# THE MINERAL POTENTIAL OF LAYERED IGNEOUS COMPLEXES WITHIN THE WESTERN GNEISS TERRAIN

by P. H. Harrison

ABSTRACT

Geological and geophysical evidence suggests that remnants of large basic/ultramafic layered complexes are present in several parts of the Western Gneiss Terrain. Various lines of evidence indicate that these rocks are some of the oldest preserved within the Western Gneiss Terrain. In spite of this, many are relatively undeformed and show only greenschist-facies assemblages. The rocks appear to be derived from a magma which had tholeiitic affinities; and they are considered to have potential for mineral deposits of the types normally associated with large tholeiitic layered intrusions. This includes potential for copper-nickel, chromite, titaniferous vanadiferous magnetite and platinum-group metals mineralization.

## INTRODUCTION

In the course of studies directed towards a future bulletin on the potential for platinum mineralization within Western Australia, occurrences of basic* and ultramafic rocks and various mineral prospects in the Western Gneiss Terrain have been examined. These studies suggest that some, at least, of these occurrences are remnants of—formerly more extensive—large layered intrusions. These intrusions appear to be some of the oldest rocks preserved in the Western Gneiss Terrain. The individual remnant bodies appear to be much more extensive than has previously been recognized.

## REGIONAL SETTING

The Western Gneiss Terrain (Gee, 1979) is that older, western part of the Yilgarn Block which has undergone polyphase medium- to high-grade metamorphism. This contrasts with generally lower grade metamorphism in the granitoid-greenstone terrain which forms most of the block.

Voluminous granitoids with whole-rock Rb-Sr ages of 2.6 to 2.7 Ga intrude both the granitoid-greenstone and gneiss terrains. In the case of the Western Gneiss Terrain, these granitoids intrude rocks of (dominantly) sedimentary and igneous composition which have reached metamorphic grades of amphibolite to granulite facies (Wilde, 1974).

The gneisses have been derived from rocks which span a period of geological history of close to 1 000 million years. In the north, protoliths of the gneisses at Mount Narryer have given Sm-Nd ages of 3.63 Ga and 3.51 Ga (de Laeter and others, 1981); in the central part of the Western Gneiss Terrain, the protoliths of the granofelsic paragneisses of the Chittering Metamorphic Belt have given Sm-Nd ages of 2.76 Ga and 2.89 Ga (Fletcher, and others, 1985). The absolute age range will probably be shown to be even greater than this, as ion probe U-Pb dating of zircon grains from quartzites at Mount Narryer has given clusters of ages around 3.75 Ga, 3.65 Ga, 3.4 Ga and 3.3 Ga (de laeter and others, 1985) and zircon ages of 4.1 Ga and 4.2 Ga have been obtained from orthoquartzites (Froude and others, 1983). This suggests that older protoliths may yet be found.

Several metamorphic belts, composed dominantly of schist and paragneiss of largely sedimentary origin, have been described within the Western Gneiss Terrain. The main belts are the Narryer (Williams and others, 1980), Jimperding and Chittering (Wilde, 1974), and Balingup (Wilde and Low, 1978) Metamorphic Belts (Fig. 1).

### METAMORPHIC BELTS

In the Narryer, Jimperding, and Balingup Metamorphic Belts, the dominant rock is banded quartz-feldspar-biotite gneiss. While some of these gneisses may be orthogneiss derived from granitoid rocks, or pre-existing migmatites, the majority, from field evidence, appear to be derived

* The term 'basic' rather than 'mafic' is used in this paper, as anorthosites form a significant component of the sequences which are discussed.

from quartzo-feldspathic sediments. The paragneisses are associated with quartz-magnetite-amphibole rocks (metamorphosed banded iron-formation) and with orthoquartzites with well preserved cross-bedding. Gee (1979) suggested that these mature sediments originated from stable-shelf sedimentation.

In the Chittering Metamorphic Belt, on the other hand, a major rock type is quartz-feldspar-cordierite-biotite-garnet granofels. This is con-

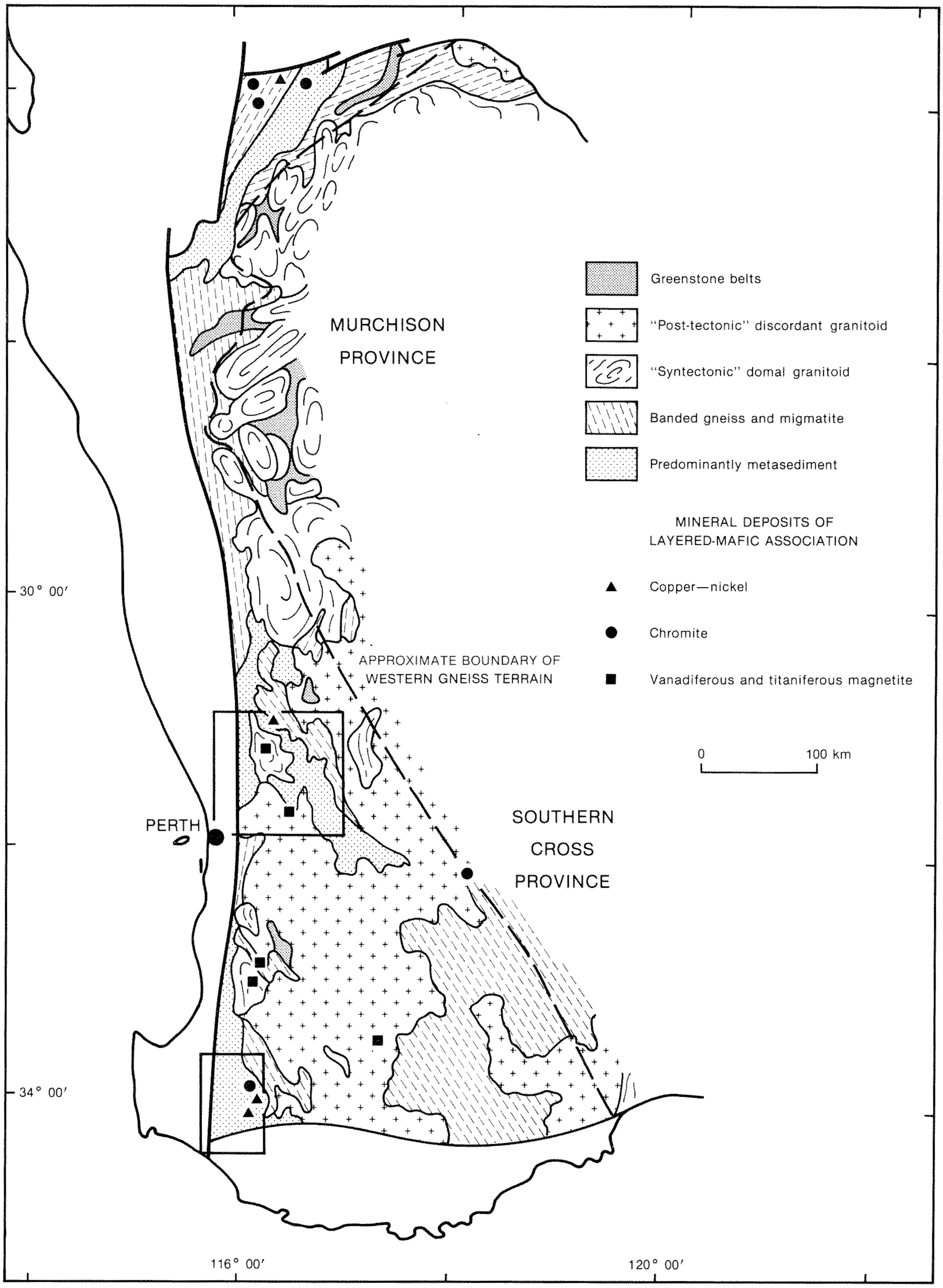


**Figure 1. A simplified geological map of the Western Gneiss Terrain, showing the location of the main metamorphic belts, mineral occurrences of a possible layered-basic origin, and areas discussed in detail in this paper.**

sidered to be metagreywacke and to indicate a greywacke-flysch type of sedimentation, less mature than in the other belts. Gneiss developed from this second facies also seems to be present, together with the shelf facies, in the Balingup Metamorphic Belt. Extensive remnants of a probable fifth metamorphic belt, of mainly Jimperding type, are present in the eastern part of the Western Gneiss Terrain on the Dumbleyung, Corrigin, and Kellerberin 1:250 000 sheets. This belt has not been formally named.

Amphibolites and/or mafic granulites, as small intrusive bodies, have been reported from all of the belts. Bodies of ultramafic rocks of various types have been identified in each of the metamorphic belts with the exception of the (younger) Chittering Metamorphic Belt.

A number of mineral occurrences, of a type normally associated with layered basic intrusive rocks, have been reported from within the Western Gneiss Terrain. The locations of these occurrences, taken from the map "Mineral Deposits of Western Australia 1981" together with additional information from Mines Department records, are shown on Figure 1, which also shows the locations of two areas examined in more detail below.

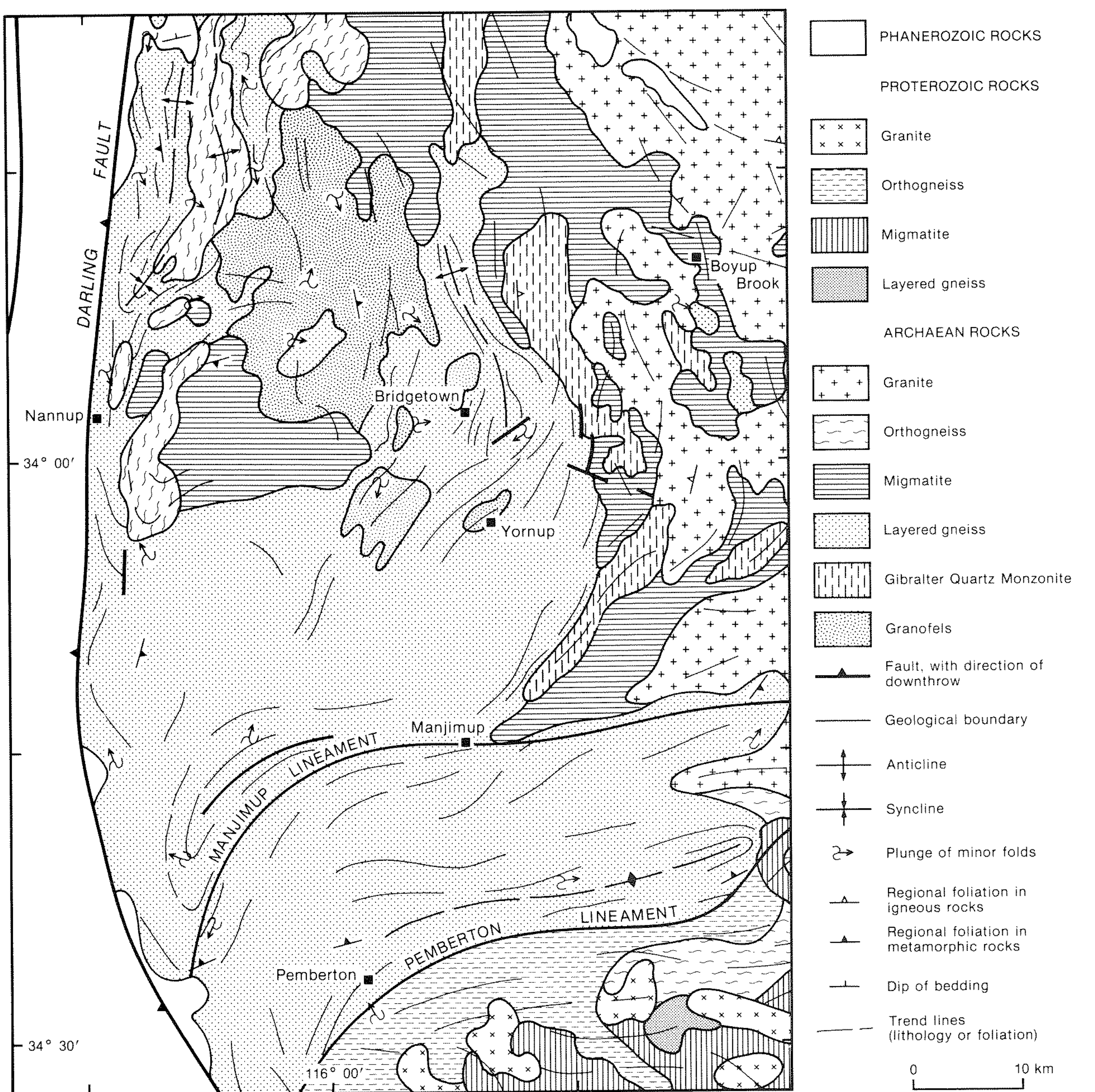


**Figure 2. Generalized geology of the southern part of the Balingup Metamorphic Belt. Modified from Wilde and Walker (1979, 1981) and Fletcher and others (1983).**

## BALINGUP-BRIDGETOWN-DONNELLY RIVER AREA

The main elements of the geology of the southern part of the Balingup Metamorphic Belt, as interpreted from the very limited outcrop information, are shown in Figure 2. Here the paragneiss sequence appears to include both "shelf" and "trough" facies of the "Jimperding" and "Chittering" types; the relationships of which in this case, are not clear. A particular feature of the Balingup Metamorphic Belt is the high proportion of granitic orthogneiss (perhaps 30% of the total) which has intruded and subsequently been infolded with the paragneiss sequence.

Amphibolite and ultramafic rocks, described by Wilde and Walker (1979, 1981) as small lensoid occurrences, are present within the gneiss sequence. They apparently increase in proportion southwards and are most abundant in the area east of Bridgetown and near to Yornup (Fig. 3). This apparent increase may merely be a function of the better exposure in the more deeply incised area of the Blackwood River drainage system. A number of ultramafic units are also present in a belt from west of Balingup to north of Nannup.

South of a line between Yornup and Nannup, the belt is largely obscured by laterite and scattered areas of Tertiary sedimentary rock.

The Balingup Metamorphic Belt is structurally complex. It has undergone a number of periods of deformation and has been metamorphosed to amphibolite facies (with localized areas of granulite-

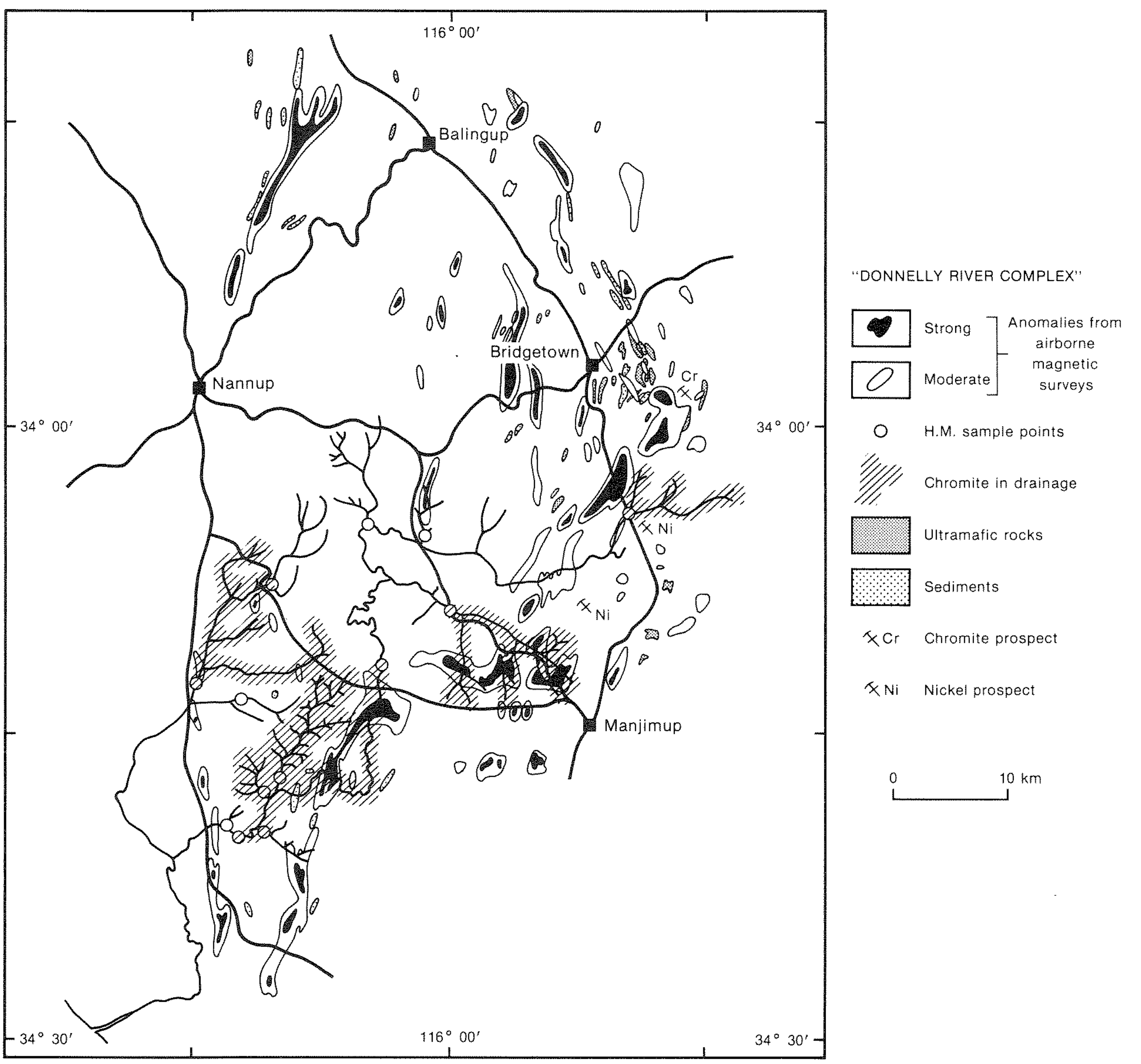


**Figure 3. The locations of drainages in the Donnelly River Basin which contain chromite, compared with magnetic anomalies from airborne surveys and the mapped occurrences of ultramafic rock. (This figure covers the same area as Figure 2).**

facies metamorphism). There is some suggestion of a regional doming around a large area of migmatite to the east of Nannup. The Manjimup Lineament corresponds closely with a change of lithological and structural trends: to the north of the lineament these are generally northerly; to the south, easterly and northeasterly trends are dominant. The Pemberton Lineament marks the southern limit of the Balingup Metamorphic Belt *sensu stricto*, as south of the lineament the gneiss appears to comprise orthogneiss of Proterozoic age (Fletcher and others, 1983).

A number of mineral prospects are known to be associated with the ultramafic rocks of the Balingup Metamorphic Belt.

At the Yornup prospect (34°11′50″S, 116°30′40″E) in the early 1970s, Planet Management and Research Pty Ltd completed 13 diamond-drill holes to test geophysical and geochemical anomalies associated with an area of lateritized and silicified ultramafic rocks. These holes encountered serpentinized peridotite and pyroxenite (and schistose talc-chlorite-anthophyllite derivatives) associated with metamorphosed norite and leuconorite. Disseminations and veinlets of pyrite, pyrrhotite, pentlandite, chalcopyrite, cubanite, bravoite, and rare millerite, were present; but the total amount of sulphide was very small and nickel assays rarely exceeded 0.3%. Planet also tested lateritic enrichments of nickel at Yornup and at the Palgarup prospect (34°13′20″S, 116°08′15″E). The best intersection, however, was only 0.83% nickel over 8.8 metres (Marston, 1984).

Outcrops of chromitite in ultramafic rocks occur close to the Blackwood River, approximately 6 km east of Bridgetown (Western Australian Government Chemical Laboratories, Annual Report for 1979).

Simpson (1914) reported that a prospector had submitted a sample of mineral concentrate from "24 miles (39 km) south of Nannup on the left-hand branch of the Donnelly River", in the general area of the present Vasse Highway. This sand sample, which was composed largely of cassiterite and monazite, carried highly anomalous quantities of platinum and assayed 8 910 g/t (291.05 oz/ton) platinum, 1681 g/t (54.90 oz/ton) osmiridium and 1 061 g/t (34.65 oz/ton) gold. At that time, ultramafic rocks were not known from within the Donnelly River Drainage basin. Saint-Smith (1912) noted that the sample closely resembled platinum-bearing beach sands which were then being mined on the northern coast of New South Wales.

## "DONNELLY RIVER COMPLEX"

The general area of the platinum occurrence reported by Simpson has recently been examined by the writer. Heavy-mineral samples were panned from the Donnelly River and various tributaries. These were further concentrated by tetrabromoethane heavy-media separation, and classified using a Frantz magnetic separator before microscopic examination. The distribution of the sampling points, shown in Figure 3, was dictated by forest tracks and quarantine regulations. No platinum, platinum-group minerals, gold, or cassiterite were found in any of the samples; however, several did contain chromite (Ahmat, 1983a). The drainages from which chromite was reported have been indicated on Figure 3, together with the mapped outcrops of ultramafic rocks (and the orthoquartzites and metamorphosed banded iron-formations which are frequently associated with them). Superimposed on Figure 3 are the locations of magnetic anomalies, which have been empirically interpreted from several semi-detailed airborne magnetic surveys that are held in Mines Department "M series" records and from Bureau of Mineral Resources 1:250 000 scale magnetic maps.

The close association between the magnetic anomalies and ultramafic rocks in the areas of outcrop, and between the magnetic anomalies and drainages that contain chromite, is considered to indicate that extensive bodies of ultramafic and basic rocks, similar to those near Bridgetown and Yornup, are present below the laterites of the Donnelly River area. This belt of ultramafic and basic rocks is here informally termed the "Donnelly River Complex".

Exposed parts of the complex in the Bridgetown-Yornup area, and a number of samples of drill material from drill holes near Yornup, have been examined in an attempt to ascertain the nature of the rocks involved.

Most of the ultramafic rocks show greenschist-facies assemblages in areas of predominantly amphibolite-facies assemblages. For this reason they were regarded by Wilde and Walker (1981) as having been intruded after the amphibolite-facies metamorphism. East of Bridgetown, however, drilling carried out by Western Mining Corporation (W.M.C.) showed that the ultrabasic bodies are themselves intruded by granitic rocks (Mazzucchelli, 1981). It appears probable that the latter are either granitic phases of the Gibralter Quartz Monzonite or orthogneiss related to the Logue Brooke Granite; both of these rock units have themselves been affected by the amphibolite-facies metamorphism, which has been dated at

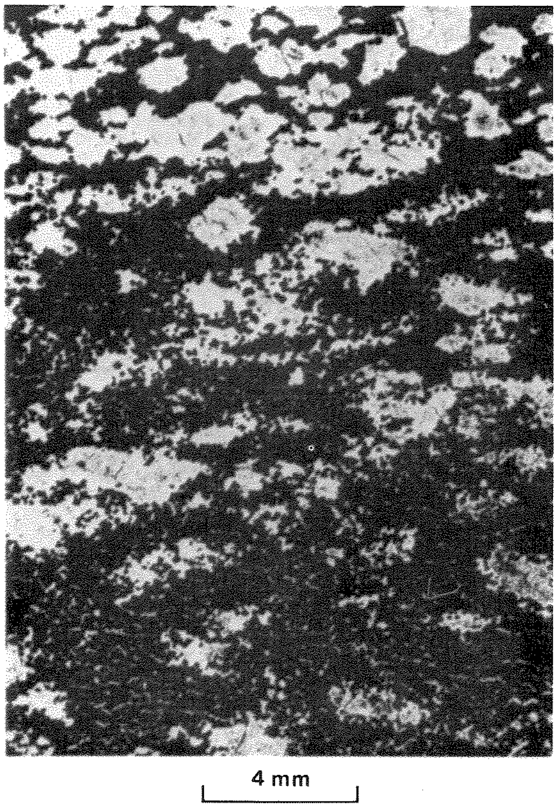


**Figure 4. Chromite-rich metadunite from near Bridgetown. A relic cumulate texture after olivine — now replaced by serpentine and chlorite — is outlined by chromite grains. (Sample 78128. Field of view 20 mm. Plane-polarized light).**

2.84 ± 0.20 Ga (D. A. Nieuwland, pers. comm., 1977; Fletcher and others, 1983). Cuttings taken from holes drilled by W.M.C. near Yornup (G.S.W.A. sample 78140) show retrograde greenschist-facies metamorphism of tremolite-olivine rocks previously at mid-amphibolite facies (Ahmat, 1983b). This demonstrates that the Yornup ultramafic bodies, at least, pre-date the amphibolite-facies metamorphism.

Nevertheless, many of the ultramafic bodies examined are relatively undeformed and show well-preserved primary igneous textures which suggest that they have never been above greenschist facies. It appears probable that the central parts of these relatively thick, competent, and anhydrous bodies, which are composed of high-temperature minerals, have been shielded from many of the thermal and dynamic effects of the amphibolite-facies metamorphism. Further evidence of this shielding effect was noted in the field. In the Bridgetown area, a number of the bodies are "rimmed" by foliated talc-chlorite-serpentinite rocks. In the Palgarup area, anthophyllite-talc schist appears to be a more deformed equivalent of nearby ultramafic rocks (Wilde and Walker, 1981).

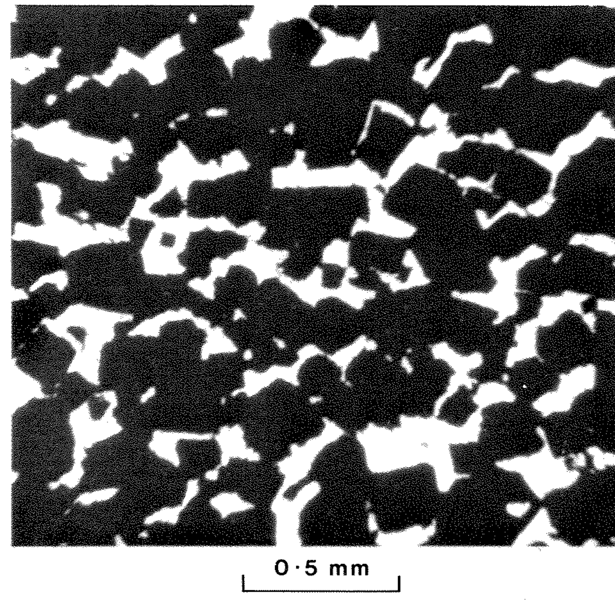


**Figure 5. A chromitite layer from near Bridgetown. The chromite grains show a well-developed "chain-link" texture. (Sample 78128. Field of view 2.5mm. Plane-polarized light).**

A number of the undeformed rocks sampled near Bridgetown show relic cumulate textures of elongate olivine grains—now replaced by chlorite and serpentine—outlined by chromite (Fig. 4). The chromitite horizons show well-developed "chain-link" textures indicative of primary igneous layering (Fig. 5).

Analyses of a number of chromitites and the host metadunites are presented in Table 1.

TABLE 1. ANALYSES OF CHROMITITES AND AN ULTRAMAFIC ROCK FROM NELSON LOCATION 575 (EAST OF BRIDGETOWN)

| *Sample* | *78125* | *78127* | *78129* | *78131* |
|---|---|---|---|---|
| | | *Percentage* | | |
| Fe(total) | 31.6 | 27.6 | 30.8 | 14.2 |
| $Cr_2O_3$ | 22.0 | 33.6 | 26.8 | 6.58 |
| FeO | 19.5 | 20.5 | 19.2 | 9.34 |
| $SiO_2$ | 11.6 | 6.83 | 9.03 | 31.6 |
| $Al_2O_3$ | 5.24 | 8.24 | 6.77 | 3.29 |
| MgO | 11.4 | 8.72 | 9.73 | 28.5 |
| | | *Parts per million* | | |
| Cu | 44 | 28 | 44 | 39 |
| Ni | 2000 | 1400 | 1800 | 2000 |
| Pt | <[0.04] | <[0.04] | <[0.04] | <[0.04] |
| Pd | <[0.005] | <[0.005] | <[0.005] | <[0.005] |

Analyses for platinum-group metals by Kalgoorlie Metallurgical Laboratory using a specially developed fire-assay method. Other analyses by the Government Chemical Laboratories.

78125, 78127, 78219, are channel samples of chromitite. 78131 is a serpentinized metadunite.

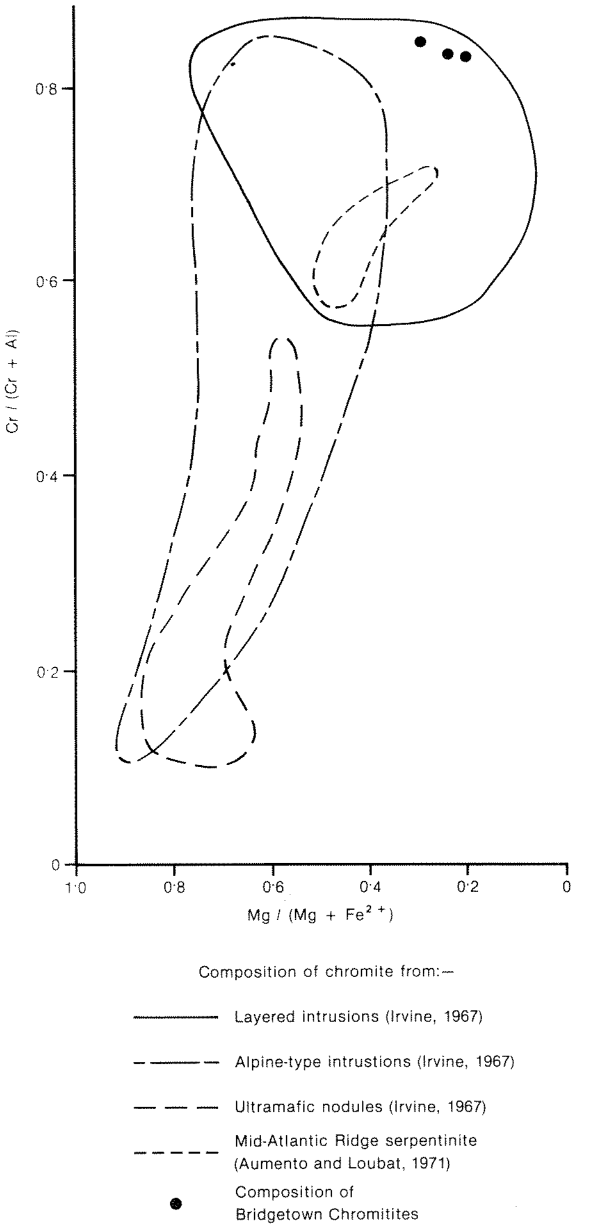


**Figure 6.** **Composition of chromitites from Bridgetown compared with the compositional fields of chromite from layered-intrusive complexes, alpine-type ultramafic bodies and deep-ocean serpentinites.**

An examination of the Cr/(Cr+A1) versus Mg/(Mg+Fe) ratios of these chromites (Fig. 6) supports an origin in a layered intrusion. A plot of the $Al_2O_3$ versus FeO/(FeO+MgO) ratio (Fig. 7) suggests that the magma had a tholeiitic rather than a komatiitic affinity. However, these data have to be treated with some caution as ferritchromit alteration—the replacement of the rims of the chromite grains by magnetite, (Fig. 8)—suggests that during metamorphism, under high $pO_2$ conditions, there has been some migration of chromium and magnesium from the chromite into chromium-bearing magnesian chlorites which replace the former olivine grains.

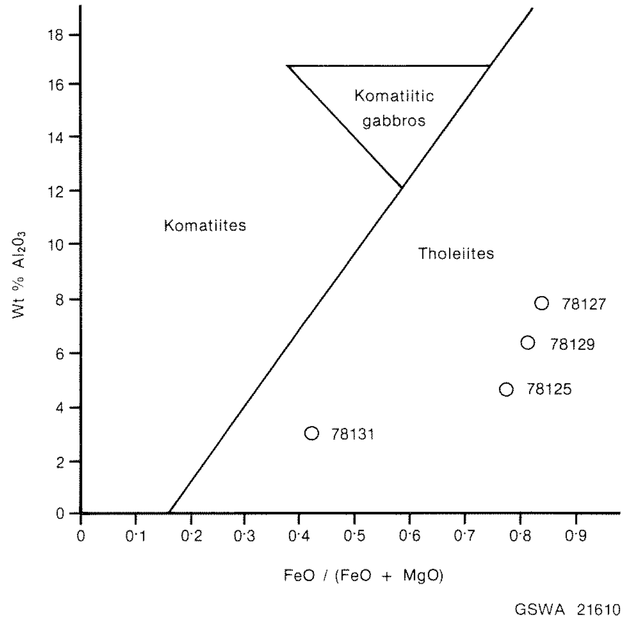


**Figure 7.** **Bridgetown rocks plotted on chemical-variation diagrams for $Al_2O_3$ versus FeO*/(FeO* + MgO) constructed after Naldrett and Cabri (1976) and Naldrett and Goodwin (1977). FeO* = Total Fe as FeO.**

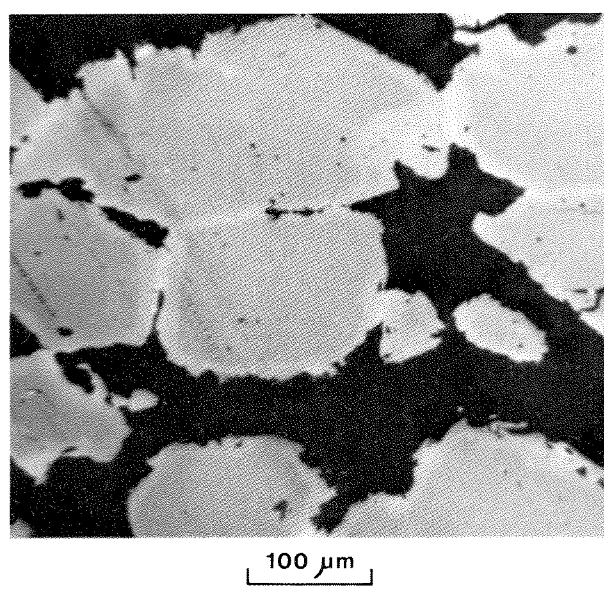


**Figure 8.** **Chromitite from near Bridgetown showing ferritchromit alteration of chromite grains: alteration of the rims of grains to magnetite. (Sample 78128. Field of view 625 microns. Reflected light).**

*Potential for mineralization*

The combination of the evidence suggests that the "Donnelly River Complex" is a series of remnants of one, or more, layered tholeiitic intrusions. The recognition of chromitite horizons in the area east of Bridgetown, together with the extensive presence of detrital chromite in the drainage samples, suggest a considerable potential for minable deposits of chromite. The economically detrimental ferritchromit alteration, caused by the metamorphism (resulting in an increase in the $FeO:Cr_2O_3$ ratio), means that exploration should be restricted to the central, less altered, parts of the larger ultramafic remnants, where higher grade chromite may still be preserved.

The unusually low values in the analyzed samples suggest that the magma, at the time of formation of the Bridgetown chromitites, was deficient in the platinum-group metals. This downgrades the potential of the complex for platinum mineralization, although it is conceivable that the deficiency might result from the precipitation of platinum (with sulphides or chromite) lower in the sequence.

The copper and nickel sulphides intersected by the Planet drilling, near Yornup, demonstrate that there is some potential for nickel sulphide mineralization. The potential for platinum-group metals associated with this mineralization cannot be assessed, as analyses for these elements were not carried out. Platinum and palladium analyses of drill core from an (unsuccessful) exploration programme for chromite carried out by the Shell Company of Australia Ltd - Metals Division, in the area of the Yornup nickel prospect, were all less than the detection limit of the method used: <0.005 ppm Pd, <0.05 ppm Pt (Richards, 1981).

## THE ARCHAEAN PORTION OF THE PERTH 1:250 000 SHEET

The Archaean geology of the Perth sheet (Figure 9) is dominated by paired metamorphic belts, which are composed mainly by gneisses of metasedimentary origin.

Most of the rocks of the Jimperding Metamorphic Belt appear to be derived from quartzo-feldspathic sediments formed under stable-shelf sedimentation. In the northern part especially, generally flat-lying metasedimentary sequences make the belt appear (superficially) structurally relatively simple. These flat-lying sequences may be the preserved remnants of large, early-generation recumbent folds formed by horizontal-folding tectonics (Gee, 1979).

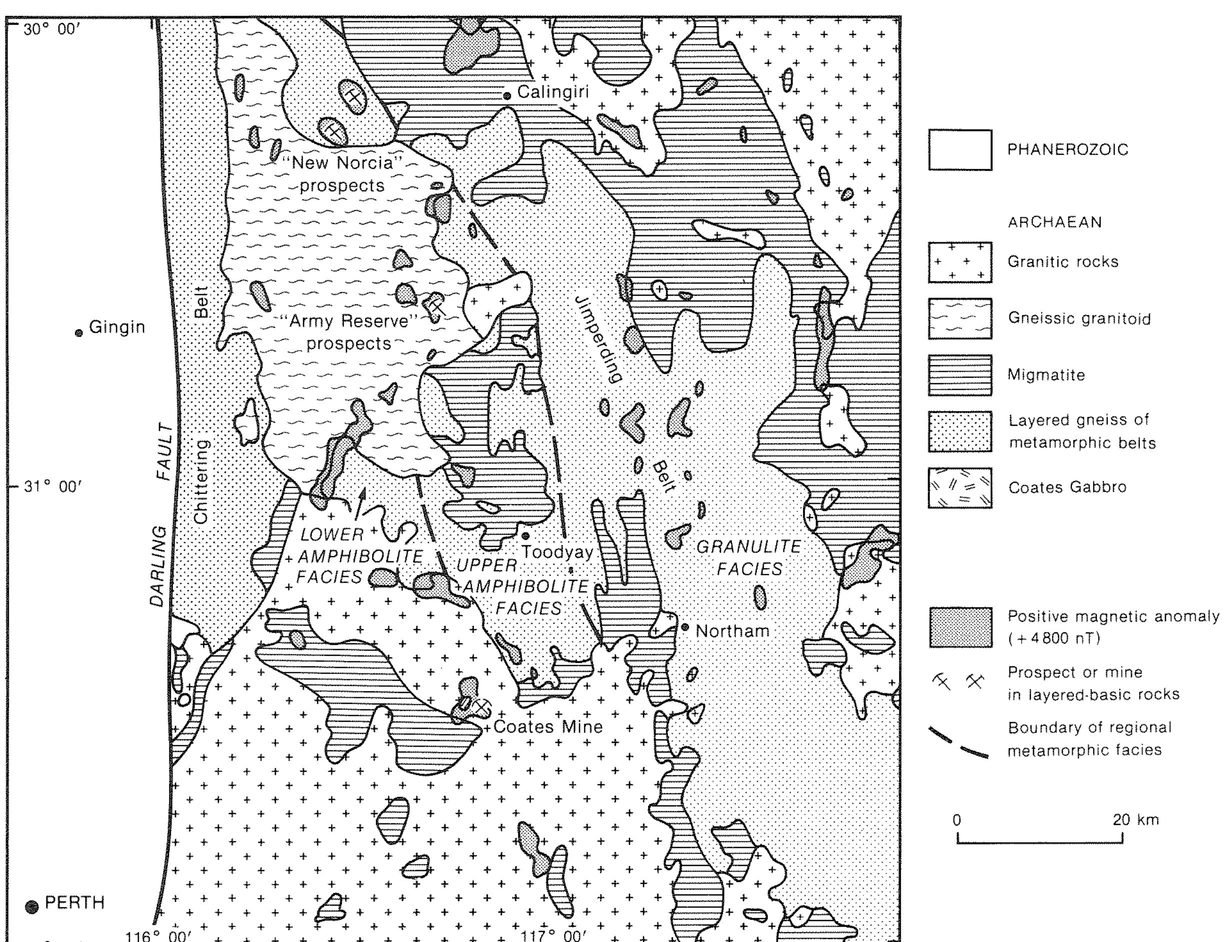


**Figure 9. Simplified geology of the Archaean portion of the Perth 1:250 000 sheet, showing major magnetic anomalies and mineral prospects associated wth layered-mafic rocks. (Partly modified from Wilde and Low, 1978).**

The Chittering Metamorphic Belt, on the other hand, is characterized by gneisses probably derived from greywacke-flysch sediments. It contains extensive tracts of steeply inclined gneiss with cataclastic and mylonitic zones. This combination was considered by Gee (1979) to be characteristic of vertical-shear tectonics.

Approximate metamorphic isograds, recognized from the regional mapping, are shown on Figure 9.

The Chittering Metamorphic Belt is characterized by (high-pressure series) amphibolite-facies metamorphism, while the Jimperding Metamorphic Belt shows (low-pressure series) metamorphism, grading from amphibolite facies in the west to granulite facies in the east.

Subordinate units of amphibolite are present in the Chittering Metamorphic Belt while both amphibolite and mafic granulite are known in the Jimperding Metamorphic Belt. Ultramafic rocks are apparently restricted to the Jimperding Metamorphic Belt. Wilde and Low (1978) regarded them as subconcordant weakly metamorphosed intrusions into the layered gneissic sequence, although they do pre-date the final deformation.

The metamorphic belts are surrounded by extensive areas of migmatite, and are intruded and disrupted by voluminous granitoids. The majority of the granitoids are post-tectonic, but one in the north of the sheet appears to be an older, syntectonic unit (Figure 9).

A body of gabbro at Coates Siding, recognized during the mapping, consists of several phases including leucogabbro, magnetite-gabbro, and gabbro. The body is enclosed by granite, but as no good exposures of the gabbro-granite contact are observed, the age relationships are unclear (Baxter 1978). Dolerite dykes intrude both the gabbro and the granitoid rocks.

A limited amount of isotopic dating has been completed within the area of the Perth Sheet. McCulloch and others (1983) showed that two groups of orthogneisses from the Toodyay and Northam areas have Sm-Nd models ages of 3.15 to 3.24 Ga and 2.95 to 3.05 Ga. A mafic granulite gave a model age of 3.05 Ga. U-Pb studies of zircons by Nieuwland and Compston (1981) showed that the protoliths of the banded paragneisses, in the same area, had dates of approximately 3.25 Ga. While detrital zircons with dates of 3.34 Ga, obtained from orthoquartzites from near Toodyay, suggest the presence of still older crustal material in the Jimperding Metamorphic Belt. A preliminary, unpublished, Sm-Nd model age of material from the Coates Gabbro suggests this unit may be older than any of the gneisses so far dated from the Jimperding Metamorphic Belt (Fletcher, pers. comm., 1984). Fletcher and others (1985) have shown, by Sm-Nd model dating, that the protoliths of the granofelsic paragneiss in the Chittering Metamorphic Belt are considerably younger than the rocks of the Jimperding Metamorphic Belt, giving ages of 2.76 and 2.98 Ga. Arriens (1971) showed that the post-tectonic granitoids have whole-rock Rb-Sr ages of around 2.6 Ga. No dates have been reported for the syntectonic granitoid, but this can be shown, from field evidence, to be younger than the gneisses of the Chittering Metamorphic Belt.

Magnetic anomalies of over 4 800 nT (taken from the B.M.R. regional magnetic survey) have been superimposed on Figure 9. In the eastern part of the sheet, a number of these anomalies occur over mapped outcrops of ultramafics or metamorphosed banded iron-formation rocks, but the relationship is far from precise. Many of the anomalies apparently relate to migmatites or gneisses: a large number occur over areas obscured by superficial deposits. In the west of the sheet, a north-trending line of anomalies occurs over rocks which are largely obscured by laterite, alluvial, and colluvial deposits. One anomaly includes the Coates Gabbro (although the anomaly is much more extensive than the mapped outcrop), and amphibolite and ultramafic rocks crop out on the flanks of a large anomaly which occurs over a laterite-covered area of the Julimar Forest (centred on Lat. 31°30'S, Long. 116°14'E).

### "JULIMAR COMPLEX"

A number of mineral deposits and mineral-exploration prospects occur along this (western) north-trending line of magnetic anomalies (Fig. 9). Drilled material from these, together with the sparse outcrops, provides some evidence as to the cause of the anomalies.

The magnetite-gabbro phase of the Coates Gabbro contains 20 to 40% magnetite and ilmenite. The balance is made up of labradorite, hornblende, biotite, epidote, and augite. An estimated minimum of 39 Mt of primary unoxidized mineralization, containing an average of 0.51% $V_2O_5$ (using a 0.4% $V_2O_5$ cut-off) is present in this unit. This resource is overlain by an inferred 5.9-7.0 Mt of oxidized rock averaging 0.55% $V_2O_5$. Near surface this is, in turn, overlain by a laterite caprock which has indicated reserves of 1.2 to 1.5 Mt averaging 0.88% $V_2O_5$ (Baxter, 1978).



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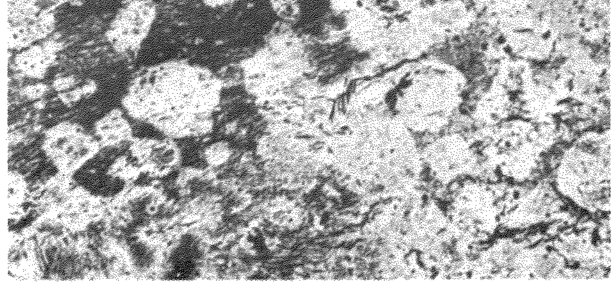
Thin section examination of material from a test shaft at Coates has shown evidence for a (basal?) ultramafic layer to the gabbro body. One sample consists of 95% serpentine minerals after olivine, in a metadunite with a well-preserved adcumulate texture (Figure 10). The outlines of former olivine

0·5 mm

GSWA 21613

**Figure 10. Serpentinized dunite from Coates Siding. A relic adcumulate texture after olivine grains is outlined by chromite. Small secondary veins are titaniferous magnetite. A "wavy" serpentinization is the only evidence of significant stress effects during metamorphism. (Sample 78180. Field of view 2.5mm. Plane-polarized light).**



4 mm

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**Figure 11. Metaperidotite from Julimar Creek. Cumulate grains after olivine are replaced by serpentine. The former olivine grains were enclosed by poikilitic orthopyroxene which has been replaced by tremolite and chlorite. The intercumulus material is "dusted" by fine-grained opaque minerals. (Sample 78169. Field of view 20 mm. Plane-polarized light).**

grains are marked by chromite and a number of secondary veinlets of titaniferous, vanadiferous magnetite are present. Here again, a greenschist-facies assemblage is present in rocks which probably pre-date the amphibolite-facies gneisses and provides further evidence of the resistance of thick, layered-intrusive bodies to many of the more severe effects of metamorphism. In this case, "wavy-textured" serpentinization is the only evidence of any significant dynamic effect of metamorphism.

Further north, in the Julimar Creek exposures, primary igneous textures of the type associated with layered-mafic intrusions are preserved. One sample shows serpentinized grains (after cumulate olivine) surrounded by a mixture of tremolite and chlorite which has replaced poikilitic orthopyroxene (Figure 11).

East of the Bindoon Army Training Area (centred on 31°20′S. 116°21′E), Hamersley Exploration Limited and Alcoa of Australia Limited carried out a drilling programme to test one of the north-trending magnetic anomalies. Existing regional mapping suggests that this area consists of laterite and scattered outcrops of deeply weathered (gneissic) syntectonic granitoid. The exploration programme of six percussion-drilled and three diamond-cored holes showed that the magnetic anomaly is underlain by an unexposed basic complex, consisting of leucogabbro, magnetite-gabbro, and anorthosite. A number of thin pyroxenitic layers are also present within the gabbro sequence, which has been intruded by (late stage?) granophyric differentiates and younger dolerite dyke rocks. The basic body appears to have been intruded into an older sequence of metasediments and (possible) acid volcanics (Pontifex, 1979). The whole sequence appears to now form a roof pendant to the older gneissic granite; a typical section is shown in Figure 12.

The drilling showed that vanadiferous, titaniferous magnetite-bearing layers (up to 25 metres thick) were present in lenses with strike lengths of at least 1.1 km. It appears, however, that the lateritic enrichment, which is a feature of the Coates mineralization is largely absent. The joint venturers estimated that the tonnage potential was 90 000 tonnes per vertical metre, at a grade of 0.3% $V_2O_5$ or 20 000 tonnes per vertical metre at 0.45% $V_2O_5$. An interesting feature is the presence of up to 10% apatite in some of the leucogabbros. This and the granophyric rocks suggest that the sequence includes the more alkaline upper part of a thick layered-intrusive body.

It is anticipated that this, and a number of other layered-basic bodies from the Western Gneiss Ter-

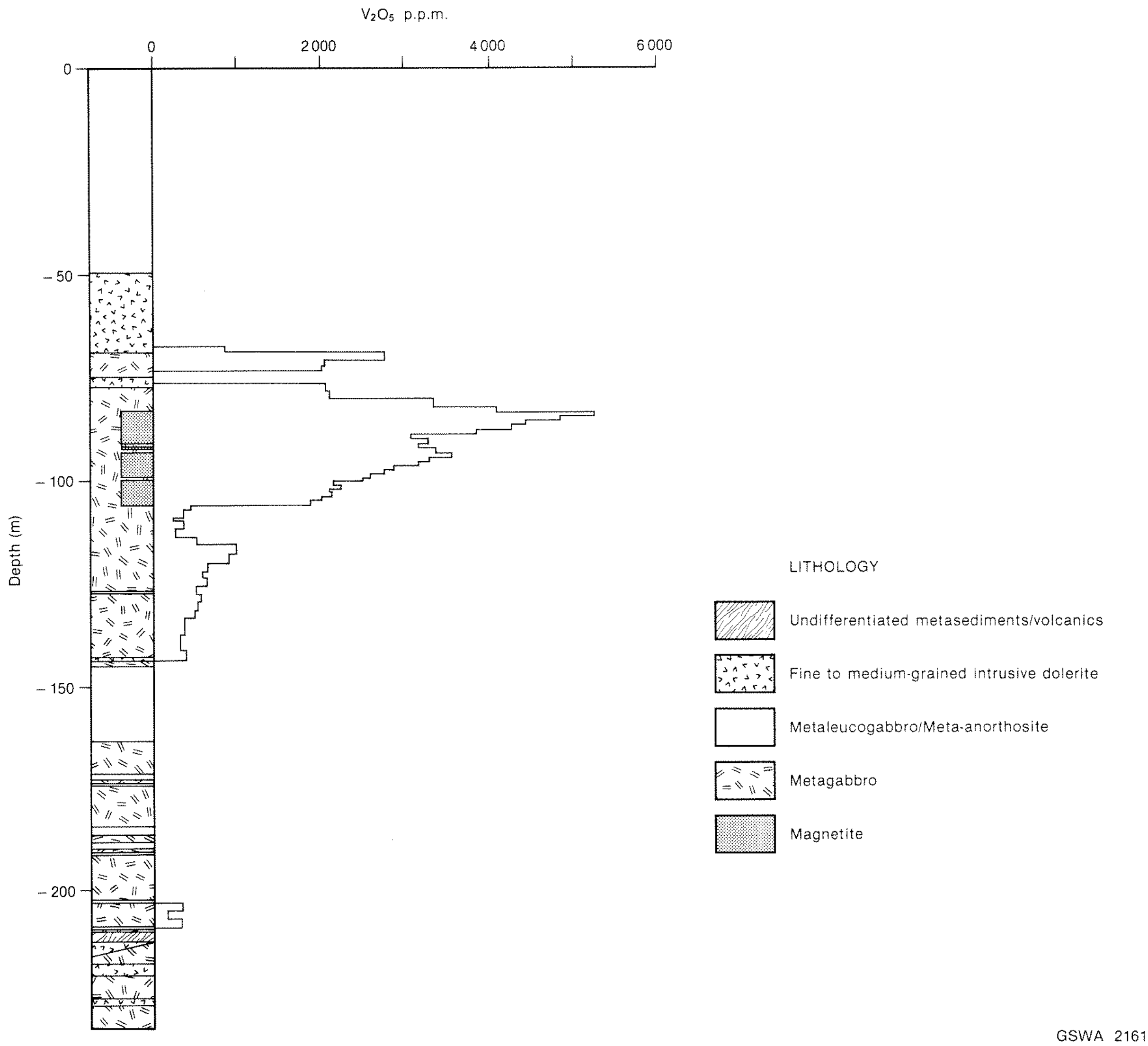



**Figure 12. A typical drill-hole section, "Army Reserve" prospect, D.D.H.1., showing analysis for $V_2O_5$.**

rain, will shortly be dated using the Sm-Nd method. To this end, a number of specimens of drill core have been examined in thin section. The samples examined include a metamorphosed leucogabbro with cumulus and intercumulus textures, in which actinolite replaces clinopyroxene; the plagioclase (of andesine composition) is partly saussuritized and, in places, replaced by grossular garnet (Figure 13). Ahmat (1984) regards the presence of the garnet as indicating calcic metasomatism. The intercumulus oxide mineralization in this sample (Figure 14) includes both titanomagnetite (with ilmenite exsolution lamellae) and primary ilmenite. Minor amounts of pyrite and chalcopyrite are present in some samples.

Another north-trending magnetic anomaly, the New Norcia Prospect (31°05′50″S, 116°15′50″E), has been examined in some detail by Otter Exploration N.L.—for a time in joint venture partnership with Shell Minerals Exploration (Australia) Pty Ltd. Their exploration programme, which included intensive rotary air-blast drilling, percussion drilling and eleven diamond-cored holes, has shown the presence of a layered sequence of basic and ultramafic rocks. These contain extensive zones of disseminated sulphides with rare thin massive zones. The higher grade intersections, assaying 1.5% nickel with similar values of copper, are quite narrow: 0.2 to 0.4 m (Marston, 1984).

A typical drill section is shown in Figure 15. Although the structural relationships from hole to hole are not clear, it appears that there is major phase layering involving metaperidotite (now serpentine-tremolite-chlorite rock), metapyroxenite (now largely tremolite-chlorite rock), and various metamorphosed melagabbros and leucogabbros. These rocks appear to be rich in tremolite rather than actinolite, indicating a probable original noritic composition. The distribution of copper and nickel may indicate the presence of some cyclicity in the layering (Figure 15).

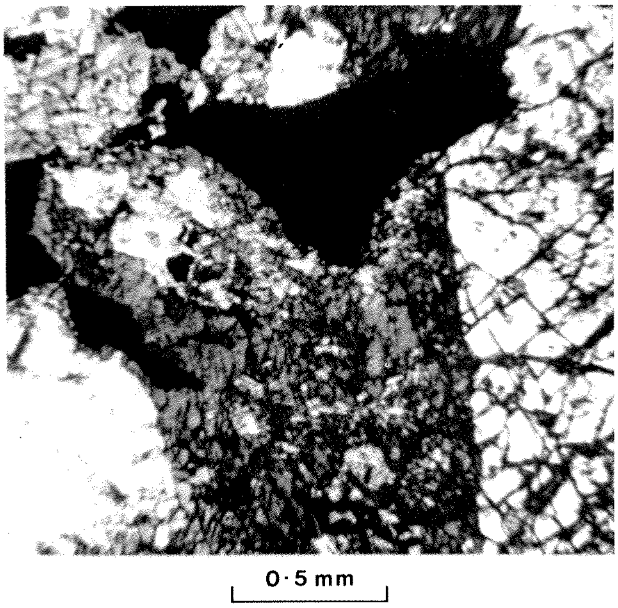



**Figure 13.** Meta-leucogabbro, D.D.H.1. "Army Reserve" prospect. Clinopyroxene has been replaced by blue-green actinolite and some minor chlorite. Plagioclase has been partly saussuritized and is partly replaced by grossular garnet. The intercumulus opaques are mainly titaniferous magnetite and ilmenite. (Sample 78157. Field of view 2.5 mm. Plane-polarized light).

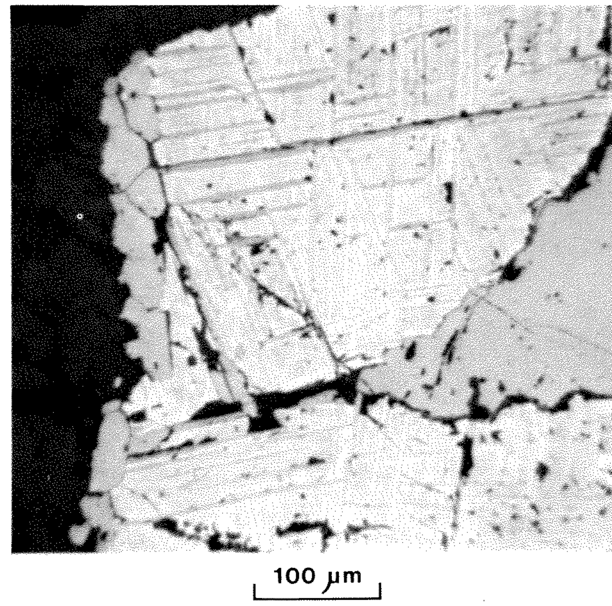



**Figure 14.** Oxide mineralization, D.D.H.1. "Army Reserve" prospect. Titanomagnetite shows well-developed exsolution lamellae of ilmenite. Coarse primary ilmenite is also present. (Sample 78157. Field of view 625 microns. Reflected light).

**TABLE 2. "JULIMAR COMPLEX": ANALYSES**

| *G.S.W.A Sample* | *Locality* | *Description* | *Cu (ppm)* | *Ni (ppm)* | *$Cr_2O_3$ (ppm)* | *Pt (ppm)* | *Pd (ppm)* | *Fe(a) (%)* | *$TiO_2$ (%)* | *$V_2O_5$ (%)* |
|---|---|---|---|---|---|---|---|---|---|---|
| 78125 | New Norcia prosp. | ? Gossanous ultramafic | 1830 | 2810 | 9000 | 0.06 | 0.24 | | | |
| 78153 | New Norcia PDH | Gossanous serpentinite | 3960 | 2850 | 3030 | 0.01 | 0.58 | | | |
| 78154 | New Norcia PDH | Tremolitic metagabbro | 260 | 120 | 130 | <0.04 | 0.01 | | | |
| 78155 | New Norcia PDH | Tremolite rock | 940 | 390 | 2900 | 0.04 | <0.006 | | | |
| 80781 | DNN7—332 m | ?Metapyroxenite | 1310 | 470 | 150 | <0.04 | 0.01 | | | |
| 80782 | DNN7—309 m | Meta-leucogabbro | 2600 | 980 | 230 | <0.04 | 0.01 | | | |
| 80783 | DNN7—292 m | Meta-melagabbro | 1650 | 540 | 100 | <0.04 | 0.01 | | | |
| 80784 | DNN7—249 m | Metapyroxenite | 4520 | 2910 | 740 | 0.06 | 0.02 | | | |
| 80785 | DNN7—225 m | Metaperidotite cumulate | 1450 | 2560 | 1360 | 0.11 | 0.37 | | | |
| 80787 | DNN7—162 m | (Cumulate) metapyroxenite | 4200 | 3720 | 1820 | 0.08 | 0.28 | | | |
| 80788 | DNN7—152 m | Metapyroxenite | 6980 | 4420 | 850 | 0.06 | 0.20 | | | |
| 80789 | DNN7—130 m | Metapyroxenite (C.G.) | 7680 | 2610 | 870 | 0.63 | 1.00 | | | |
| 78158 | Army Reserve PDH | Anorthosite | 160 | 40 | 25 | <0.04 | 0.02 | 18.0 | 1.31 | 0.078 |
| 78159 | Army Reserve PDH | Magnetite in leucogabbro | 190 | 40 | 70 | <0.04 | <0.006 | 31.4 | 8.33 | 0.36 |
| 78161 | Army Reserve PDH | Magnetite in leucogabbro | 190 | 50 | 60 | <0.04 | <0.006 | 30.3 | 8.89 | 0.30 |
| 78162 | Army Reserve PDH | Magnetite in leucogabbro | 190 | 70 | 60 | <0.04 | <0.006 | 29.8 | 8.61 | 0.37 |
| 78163 | Army Reserve PDH | Leucogabbro/mag gossanous? | 300 | 120 | 80 | <0.04 | <0.006 | 37.3 | 2.68 | 0.37 |
| 78179 | Coates Gabbro | Serpentinite | 30 | 2390 | 1950 | <0.04 | 0.01 | 8.44 | <0.01 | 0.37 |
| 78180 | Coates Gabbro | Serpentinized dunite | 40 | 2390 | 8380 | <0.04 | <0.006 | 8.10 | 0.075 | 0.048 |

(a) Total iron

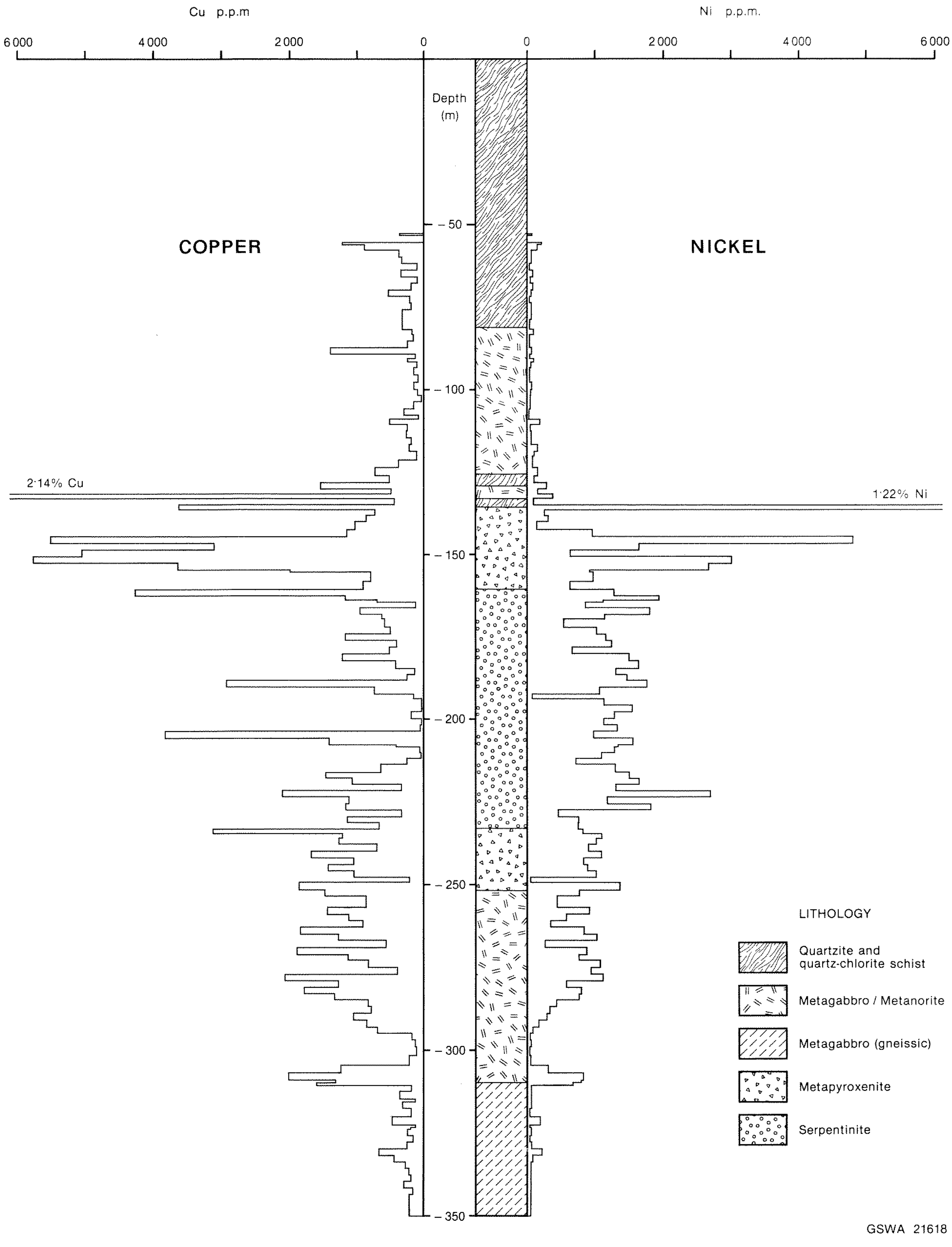
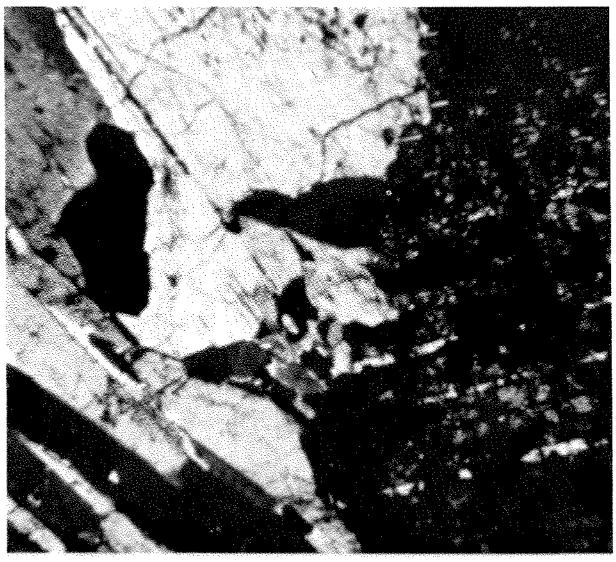


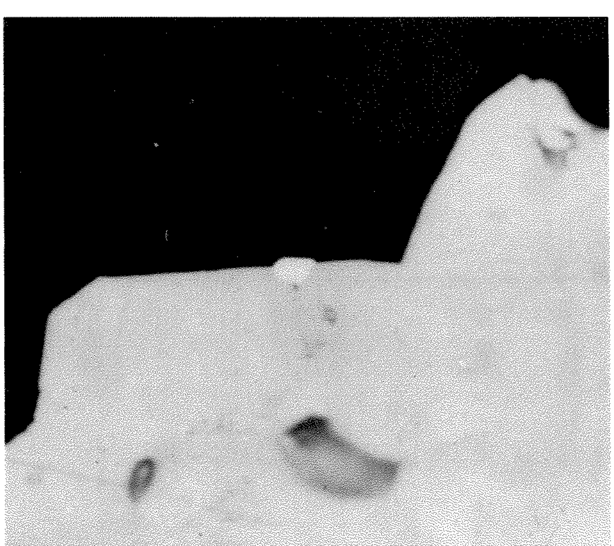

**Figure 15. A typical drill section, New Norcia nickel prospect: D.D.H.7. Also showing analyses for copper and nickel.**

Although this intrusion has been metamorphosed to amphibolite facies, many recognizable igneous textures are preserved in the samples examined. Figure 16, for example, shows coarse-grained metamorphosed norite. In this, a first-generation growth of tremolite replaces




GSWA 21619

**Figure 16.** **Metanorite from D.D.H.7. New Norcia nickel prospect. Plagioclase, of labradorite composition, has been extensively saussuritized. A "first-generation" growth of tremolite has replaced cumulate orthopyroxene, however, primary textures are partly obscured by a "second-generation" growth of nematoblastic metamorphic tremolite. (Sample 80733. Field of view 2.5 mm. Crossed polars).**




GSWA 21620

**Figure 17.** **Platinum-bearing sulphide mineralization, D.D.H.7. New Norcia nickel prospect. The small (4 micron diameter) bright grain on the margin of intercumlus textured chalcopyrite is a probable platinum-group mineral. (Sample 80789. Field of view 100 microns. Reflected light, oil immersion).**

recognizable cumulate textures (after orthopyroxene), and a second-generation growth of granoblastic tremolite partly obscures these textures. Labradorite, although highly saussuritized, is still partly preserved. The sulphides (mainly pyrrhotite, subordinate chalcopyrite and pentlandite) show remnant intercumulus textures. There is minor remobilization of sulphides into fine hair-like cracks. Under high magnification (x 1 250) rare, small, (4µm) very bright grains of sulphide within chalcopyrite were observed (Figure 17). These grains are considered to contain platinum-group minerals. This is borne out by the assays included in Table 2.

The evidence from the four areas discussed suggests that many of the north-trending magnetic anomalies in the western part of Figure 9 may be related to one, or several, layered basic/ultramafic intrusions. These are here informally named the "Julimar Complex".

*Potential for mineralization*

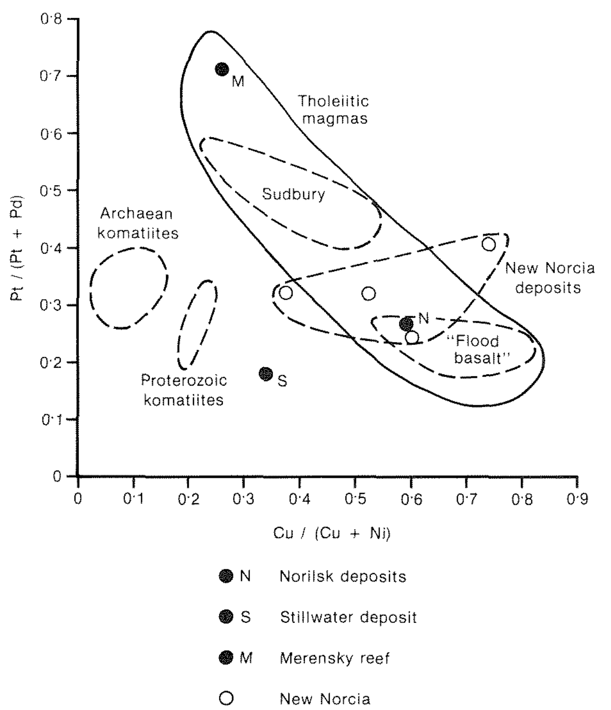
Work completed to date clearly demonstrates the potential of the "Julimar Complex" for vanadiferous, titaniferous magnetite and for nickel sulphides. The presence of chromite in some of the ultramafic samples indicates that chromitites may be developed in the sequence, while the apatite in the leucogabbros suggests some potential for phosphate deposits in the laterite profile and in residual deposits derived from these. The most interesting possibility, is for the development of economic deposits of platinum-group metals. The assays for platinum and palladium, from the New Norcia prospect (Table 2), are not in themselves economic. The presence of anomalous values over such a thick interval (at least 100 m), however, does indicate that the intrusion is derived from a magma which was highly anomalous in platinum-group metals. In the case of the New Norcia prospect, the widespread disseminated sulphides, which are present, result in platinum being disseminated through the intrusion. (This is perhaps a result of extensive sulphuration caused by contamination from the metasediment sequence which has been intruded.) If, however, some of the other bodies in the complex were derived from a similar magma, but have only a thin, concentrated zone of sulphide mineralization, such mineralization may contain economic grades of platinum-group metals.

Plots of Pt/(Pt+Pd) and Cu/(Cu+Ni) ratios of the New Norcia mineralization suggest that the parent magma had tholeiitic affinities and showed some similarities to flood-basalt related intrusions of the Norilsk type (Fig. 18). If the "Julimar Complex" intrusions formed in a similar tectonic setting to Norilsk (fundamental rifting close to the margins of a stable craton with magma derived from the immediately underlying mantle), this provides evidence of major fracturing in this very ancient Archaean crustal area.

Platinum and palladium analyses from the New Norcia prospect, recalculated to the value in 100% sulphides, and normalized with respect to their average abundance in chondritic meteorites (McBryde, 1972), are shown in Figure 18. Similarly normalized values are shown for the Merensky Reef and Norilsk deposits together with fields of values for the Sudbury nickel deposits and komatiitic nickel deposits, after Naldrett and others (1979). Values for certain ophiolitic chromitites, after Page and others (1982), are also plotted.

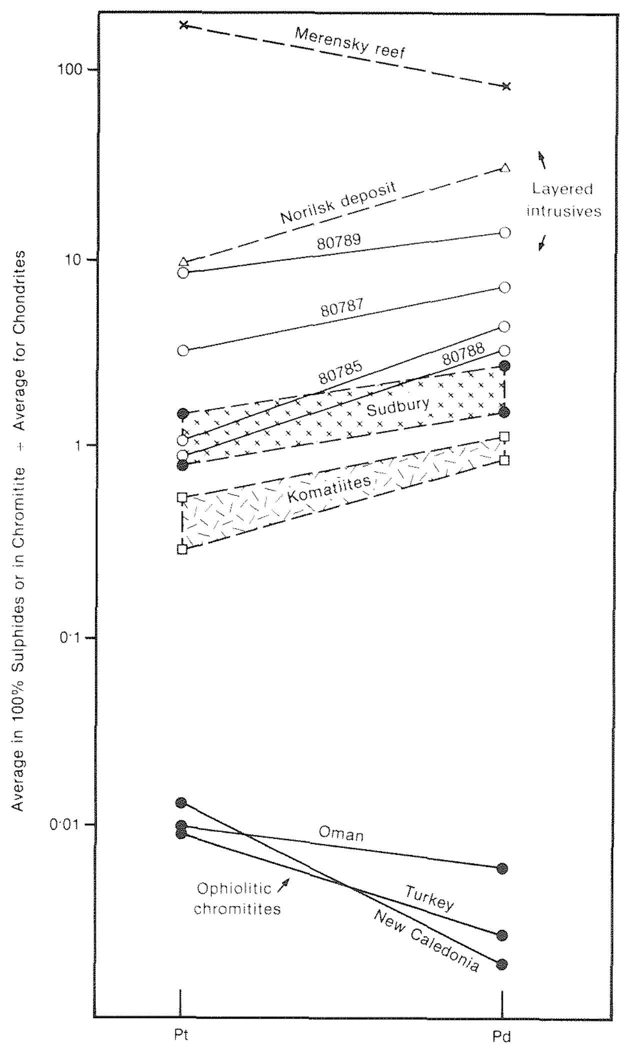
The four samples from New Norcia show a marked enrichment in platinum and palladium, relative to chondrite—and hence presumed mantle values—which is typical of deposits from layered intrusions. This is in marked contrast to komatiite-derived samples which normally show values close to chondrite values, and to samples from ophiolitic sequences which are characterized by a very strong depletion relative to chondrite values.

Sample 80789, which is the stratigraphically lowest sample from the New Norcia prospect and presumably contains the earliest precipitated sulphides, plots very close to values reported from the Norilsk deposit. Two samples from stratigraphically higher positions (80785 and 80788) show less enrichment relative to chondrite values and show some overlap with the field for the Sudbury nickel deposits. This "stratigraphic" variation suggests that the mineralization in the New Norcia prospect may have been derived by a series of successive segregations of sulphide. The more highly chalcophile elements, such as platinum and palladium, would partition strongly in the earliest segregated sulphides. This would result in the remaining magma being (relatively) depleted in these elements. The fact that this relative depletion is not uniform (sample 80787 in Figure 8 is more enriched than sample 80788, which is stratigraphically lower) may indicate that the chamber was receiving new pulses of magma during the formation of the sulphides.




GSWA 21621

**Figure 18. The relationship between the Pt/(Pt + Pd) and Cu/(Cu+Ni) ratios of mineralization from the New Norcia prospect compared with the fields for ores for various magma types, after Naldrett and Cabri (1976), and certain deposits with platinum-group metals, after Cabri (1981).**




GSWA 21622

**Figure 19. Chondrite-normalized platinum and palladium values, from the New Norcia prospect, compared with values for Norilsk deposit, the Merensky Reef, and certain ophiolitic chromitite deposits.**

Each of the mineral prospects and many of the magnetic anomalies described from the Perth sheet are associated with areas, frequently hilly, of ferruginous laterite. The iron-rich composition of the basic intrusives may be the reason that particularly well-developed ferruginous layers have formed in the laterite profile. This, in turn, probably accounts for the relative lack of exposure of these rocks.

## BYRO 1:250 000 SHEET

On the Byro 1:250 000 sheet, several areas of mafic granofels, basic granulite, and ultramafic rocks have been mapped. In spite of the medium- to high-grade metamorphism, primary igneous texture and gross igneous layering are preserved in several places.

These features, coupled with drill-core evidence from several localities, indicate that these rocks are derived from layered basic-ultramafic bodies, which included peridotite, lherzolite, norite, gabbro, anorthositic gabbro, and anorthosite (Williams and others, 1980). These remnants of early layered-basic complexes have been termed "Manfred Complex" by Williams and Myers (in prep).

were considered to be uneconomic because of the poor quality of the chromite and the limited tonnage (Williams and others, 1980). Drilling by Pacminex Pty Ltd near Taccabba Well, (26°05′27″S, 116°37′57″E), located a 1.5 km long magnetite-chromite band associated with meta-lherzolite in a concealed metamorphosed mafic-ultramafic body contained within granulite-facies terrain. A little pyrite and some chalcopyrite were associated with the chromite (Horsley, 1974). Exploration of ultramafic bodies on the sheet by various companies in the late 1960s and early 1970s located a number of possible nickel gossans. None of these proved to be of any significance.

Samples of chromitite collected on the Byro Sheet (held by the Government Chemical Laboratories in the "Simpson Collection" of minerals) have recently been analyzed for a variety of elements, including chromium, platinum, and palladium. These analyses (Table 3) returned low platinum and palladium values, all of which were below the detection limits of the method used. This suggests that the magma contained a low concentration of platinum-group elements. The layered intrusives of the Byro sheet, therefore, may have limited potential for platinum mineralization.

**TABLE 3. ANALYSES OF CHROMITITES ON THE BYRO 1:250 000 GEOLOGICAL SHEET.**

| *Sample number* | $Cr_2O_3$ *(%)* | *FeO (%)* | *Cu (ppm)* | *Ni (ppm)* | *Pd (ppm)* | *Pt (ppm)* |
|---|---|---|---|---|---|---|
| MDC 838 | 30.5 | 12.1 | 82 | 850 | <0.005 | <0.04 |
| MDC 1012 | 47.8 | 10.2 | 43 | 1000 | <0.005 | <0.04 |
| MDC 1171 | 29.3 | 9.76 | 91 | 1400 | — | — |
| MDC 2379 | 33.8 | 13.2 | 57 | 1300 | <0.005 | <0.04 |
| MDC 2454 | 41.8 | 8.28 | 280 | 730 | (a)<0.01 | (a)<0.1 |
| MDC 2607 | 33.8 | 18.1 | 41 | 1000 | (a)<0.01 | (a)<0.1 |
| MDC 3712 | 46.3 | 9.14 | 147 | 680 | (a)<0.01 | (a)<0.1 |
| MDC 4443 | 29.0 | 16.5 | 26 | 940 | <0.005 | <0.04 |

(a) Limits of detection reduced because of small sample size.

The metamorphosed basic bodies appear to pre-date orthogneisses in the Mount Narryer area which have given Sm-Nd model ages of 3.51 Ga (de Laeter and others, 1981).

A number of mineral occurrences within these layered-basic intrusive bodies have been examined by mining companies. Near Iniagi Well (26°11′53″S, 116°12′33″E), a chromite prospect has been explored by Electrolytic Zinc Company Australasia Limited and by Western Mining Corporation. Drilling by W.M.C. showed that chromitite lenses are associated with the ultramafic layers on the western side of the body and that iron-rich chromite layers are present in a metanorite higher in the sequence. The deposits

## OTHER AREAS

There is evidence for the existence of remnants of layered basic-ultramafic intrusive bodies from several other parts of the Western Gneiss Terrain. Davidson (1968) interpreted mafic granulite from Quairading as having been derived from a layered-mafic intrusion. Morgan (1982) has described rhythmic layering in a metamorphosed layered harzburgite-lherzolite-anorthosite intrusion from West Bendering, near Kondinin. Up to 10% chromite has been recorded from the meta-lherzolite member of this body. Baxter and Harris (1980), in a report of drilling results from a copper prospect 25 km northeast of Mingenew, noted the presence of metagabbro rocks within the gneiss sequence adjacent to the Darling Fault. Also close to the Darling Fault, Drake (1976) showed unusual mineralogically and texturally zoned ultramafic bodies within banded gneiss, formed as a result of the boudinage of mafic-ultramafic igneous rocks during deformation. The deformation was accompanied by amphibolite-facies metamorphism followed by a static greenschist-facies metamorphism.

A metagabbro containing lenticular bands of vanadiferous titaniferous magnetite, largely obscured by laterite, occurs south of Tallanalla, 33°09'S 116°08'E (Baxter, 1978). Recent discoveries of titaniferous magnetite near Katanning and the discoveries of mafic granulites, which are believed to be derived from layered-basic intrusive rocks, during the mapping of the Dumbleyung 1:250 000 sheet (R. J. Chin, pers. comm.), suggest that other remnants of basic intrusions will be found.

## CONCLUSION

Remnants of layered basic intrusions seem to be more common within the Western Gneiss Terrain than have previously been recognized. These rocks, once thought to be late-stage intrusions, are now considered to be amongst the oldest rocks of the Western Gneiss Terrain. Their thickness and composition have been responsible for protecting them from the more extreme effects of metamorphism; in many of the larger remnants, recognizable igneous textures are well preserved. The limited geochemical data suggest that the intrusives are derived from a magma of tholeiitic affinities, and they are considered to have potential for mineralization of the kind normally associated with layered intrusions of this type. Exploration which has been completed, thus far, has clearly demonstrated the potential for vanadiferous titaniferous magnetite, for chromite, and for nickel sulphides. Data presented in this paper suggest that some of the bodies may also have considerable potential for platinum-group metal mineralization.

## ACKNOWLEDGEMENTS

The assistance of Otter Exploration N.L. and Alcoa of Australia Ltd in providing access to drill cores from their exploration projects on the Perth 1:250 000 sheet is gratefully acknowledged. Analyses for platinum-group metals were carried out by the Kalgoorlie Metallurgical Laboratory using a specially developed fire-assay method; other analyses were completed by the Government Chemical Laboratories.

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