Tasmania to northern Queensland. Recognition of these mineralised bodies has been related in most cases to the initial identification of an associated placer deposit, with subsequent mining concentrating on the alluvial rather than the lode source. The Fifield (Pt) district of central New South Wales and Adamsfield (Os) southwest Tasmania have dominated PGE production, with total eastern Australian platinum production being 595.4 kg, and 909.1 kg of osmiridium to 1961 (McLeod, 1965). Production since 1961 has been negligible.

Platinum Group mineralisation within the Archaean and Proterozoic of Australia is rare, and where present of low tenor. Platinum-chromite mineralisation is known within basal ultramafic differentiates of tectonically disturbed Lower Proterozoic intrusive gabbro sills of the Halls Creek Mobile Zone (Panton, Lamboo, and Eastman's Bore Prospects) and platinum-palladium are common accessories to the copper-nickel sulphide deposits of the Yilgarn, Eastern Goldfields Province.

On a world scene, it is the large stratiform layered mafic-ultramafic intrusive complexes suhc as Bushveld-Transvaal, Stillwater-Montana and Lac des Iles - Ontario which dominate world PGE reserves. Despite these complexes displaying great variability in detail, several features relating to age, tectonic setting, scale, etc. are common, and collectively provides a useful tool for narrowing in on favourable provinces. These PGE hosted layered complexes are characterised by: a thick stratigraphical succession (mafic-ultramafic component at least 5-6 km thick) of diverse lithologies which include harzburgite, orthopyroxenite, websterite, norite, gabbro, anorthosite, granophyre and dolerite among others, and display great lateral continuity; prominent cumulate-layering features, i.e. rhythmic, phase, cyclic and cryptic; age of emplacement being pre-1000 m.y. with the larger deposits pre-2000 m.y. within stable Precambrian terrains, or basaltic terrains of any age; form is generally of lopolithic sill or basinal type of great lateral extent; and economic deposits include chromite, vanadiferous magnetite, copper-nickel sulphides, native platinum, platinum sulphides. PGE distribution is generally within the lower more magnesian (iron-poor) parts of the stratigraphy and often shows a close spatial association with chromite, but not necessarily a sympathetic relationship in tenor. Horizon prediction of PGM concentrations cannot be generalised, with the larger deposits showing different sytles both between and within the one complex, i.e. juxtaposition of olivine cumulates with overlying plagioclase cumulates, with chromitite bands, and dunitic pipes (Bushveld); interface of feldspathic clinopyroxene and orthopyroxene cumulates (Great Dyke of Zimbabwe); within cyclic olivine-pyroxene cumulates (Stillwater) and nickeliferous norite-clinopyroxenite layers (Lac des Iles).

Three factors believed to be critical for the formation of PGE-chromitite horizons within layered intrusive complexes are:

(i) A large volume of magma, i.e. at least 200 km^3. Since the average abundance of platinum within ultramafic rocks is 0.051 $\pm$

0.045 ppm (Yushka-Zakharova & others, 1967) and most mines operate at 5 ppm (min.), a concentrating factor of ≃100 is required. With a greater mafic (0.02 ± 0.009 ppm av. Pt), felsic (0.007 ppm av. Pt) component in the parental magma the concentrating factor increases considerably.

(ii) high sulphur content of parental magma, by either assimilation of country rock or mantle derived is important since the sulphides act as collectors-precipitators for PGE. The transformation of precious metals into sulphide type complexes needs to be an efficient, near equilibrium process.

(iii) the parental magma must have PGE-Cr metal character.

Many of the layered mafic-ultramafic intrusions of the Archaean-Proterozoic terrains of Australia such as the Yilgarn, Pilbara, Halls Creek, Musgrave etc. display similar features to the overseas complexes, however there are some significant differences. They include:

(i) The dominance of gabbroic type lithologies over the ultramafic component (this may not be a great shortfall since the Lac des Iles deposit has a gabbro content in the mineralised stratigraphy of 70% volume).

(ii) Poor development and paucity of widespread rhythmic and cyclic layering throughout the stratigraphy, particularly in the Archaean complexes.

(iii) Scale, both in area and thickness. Apart from the Windimurra Complex (thickest intrusion known, at ≃ 8.5 km) some Giles Intrusions (around 6.0 km) and Munni-Munni of the Pilbara (5.5 + km) the stratigraphic mafic-ultramafic thickness rarely exceeds 3 km. This factor probably controls point (ii) to a degree.

(iv) level of sulphur saturation within parental magma appears to be low as shown by the scarcity of major nickel-copper sulphide deposits within the layered tholeiitic complexes. The Carr Boyd Rocks Complex is an exception.

(v) Absence of titaniferous-vanadiferous magnetite and chromitite zones occurring within the one complex.

Greatest platinum potential within Australia appears to exist within three distinct geological settings: the Palaeozoic serpentinite belts of the Tasman Geosyncline, stratiform layered mafic-ultramafic intrusive complexes of stable Archaean-Proterozoic Blocks and tectonically disturbed layered complexes of Proterozoic Mobile Zones. Of the three settings, the alpine podiform types of Eastern Australia are believed to hold the least potential for a new major deposit, since they have a relatively high degree of predictability about their potential distribution due to their well defined geographical belts, associated placer deposits, and topographically high relief. Deposits are also of low tonnage status and dependent on associated minerals for economic mining.

Greater potential appears to exist within the variably deformed layered mafic-ultramafic complexes of Western and Central Australia. Most complexes can probably be discounted on magma volume criteria, however some of the thicker higher pressure central intrusions of the Giles Complex, grabbro-anorthosite complexes of the Yilgarn, i.e. Windimurra, Barrambie-Gabanintha trend, and the Munni Munni Complex of the Pilbara warrant investigation for PGE mineralisation. The occurrence of stratiform PGE-chromite mineralisation at Panton Sill and the difficulty of recognising favourable complexes in highly deformed terrains (i.e. precluding early identification by prospectors/private companies) suggests the Halls Creek-King Leopold Mobile Zone may be favourable for tectonically dismembered type PGE mineralisation.

The apparent association of intracontinental rift zones and Lower Proterozoic dolerite dyke swarms within both orogenic and stable basinal environments of northern Australia indicates these areas may be prospective for Noril'sk-Talnakh West Siberia, Duluth-Minnesota type PGE mineralisation (feeder dykes to flood basic volcanism which are associated with intracontinental rifting). Their thin sill-like form, fault related distribution, continental tholeiitic types (of subalkaline character) internal differentiation and layering, level of intrusion, association with sulphur bearing country rock suggests the Zamu, Roper River-Urapunga-Mount Marumba Dolerites, and in particular the Oenpelli Dolerites may be favourable for this unique form of PGE mineralisation within the Pine Creek Geosyncline and McArthur River Basin. The Woodward Dolerites of the Kimberely region do not appear to be as prospective due to their limited differentiation, more massive character, higher metamorphic grade and paucity of sulphur bearing intruded country rock.

Due to their similarity with occurrences in the Bushveld Complex - South Africa, bronzite pegmatoidal dunite pipes within some of the smaller tholeiitic layered complexes of the Eastern Goldfields Province, i.e. Carr Boyd Rocks should be investigated for Pt-Fe alloy dominant mineralisation. These pipes which show both stratigraphical and structural controls at Carr Boyd, are known to be high grade and widespread throughout both the eastern and western portions of the Bushveld.

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SD/53-14 Hodgson Downs, SD/53-15 Mount Young, SD/53-11 Roper River, SD/53-10 Urapunga, SF/53-11 Huckitta, SE/55-9 Einasleigh, SE/55-5 Atherton.
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Appendix Table 15

Company Statutory Reports on Mineral Exploration in Western Australia to 23 October 1982 (source GSWA Microfilm Rolls)

M File No.	Project Name	Principal Source	Duration of Operations	Location 1:250,000 with 1:100,000 Component i.e. 1 2 3 / 4 5 6	Principal Commodity BM - Bassmetals	Drilled D - Drilled CD - Core Drilled
M 1756	Harris River	Alcoa	1974	Pinjarra 5 Collie 2	V	-
M 2013	Mt Gnanagooragoo	C.R.A.	1976	Belele 5	Cr	-
M1797	Eastmans Bore	Union Corp	1974-1975	Mt Ramsay 5	Ni, Cu, Pt. B.M.	-
M965/1	Plumridge Lakes	Mineral Search	1970-1972	Plumridge 1,4	BM,Ni, Cu, Cr	D
M965/2	Plumridge	Amax	1970-1972	Plumridge 4	BM, Ni, Cu, Cr	-
M1996	Byro-Melun Well	WMC	1976-1979	Byro 2 Glenburgh 5	Cr	D
M1997	Erong & Innouendy	WMC	1976-1977	Glenburgh 5 6	Cr	D
M1998/1	Trilbor-(Mt Seabrook)	WMC	1976-1978	Robinson Range 4, 5	Cr	D
M2088	Mt Ramsay 4	Kennecott	1976-1978	Mt Ramsay 3,6	Cr,BM,Ni,Cu,Au Pt	D
M2384/3	Mini M and Tago 5	Anglo	1978-1979	Dixon Range 4	Cr, BM,Ni, Cu	-
M299	Byro	E.Z.	1969-1972	Byro 2	Cr	CD
M631	Corrigin-West Bendering	E.Z.	1969-1973	Corrigin	BM, Ni, Cu, Cr	CD
M1225	Taccabba Well	Pasminex	1972-1974	Byro 3	BM, Ni, Cu, Cr	CD
M2555	Bolgart	Hamersley/ CRA	1977-1979	Perth 2	V	CD
M1725	Windimurra	Hawkstone Minerals	1968-1975	Kirkalocka 3 Youanmi 1	BM, V, Ti	CD

Appendix Table 16

M File No.	Project Name	Principal Source	Duration of Operations	Location	Principal Commodity	Drilled
M2121/4	Wongi Hill	WMC	1979-1980	Kalgoorlie 2	Cr	-
M2224	Yamama etc.	CRA	1977-1978	Rason 2	Cr	CD
M2658	Blackwood	WMC & ARMCO	1978-1981	Collie 5 Pemberton 2	Cr	D
M2975	Bulong	Metals Ex.	1982	Kurnalpi 4	Cr	
M2770	Pear Creek	General Mining	1970-1974	Port Hedland 6	BM, Ni, Cu, Cr	D