GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

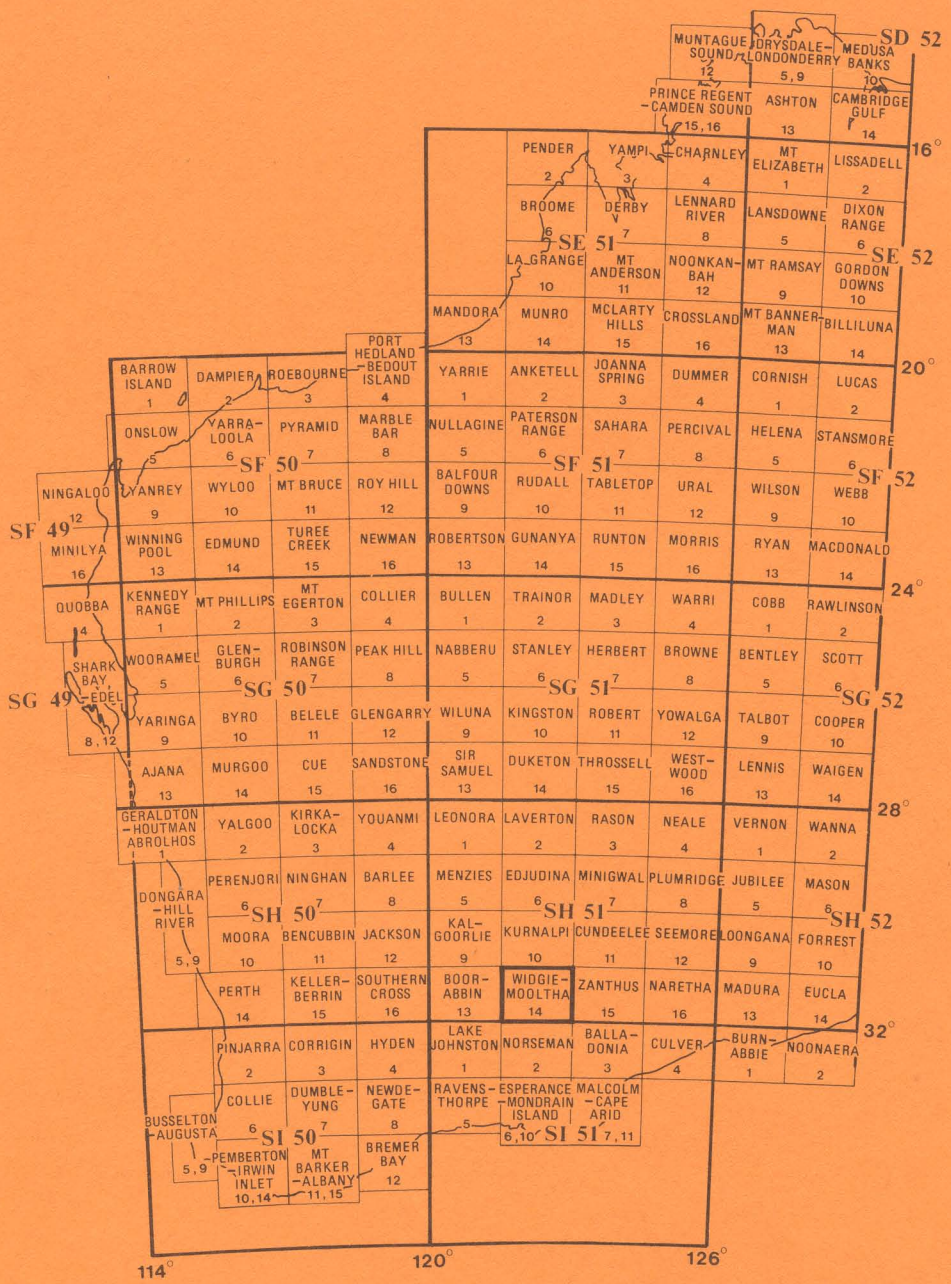
REPORT 32

GEOLOGY OF THE GRANITE — GREENSTONE TERRANE OF THE LAKE LEFROY AND COWAN 1:100 000 SHEETS, WESTERN AUSTRALIA

by

T.J. Griffin

DEPARTMENT OF MINES
WESTERN AUSTRALIA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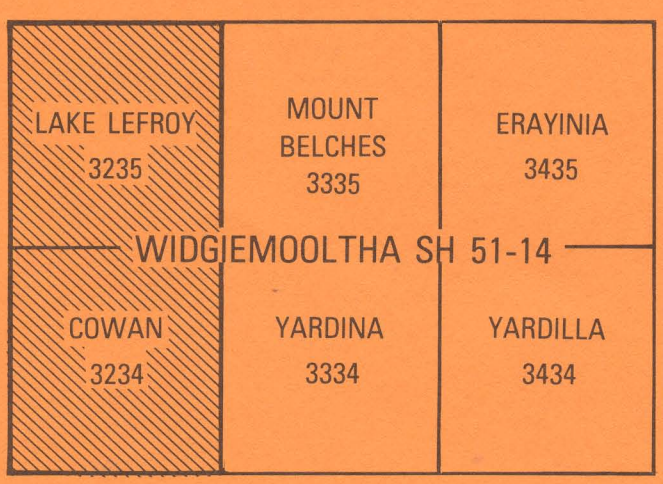
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YARDILLA
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Perth 1990

MINISTER FOR MINES
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GEOLOGY OF THE GRANITE–GREENSTONE TERRANE OF THE LAKE LEFROY AND COWAN 1:100 000 SHEETS, WESTERN AUSTRALIA

Abstract

Lake Lefroy and Cowan 1:100 000 sheets cover a richly mineralized area of Archaean granite–greenstone terrane between Kalgoorlie and Norseman, in the southern part of the Eastern Goldfields Province of the Yilgarn Craton. A sequence of greenstones up to 7000 m thick accumulated 2800 to 2600 Ma ago. Basement to the greenstones is unknown; however, zircon xenocrysts in volcanic rocks at Kambalda indicate that sialic basement, containing rocks as old as 3500 Ma, existed at the time of eruption of mafic and ultramafic lavas early in the development of the greenstone sequence.

A generalized stratigraphic succession is recognized; however, direct correlation of individual units across strike has not been attempted because of an intense and complex deformation history. The lowermost greenstones are a thick sequence of mafic and ultramafic lavas. High-Mg basalt generally overlies komatiite throughout the area. At Kambalda and Carnilya, significant tholeiite and high-Mg basalt also occur beneath nickel-bearing komatiite.

Thin shale and chert beds occur throughout the greenstone sucession, except in the uppermost Merougil beds, and are particularly abundant on, or near, the contact between komatiite and overlying basalt. A sequence of felsic volcanic rocks, dominated by dacite and rhyodacite, and associated epiclastic rocks, overlies the mafic and ultramafic lower sequence. The felsic rocks are succeeded by clastic sedimentary rocks that were largely derived from felsic volcanics. Layered mafic sills intrude all three units but are most abundant in the mafic and ultramafic sequence. Polymictic fluviatile, pebbly sandstone of the Merougil beds unconformably overlies the clastic sedimentary rock sequence.

Some granitoid rocks are probably sub-volcanic intrusions related to felsic volcanism; however, most granitoid intrusions post-date the first major deformation event. This deformation included recumbent folding and thrusting, which resulted in local repetition of the original greenstone stratigraphy similar to that observed in the Republican area, 50 km south of Kambalda. Following intrusion of granitoids, such as the Widgiemooltha Monzogranite, uplift and erosion provided material for deposition of the Merougil beds in a fluviatile environment. Further intense deformation produced strong north-northwest trends in the granite–greenstone terrane, which is reflected in tight upright folds, steep cleavage and major wrench faults, such as the Boulder–Lefroy Fault.

The Fifty Mile Tank Gneiss is thought to have been emplaced prior to, or early in, this major and highly complex deformation event. Granitoid and pegmatite stocks and dykes, and quartz veins, are syn-tectonic; but some are undeformed and thus post-date the last phase of deformation.

Metamorphic grades are at upper greenschist to low amphibolite in most of the greenstones. In areas of domal culminations, often associated with granitoid, grades are slightly higher (middle to upper amphibolite). This reflects a regional increase in temperature, and is usually associated with areas of higher strain.

Mafic and ultramafic Proterozoic dykes that intruded at 2400 Ma are undeformed, and post-date cratonization of this part of the Eastern Goldfields granite–greenstone terrane.

Keywords: granite–greenstone terrane, Archaean, structural geology, metamorphism, Lake Lefroy, Cowan, Eastern Goldfields Province.

Introduction

This report provides a detailed discussion and interpretation of the Archaean granite–greenstone terrane of the Widgiemooltha and Kambalda Districts on the LAKE LEFROY* and COWAN* 1:100 000 sheets (SH51-14-3235/3234). These sheets include most of the greenstones between Kalgoorlie and Norseman—a greenstone belt richly mineralized with nickel and gold. The two sheets are from the western side of the WIDGIEMOOLTHA 1:250 000 sheet (Griffin, 1989) as shown on Figure 1. The history of investigation, physiography, and Cainozoic, Palaeozoic and Proterozoic geology are discussed in explanatory notes that accompany the WIDGIEMOOLTHA 1:250 000 geological sheet (Griffin, 1989).

Presentation of the regional geology at 1:100 000 scale is warranted by the concentration of well exposed greenstone supracrustal rocks, and by the continuing interest by mining and exploration companies which have provided much of the locally detailed geological data for the western part of WIDGIEMOOLTHA.

Discussion in this report will concentrate on interpretation of the geology of individual areas of mafic and ultramafic rocks on LAKE LEFROY and COWAN. Metasedimentary rocks are, in general, poorly exposed; however, together with the metamorphosed felsic volcanic rocks they are included in the discussion as part of the greenstones.

Some attempt will be made to establish stratigraphic successions and to correlate across strike. Correlations are based only on similarity of lithologies and successions, regional aeromagnetic contour maps, and Landsat images. Therefore, in this multiply deformed terrane, with no means of dating various units, correlations across areas without outcrops are speculative.

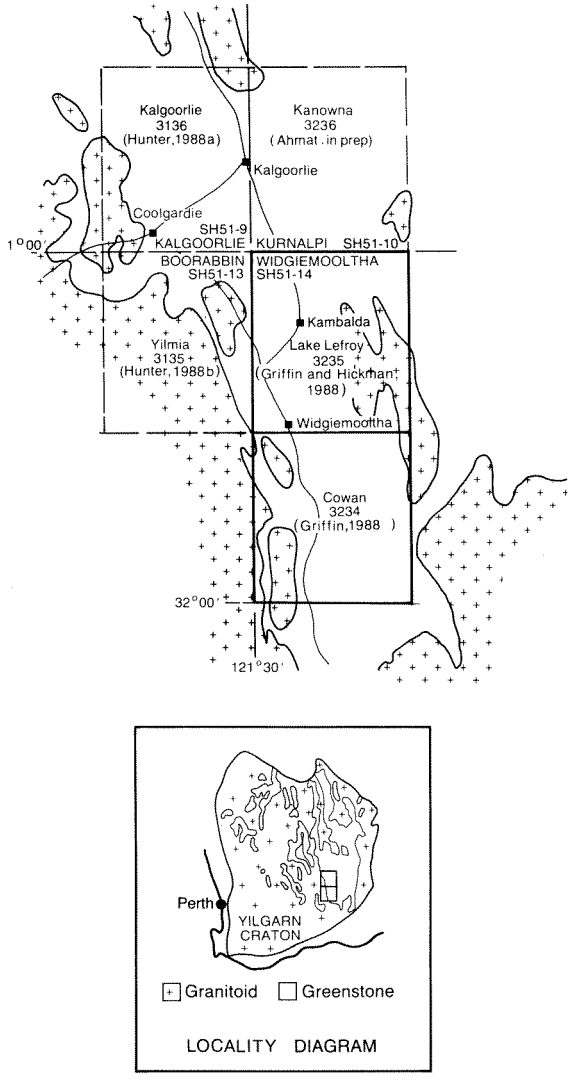


Figure 1. **Location of the LAKE LEFROY and COWAN 1:100 000 geological maps in the southern Eastern Goldfields Archaean granite–greenstone terrane.**

Regional stratigraphy and structure

The Precambrian geology on LAKE LEFROY and COWAN (simplified in Figure 2) is characterized in the west by narrow north-northwest trending belts of mafic and ultramafic-dominated greenstones. In west COWAN, two ovoid masses of metamorphosed granitoid and minor gneiss (Widgiemooltha Monzogranite and the Pioneer Granitoid Complex plus the Fifty Mile Tank Gneiss) control outcrop trends, whereas in central COWAN, around Eundynie and Hayes Hill, the outcrop does not reflect the strong north-northwest regional trend. Lithologies in northeast LAKE LEFROY trend southeast, but in the southeast of LAKE LEFROY and northeast COWAN they trend north–south. These trends outline broad regional folds such as in northeast COWAN, north of the prominent Proterozoic Binneringie Dyke.

Fold axes, on both small and large scales, generally have north-northwest trends; an exception is the east–west Carnilya Anticline in north LAKE LEFROY. The north-northwest folds plunge in both directions forming dome and basin structures.

* Sheet names are printed in full capitals to avoid confusion with similar place names.

The zone through Kambalda and to the south-southeast onto COWAN seems to contain more open structures in comparison with the elongate outcrops to the west which are more tightly folded and attenuated. Overturned limbs are observed on some larger folds, such as the northern limb of the Carnilya Anticline and part of the western limb of the Merougil Syncline.

Major regional faults, such as the Boulder–Lefroy Fault, a wrench fault, (Swager, 1989), as well as minor faults and shear zones, trend north-northwest, parallel to lithological contacts. Folded faults—also parallel, or roughly parallel, to the lithological contacts—are observed in the more open regional structures. One such fault is between the Victory–Defiance gold mine and the Jan nickel mine, across the causeway south of Kambalda (Gresham and Loftus-Hills, 1981). The faults are difficult to recognize in tightly folded sequences, and contribute to the attenuation of prominent horizons such as in the Republican–Bluebush area.

Recognition of original stratigraphic sequences in such an intensely deformed terrane is difficult, and requires detailed knowledge of the structure. Correlation across areas without outcrop, particularly across strike from one greenstone belt to another, is uncertain. Lithological successions, both broadly and in detail, are sufficiently variable to cast doubt always on correlations between various areas of greenstone outcrop. Griffin and others (1983a; 1983b) have suggested tectonic dislocation and stacking of the original sequences as a model for development of greenstones now exposed in the Kalgoorlie–Widgiemooltha area. This style of deformation in a metamorphic terrane can be difficult to recognize, and may account for many problems in determining original stratigraphic sequences and making correlations across strike.

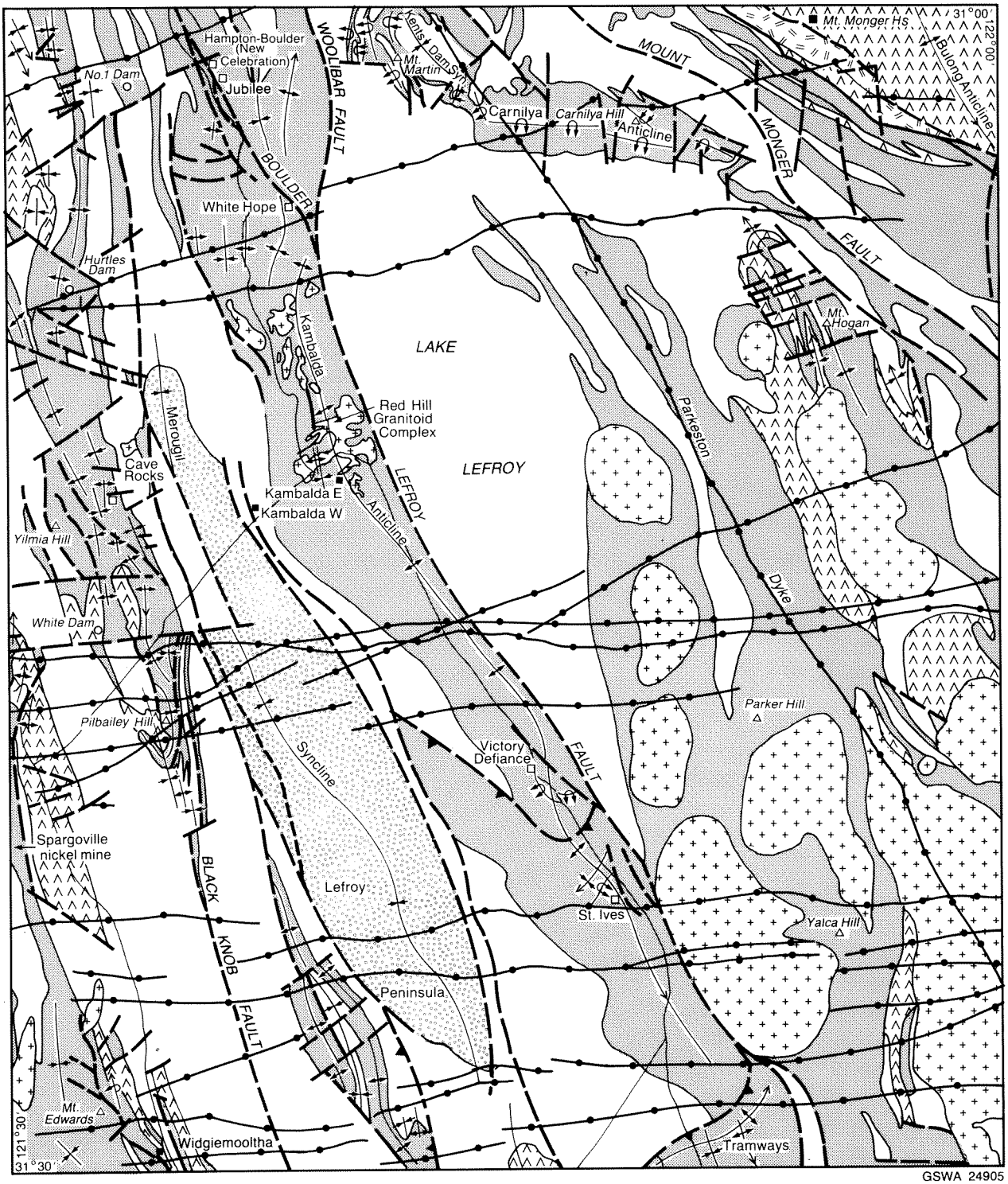
A very broad stratigraphy can be recognized in most outcropping belts (Fig. 3). It consists of a basal part dominated by mafic and ultramafic subaqueous volcanic rocks, with ultramafic rocks generally low in the succession. Overlying this basal unit, and probably transitional from it, is a thick sequence of metamorphosed felsic volcanic rocks and fine-grained metasedimentary rocks. The metamorphosed felsic volcanic rocks are more abundant at the base. The metasedimentary rocks are dominated by rocks from a subaqueous environment and include areas of metaturbidite. The youngest rocks of the greenstones are metamorphosed, fluviatile, polymictic conglomerate and sandstone of the Merougil beds. Mafic and ultramafic sills intrude the sequence and appear to be related to the mafic–ultramafic volcanism.

Recognition of this stratigraphic succession in different belts does not necessarily indicate that they are the same age. Rather, it suggests that the same model for development can be applied, either as part of the same depositional basin, or as equivalent but separate basins in time and space, or as a repeating cycle (Williams, 1975; Gemuts and Theron, 1975).

Maximum stratigraphic thicknesses for the units, based on the Kalgoorlie–Kambalda belt (Groves and Gee, 1980), are 3000 m of mafic–ultramafic rocks and 3000 m of metamorphosed felsic volcanics and metasedimentary rocks. In west LAKE LEFROY the metamorphosed felsic volcanic rocks alone reach a thickness of 3000 m and are overlain by a substantial but indeterminate thickness of metasedimentary rocks. This indicates that there is a wide range in thickness of felsic volcanic and sedimentary rocks throughout LAKE LEFROY and COWAN. The Merougil beds, 2300 m thick, were deposited in a restricted basin on deformed greenstones.

The basement to the greenstones and the nature and thickness of further greenstone material below the lowest rocks seen in the Kambalda Anticline are unknown. Archibald and Bettenay (1977), Gee (1979), and Archibald and others (1978, 1981) have considered the Fifty Mile Tank Gneiss as basement to the greenstones; however, the data is inconclusive and the gneiss could equally represent a tectonic fragment of highly veined and deformed intrusive granitoid from within the granite–greenstone terrane (Griffin, 1989). Work by Compston and others (1984a, 1984b) indicates that the metabasalt and metakomatiite at Kambalda was extruded through old sialic crust.

The majority of granitoids show evidence of recrystallization due to the influence of regional metamorphism. The effects are generally heterogeneous; however, some of the most intensely deformed and recrystallized granitoids are considered to be older than those less deformed. A subdivision has been made into syntectonic and post-tectonic types by Archibald and Bettenay (1977), with the second group containing evidence of static recrystallization. There is gradation between the two groups; it is possible that the granitoids were intruded over a long period, beginning as sub-volcanic phases to the felsic volcanism of the greenstone succession (as suggested for the Laverton–Leonora area by Hallberg, 1986) and continuing to final stages of the tectonism that saw this part of the crust cratonized prior to intrusion of Proterozoic mafic–ultramafic dykes at ca. 2400 Ma (Turek, 1966; Fletcher and others, 1987).


Hampton-Boulder (New Celebration)
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BOULDER
Lens Dam
Syn
Mt. Martin
Carnilya
Carnilya Hill Anticline
MOUNT MONGER FAULT
Mt. Monger Hs
Bulong Anticline
White Hope
Hurtles Dam
Kambalda
LAKE
Red Hill Granitoid Complex
LEFROY
Parkeston
Mt. Hogan
Merougil
Cave Rocks
Kambalda E
Kambalda W
LEFROY Anticline
Yilmia Hill
White Dam
Dyke
Parker Hill
Pilbailey Hill
Syncline
Victory Defiance
FAULT
Spargoville nickel mine
BLACK KNOB FAULT
Lefroy
St. Ives
Yalca Hill
Peninsula
Mt. Edwards
Widgiemooltha
Tramways
31°00'
122°00'
121°30'
31°30'
GSWA 24905
Proterozoic mafic and ultramafic dyke
Merougil Beds
Metasedimentary rocks, including felsic volcaniclastics and minor metamorphosed felsic volcanics
Metamorphosed felsic volanics
Metakomatiite, metabasalt and metamorphosed mafic and ultramafic sills
Metamorphosed ultramafic intrusive rocks
Granitoid
Quartzo-feldspathic gneiss
Lake boundary
Fault
Thrust
Concealed Fault
Fold axis
Overturned fold axis
Road

Figure 2. Simplified interpretive Precambrian geology of LAKE LEFROY and COWAN.

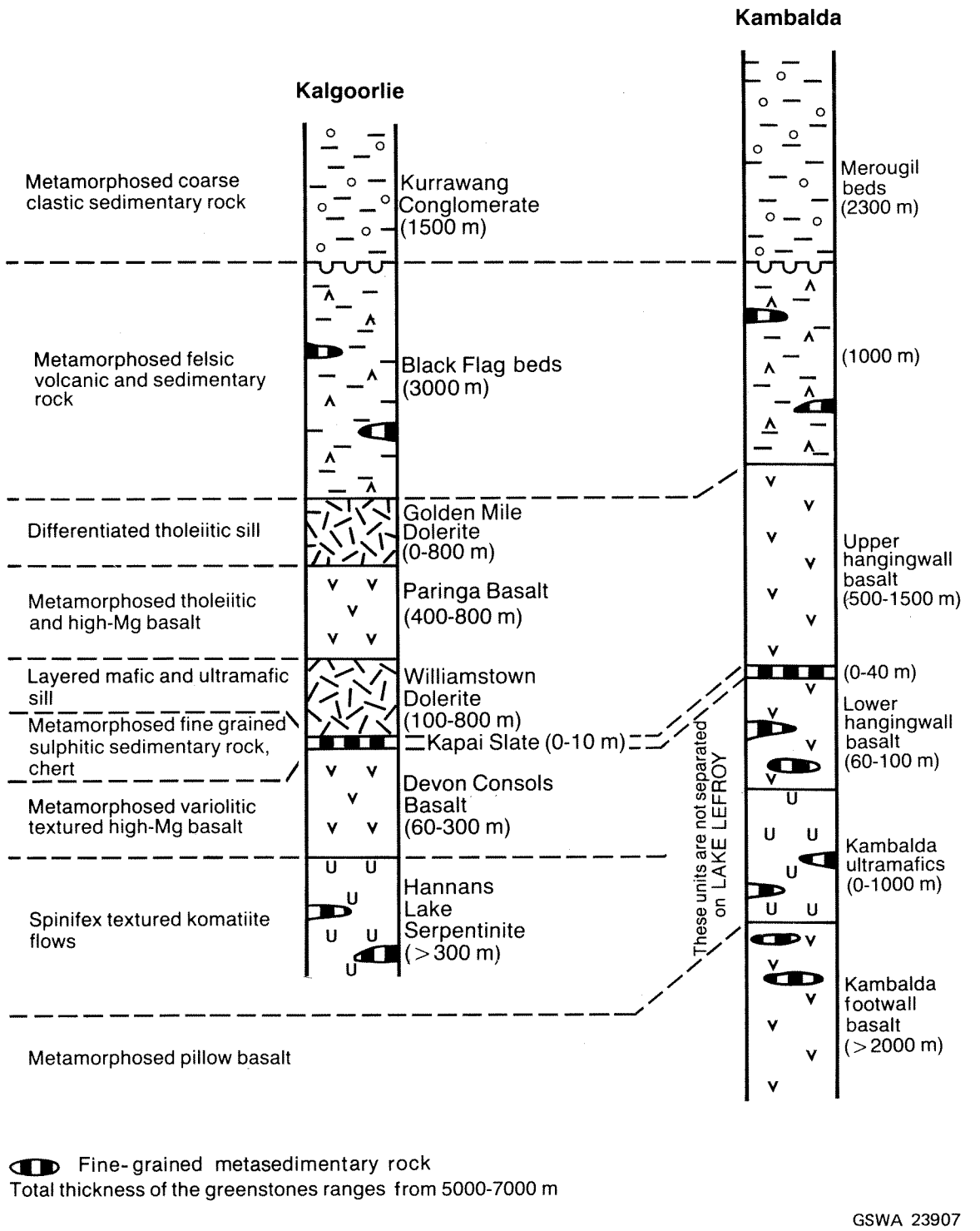


Figure 3. **Broad stratigraphic sequence for the greenstones based on stratigraphic work at Kambalda (Gresham and Loftus-Hills, 1981) and Kalgoorlie (Travis and Woodall, 1975).**

Greenstones

Metamorphosed mafic and ulframafic volcanic rocks

LAKE LEFROY and COWAN contain examples of a wide range of metamorphosed mafic and ultramafic intrusive and extrusive rocks (*Ab*, *Au*). In particular, the area includes large volumes of metakomatiite and metamorphosed high-Mg basalt—rock types that characterize Archaean greenstone belts. Following from Griffin (1989), the nomenclature adopted for mafic and ultramafic rocks is based largely on field criteria that take account of the low-grade metamorphism and deep weathering:

(a) Metakomatiite—Ultramafic flow rocks dominated by talc, serpentine, tremolite and chlorite. Platy "spinifex" texture after olivine is distinctive (MgO >18%; Arndt and Nisbet, 1982).

(b) Metamorphosed high-Mg basalt—Mafic rocks characterized by fibrous amphibole after acicular pyroxene "spinifex" texture, and/or variolitic (ocelli) texture. Tremolite–actinolite, chlorite, and plagioclase dominate the mineralogy (MgO approximately 9–18%; Williams, 1972; Hallberg and Williams, 1972; Arndt and Nisbet, 1982).

(c) Metatholeiite—Aphyric or plagioclase-phyric rocks dominated by actinolite–hornblende and feldspar (generally MgO < 9%).

Metakomatiite

Metakomatiite (*Aku*) is widespread on LAKE LEFROY and COWAN, with a mineralogy that reflects metamorphism from greenschist to middle amphibolite grade. These rocks were derived from flows of peridotitic or picritic bulk compositions. Some flows are zoned, particularly the thicker ones. The basal part has a cumulate texture and the upper part a platy "spinifex" texture with lower MgO content. There is often quenching at the contacts, both top and bottom (Fig. 4). The Kambalda area contains many examples of zoned metakomatiite flows, well documented during nickel mining (Ross and Hopkins, 1975; Gresham and Loftus-Hills, 1981; Groves and Lesher, 1982). They provide valuable facing information, critical to understanding both the complex local structure, and the distribution of nickel ore, which is located preferentially at the base of the thickest flows.

The metakomatiite consists of tremolite, chlorite, serpentine (antigorite), talc, magnetite, and carbonate. Primary olivine and pyroxene are sometimes observed as relict phases; metamorphic clinopyroxene and olivine, subsequently retrogressed, have also been seen (Groves and Gee, 1980). Metakomatiite flows are generally from 1 to 10 m thick, although flows over 100 m have been recorded at Kambalda (Gresham and Loftus-Hills, 1981). Fine-grained metasedimentary rocks are present in most sequences of metakomatiite; between flows, metakomatiite is generally associated, spatially and temporally, with metamorphosed high-Mg basalt and dolerite. In many areas the metakomatiite units are thin and interlayered with a range of rock types that include pelitic schist and metamorphosed felsic volcanic rocks. Consequently, units shown on the maps represent only the dominant lithology, but in detail they include a range of lithologies with complex relationships.

The ultramafic volcanics are generally highly magnetic and can be traced through areas of poor outcrop on aeromagnetic maps, thus assisting correlation along greenstone belts.

Geochemistry

The geochemistry of 69 metakomatiite samples from the Lunnon mine at Kambalda are averaged and plotted in Figure 5 (Ross and Hopkins, 1975). These rocks, along with data summarized by Groves and others (1982) for the Norseman–Wiluna zone, show that metakomatiite is characterized by CaO/Al_2O_3 ratio equal to 1 which contrasts with the first defined komatiites from Barberton which have CaO/Al_2O_3 ratio greater than 1 (Nesbitt and others, 1979). MgO contents are very high, and range from 23 to 44% MgO at Lunnon. The Al_2O_3/TiO_2 ratio equals 20; total alkalis are very low, although this is probably in part an alteration effect. Ni and Cr contents are high. Groves and Lesher (1982) reported that metakomatiite has near-chondritic trace-element ratios and is strongly depleted in light rare-earth elements (LREE).

Metabasalt

Metamorphosed high-Mg basalt (*Abm*) dominates the mafic rocks on LAKE LEFROY and COWAN. In many places they contain obvious pillow structures and flow-generated breccia. Thin interflow metasedimentary units are abundant. The rocks consist of tremolite–actinolite, chlorite, plagioclase, albite, carbonate, epidote, quartz, biotite and hornblende, in variable proportions depending on metamorphic grade and composition. Some of the metamorphosed high-Mg basalt has prominent variolitic textures with a wide range in both the size of variolites (2–20 mm) and the density of distribution. In some rocks the variolites coalesce to form large patches, and occasionally form an unusual surface texture of

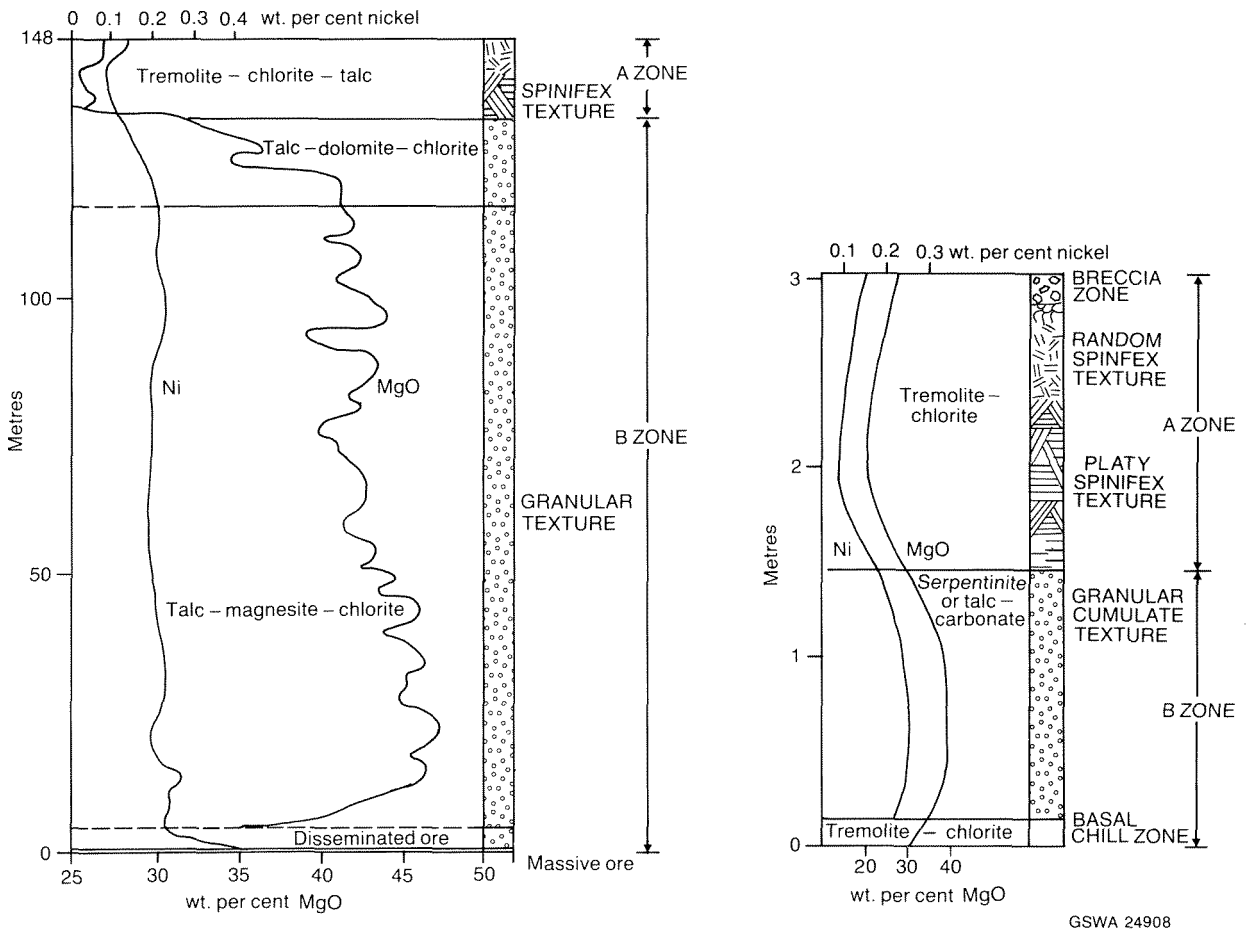


Figure 4. **Diagrammatic sections and geochemical profiles through a thick mineralized metakomatiite flow unit differentiated from olivine peridotite to picrite; and a thin barren flow unit differentiated from peridotite to picrite (from Marston, 1984).**

rounded bumps and hollows. Fibrous "spinifex" textures are also common where secondary amphibole has replaced original acicular pyroxene.

Metamorphosed tholeiitic basalt is widespread, and has been described from several areas on LAKE LEFROY and COWAN (Lake Zot, Higginsville, Lefroy Peninsula, Widgiemooltha, Mount Monger) by Hallberg and Williams (1972) and Hallberg (1972). However, apart from the Kambalda footwall basalt (*Abt*), no major units of tholeiitic metabasalt have been recognized. Rather, the metatholeiites are thin units closely associated with metamorphosed high-Mg basalt with characteristic spinifex and variolitic textures.

Metatholeiitic basalts are aphyric or plagioclase-phyric and contain plagioclase, actinolite, quartz, and epidote. Hornblende and biotite are abundant at the highest metamorphic grades. Ilmenite and magnetite are accessory phases. Clinozoisite, carbonate, and chlorite are minor components.

The metamorphosed tholeiitic and high-Mg basalts appear chemically continuous on Figure 5. Redman and Keays (1985) present textural and geochemical data on the mafic volcanics of the southern part of the Eastern Goldfields Province, and include material from LAKE LEFROY and COWAN (Kambalda, Yilmia, Redross, Hayes Hill/Eundynie). They recognized three distinctive suites:

(a) Low-magnesian series basalts (LMSB), characterized by intergranular textures, generally contain less than 9.5% MgO and are typically depleted in the more incompatible elements.

(b) High-magnesian series basalts (HMSB), characterized by skeletal textures, have both high MgO (9.5–14%) and low MgO (< 9.5%) types, and are typically variably depleted in the more incompatible elements (Rb, Ba, Th, K, and light REE) relative to compatible elements (heavy REE, P, Zr, Ti, and Y).

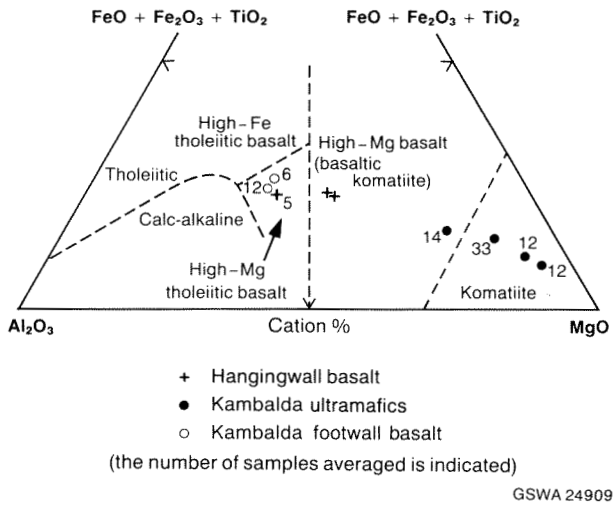


Figure 5. **Cation percent plot of mafic and ultramafic volcanic rocks from LAKE LEFROY and COWAN illustrating the chemical continuity between high-Mg and tholeiitic types. Data from Ross and Hopkins (1975), Hallberg (1972), Gresham and Loftus-Hills (1981), and Redman and Keays (1985).**

(c) Siliceous high-magnesian basalts (SHMSB), characterized by high MgO and variolitic, spinifex and skeletal textures, are enriched in SiO_2 (52–55%), Rb, Ba, Th, K, Zr, and light REE relative to HMSB.

Redman and Keays (1985) conclude that the HMSB and SHMSB constitute differentiation series which contain high-MgO and low-MgO members. The HMSB and LMSB were derived from source regions in the mantle which were variably depleted in incompatible elements, similar to those regions that produced komatiite. The differences between the volcanic suites are caused by variation in the degree of partial melting (Redman and Keays, 1985). The mantle source regions for SHMSB were variably enriched in incompatible elements and water, according to Redman and Keays (1985). Figures 6A and 6B illustrate the considerable large-ion lithophile element heterogeneity in the mafic and ultramafic volcanics, which Redman and Keays (1985) interpreted as reflecting heterogeneity within the Archaean upper mantle, since large degrees of partial melting are envisaged. However, Barley (1986) argued that contamination of partial melts of komatiite or HMSB compositions by assimilation of sialic crust could lead to the level of enrichment of incompatible elements observed by Redman and Keays (1985).

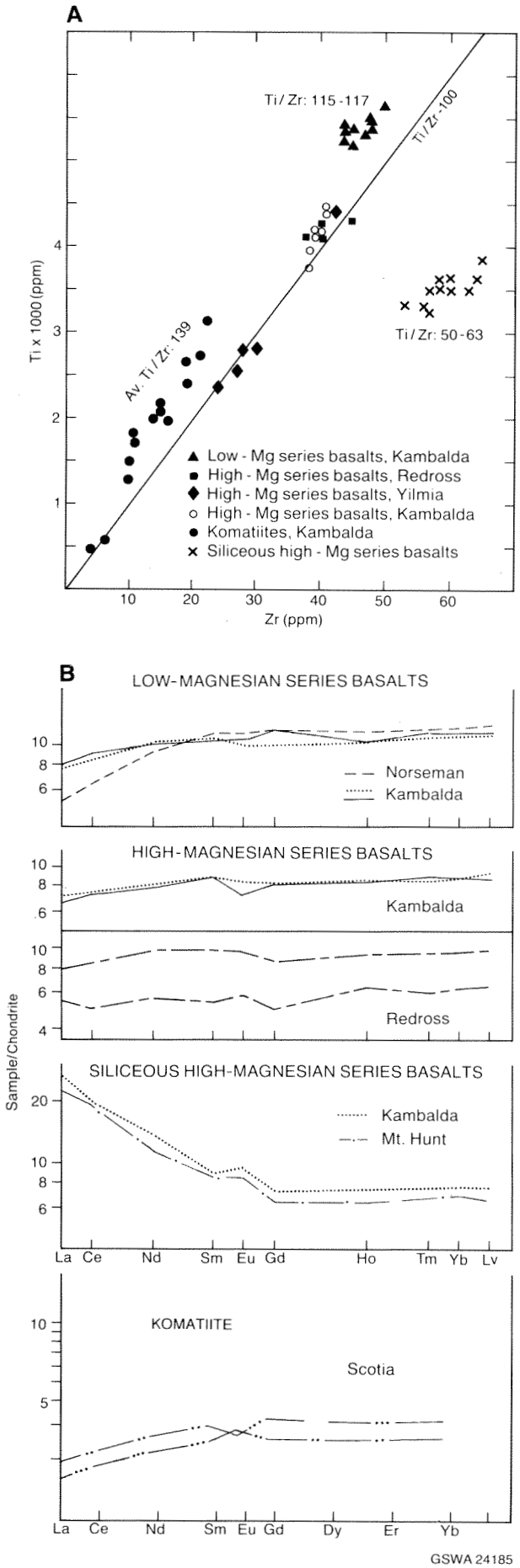


Figure 6. **Chemical plots illustrating heterogeneity of large-ion lithophile elements in mafic and ultramafic volcanics at Kambalda (from Redman and Keays, 1985). A. Ti–Zr plot. B. Chondritic-normalized REE plots.**

Metamorphosed mafic and ultramafic sills

Mafic and ultramafic intrusive rocks (*Ao*) include metadolerite *(Aod)*, and metagabbro (*Aog*), metaperidotite, metapyroxenite and metanorite (*Aou*). Most occur as sills within the mafic and ultramafic volcanic sequences, but some intrude metasedimentary rocks, such as at Cutters Luck northeast of Kambalda. These sills range in thickness from a few metres to 1000 m (e.g. at Mount Monger, which, at 7 km, is also the longest sill). Deformation has disrupted sill units in the Mount Monger and Yilmia areas causing off-sets along strike, and possibly repetition by folding and tectonic interleaving (Griffin and others, 1983b). The sills are metamorphosed, and comprise tremolite–actinolite, hornblende, chlorite and albite. Primary subophitic textures are preserved. Most of the larger bodies are differentiated; the mineralogy of the ultramafic basal zone is dominated by chlorite, serpentine, talc and tremolite. Relict textures and mineralogy include cumulus olivine and orthopyroxene in the basal zone, and orthopyroxene, clinopyroxene and plagioclase in the upper mafic zone (McCall and Doepel, 1969; Williams and Hallberg, 1973). Details of mineralogical layering in the Yilmia Sill are provided by McCall and Doepel (1969), and in the Mount Monger and nearby Seabrook Sills by Williams and Hallberg (1973). Rhythmic layering, involving plagioclase and actinolite (after pyroxene), is often seen in the thick gabbroic zones at Yilmia. Strongly serpentinized ultramafic rock dominates sills west of Lake Cowan in southern COWAN. These are possibly an extension of the Mount Thirsty and Mission Sill Complexes on NORSEMAN 1:250 000 sheet (Doepel, 1973; Gemuts and Theron, 1975).

Mafic and ultramafic sills are often parallel to thin grey and black slate units that presumably provide an extensive fissile zone within the sequence of metabasalt and metakomatiite, into which the mafic magmas can readily intrude and develop as extensive layered sills. Thick sills in many places acted as competent masses within the greenstone pile during deformation and have formed open folds (e.g. Mount Monger and Stony Hill), which resisted recrystallization and cleavage development—in contrast to the tight folds preserved in the metasedimentary rocks. The strain has largely been absorbed by surrounding rocks and in shear zones on the contact.

The mafic–ultramafic sills are regarded as an integral part of the greenstone succession; they probably intruded during, or soon after, the major phase of mafic–ultramafic volcanism. Williams and Hallberg (1973), from field and chemical evidence, suggest that they are genetically associated with, and probably subvolcanic to, the metamorphosed high-Mg basalts (Fig. 7). The lack of discordant relationships indicates that these rocks were intruded prior to deformation of the greenstones.

Metamorphosed felsic volcanic rocks

Metamorphosed felsic agglomerate, flow-banded felsic lava, felsic tuff *(Aft)*; and a variety of quartz-feldspar porphyries *(Afp)* are widespread on LAKE LEFROY and COWAN. Both extrusive and intrusive porphyry are recognized, although metamorphism and deformation makes the distinction difficult. Interlayered volcanic and volcaniclastic sedimentary units *(Afv)* from proximal volcanics, such as the metaconglomerate exposed on the Mount Edwards microwave tower road, northwest of Widgiemooltha, are included in this unit.

The metamorphosed felsic volcanic rocks are generally dacitic, and consist of quartz, feldspar, and minor sericite, chlorite after biotite, carbonate and pyrite. Subhedral quartz phenocrysts are embayed. Feldspar phenocrysts are subhedral albite, and most feldspar is altered to clinozoisite, chlorite and sericite.

Coarse angular clasts in metamorphosed agglomerate are indistinguishable from the matrix, except on some weathered surfaces such as 2 km east of the Coolgardie–Esperance Highway on the Kambalda road. Flow-banding is preserved in fine-grained porphyritic rocks south of Paris mine, south of Mount Hogan, and southeast of Hinamoa mine. Most laminated units, interbedded and spatially associated with the metamorphosed flows and agglomerate, are interpreted as metamorphosed tuff beds. Original fine fragmental texture is evident in some weathered exposures.

The largest areas of metamorphosed felsic volcanic rocks on northeast LAKE LEFROY are only mildly deformed and contain a weak foliation. This area has been subdivided into metamorphosed intrusive rhyodacite and dacite porphyry (*Afp*), and dacite and rhyolite agglomerate and tuff (*Aft*), based primarily on work on YILMIA 1:100 000 sheet (Hunter, in press b). These large areas of metamorphosed felsic volcanics appear to have acted as competent masses, while most of the strain has been taken up by adjacent metasedimentary rock or metabasalt.

The metamorphosed felsic rocks are interbedded with, and grade into, the metamorphosed sedimentary sequences. The felsic rocks are the most likely source for most of the sedimentary detritus.

Minor metamorphosed andesitic volcanics (*Ais*) occur with metamorphosed volcaniclastic sedimentary rocks east of Mount Monger homestead (Hickman, 1986).

Quartz–feldspar–sericite schist (*Afs*), comprising feldspar, quartz, sericite, and minor chlorite, biotite, carbonate and pyrite, is abundant throughout the greenstone sequences. Deformation and metamorphism

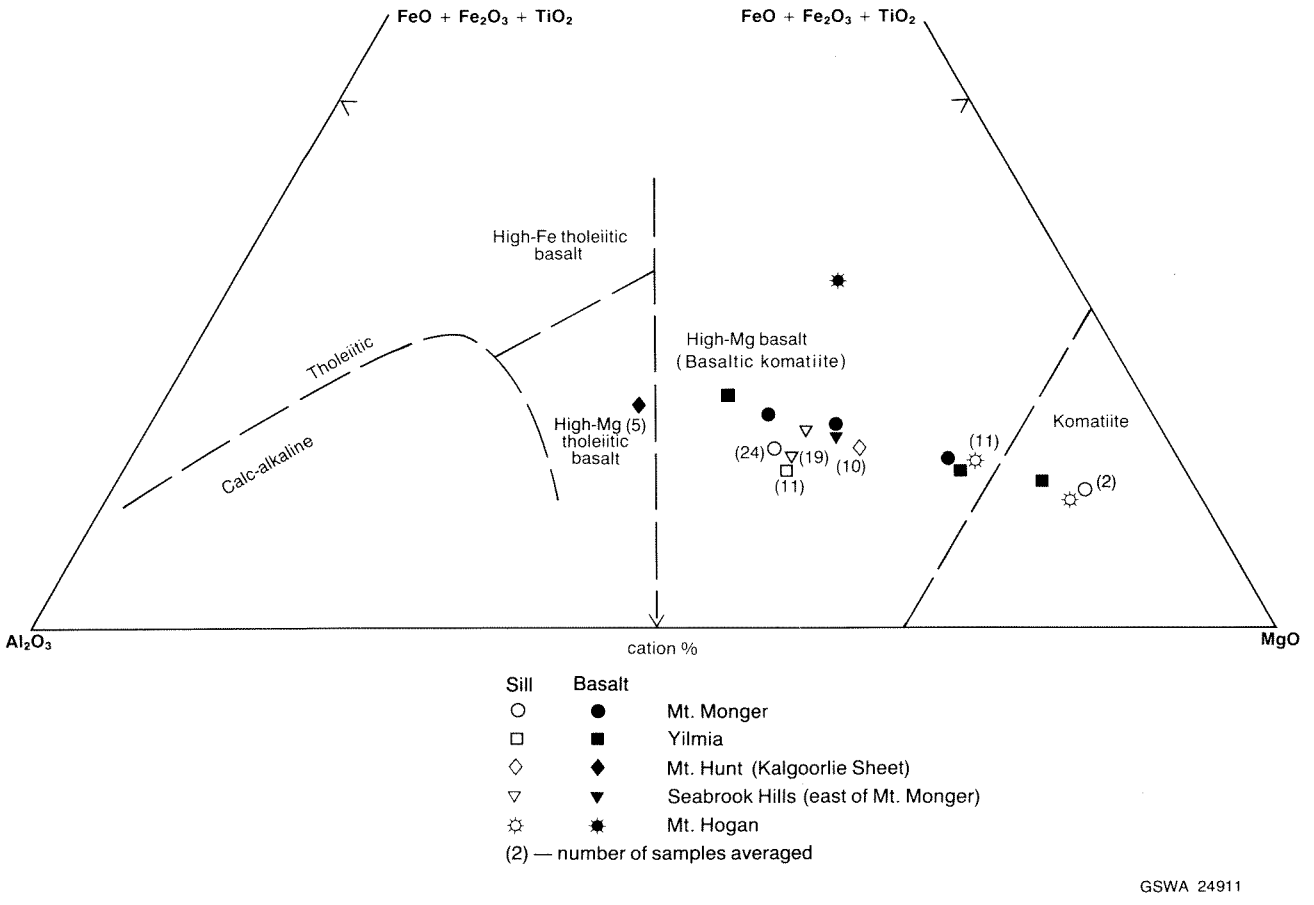


Figure 7. Cation percent plot of mafic and ultramafic sills, with adjacent basalts. Data from Hallberg and Williams (1972), Williams (1972), and Williams and Hallberg (1973).

have destroyed the primary textures which would have enabled these rocks to be classified as either metamorphosed felsic volcanic or sedimentary rocks.

Metasedimentary rocks

Archaean metasedimentary rocks (*As*) occupy large areas, but these generally have few outcrops. The metasedimentary rocks also form thin, fine-grained units interlayered with the mafic–ultramafic rocks.

Pelitic and psammitic rocks

These are generally deeply weathered, and outcrops are restricted to low country and around lakes. Large areas are recognized from a distinct mottled airphoto pattern, and open grassland with scattered eucalypts. Outcrop is generally sparse, but siltstone fragments occur in the soil. These areas are shown on the map by the symbol *Czc/As*. The deep weathering pre-dated the deposition of Upper Eocene deposits, since trace fossils, such as burrows, can be observed in the metasedimentary rocks at several localities in northwest LAKE LEFROY, below Tertiary sandstone that lies unconformably on the Archaean rocks (Griffin, 1989).

Most metasedimentary rocks on LAKE LEFROY and COWAN are derived from pebbly sandstone, sandstone, siltstone and shale with a generally high felsic volcanic component (*Asf*). Coarse, graded and cross-stratified sandy beds (*Asg*) are widespread,and interbedded with laminated siltstone. Slump, scour, and flame structures are abundant. The well exposed clastic sequence (*Asw*) at Mount Belches east of LAKE LEFROY (Griffin, 1989) has been attributed to deposition in a turbidite environment (Dunbar and McCall, 1971). A similar environment was probably responsible for the large, poorly exposed areas of clastic rocks on LAKE LEFROY and COWAN.

Small lenses of laminated carbonaceous shale, associated with fine-grained pelitic schist within metasedimentary sequences, have been observed in the Widgiemooltha area (Archibald, 1979) and the Mount Hogan area. The origin of these rocks is uncertain; Archibald (1979) has attributed those at Widgiemooltha to chemical deposition.

Small mafic schist outcrops occur in the Mount Martin–Carnilya Hill area. These rocks contain abundant hornblende and epidote in laminated sequences, and are

probably sedimentary in origin, derived locally from mafic rocks.

The metasedimentary rocks range from lower greenschist to middle amphibolite grade. They contain quartz, feldspar, biotite, chlorite, sericite and minor tourmaline. At low grades, deformed biotite is partly replaced by chlorite; at higher grades, secondary biotite replaces original clay minerals and also defines the foliation. Coarse random overgrowths of andalusite, staurolite, cordierite, garnet, kyanite and muscovite indicate that the peak of metamorphism was associated with low strain and post-dated the last major deformation event, at least in some areas. These rocks can be seen east of Widgiemooltha and northwest of Kambalda (Sofoulis, 1966; Archibald, 1979).

Metamorphosed volcaniclastic sedimentary rocks *(Asf)* are particularly abundant adjacent to felsic schist *(Afs)* and metamorphosed felsic volcanic rocks. They were probably deposited as subaqueous fans flanking felsic volcanoes.

The Merougil beds *(Asm)* (McCall and others, 1970) crop out within a large syncline in the southwest of LAKE LEFROY. They consist largely of fluvial, trough cross-bedded, pebbly sandstone and appear to represent the latest deposits in the Archaean, resting on metamorphosed sedimentary and felsic volcanic rocks above the thick mafic–ultramafic sequence.

Slate and thin silicified metamorphosed black shale *(Ash)*, and laminated chert *(Ach)* are abundant throughout the greenstone sequences, including the clastic metasedimentary rocks described above. Thin chert and slate units are important marker horizons in many areas, and are the only horizons which define mesoscopic folds. At the surface they are less than 5 m thick, generally only 1–2 m, and consist of quartz, and minor sericite, tourmaline and pyrite. Mine workings and drillcore indicate that the chert is the silicified surface expression of a variety of metamorphic rocks. These were derived from original siliceous chemical sedimentary rocks, sulphide-rich shale, carbonaceous shale, fine-grained felsic volcanic and volcaniclastic sedimentary rocks, and psammitic and pelitic sedimentary rocks (Bavington, 1981). In places these rocks are in contact with major mafic sills (such as in the Yilmia Hill area). They have been the loci of tectonic movements and many are strongly deformed.

Cherty, carbonaceous, and less abundant, thin, fine-grained chlorite or amphibole-rich rocks, between mafic–ultramafic flows at Kambalda, are interpreted as metasedimentary rocks by Bavington (1981). He considers them to be derived from both felsic and mafic–ultramafic sources, with exhalative addition of sulphur and chalcophile elements. Minor felsic volcanic material associated with the mafic–ultramafic flows probably represents detritus from explosive eruptions of a distant felsic volcano.

The metasedimentary cherts were presumably being precipitated continually, and their accumulations represent quiescent periods involving little detrital influx or volcanic activity.

Banded iron-formation (BIF) *(Aci)* is absent apparently from the main greenstone sequences on LAKE LEFROY and COWAN. This area of the Eastern Goldfields is dominated by mafic–ultramafic rocks and contains particularly thick sequences of ultramafics. BIF is present in greenstones to the west (Griffin, 1989), in particular at Mount Belches, and to the south, east of Norseman (Doepel, 1973).

Age

An Archaean age for the greenstones on LAKE LEFROY and COWAN is based on regional geochronological studies in the southern Eastern Goldfields Province by Turek and Compston (1971), Compston and Turek (1973), McCulloch and Compston (1981), Claoué-Long and others (1984), Fletcher and others (1984), and Chauvel and others (1985). Most of the recent work has been based on the greenstones at Kambalda. Sm–Nd isochron ages vary: 2790 ± 30 Ma (McCulloch and Compston, 1981); 3200 Ma (3262 ± 44 Ma, Claoué-Long and others, 1984); and on the same samples, 3230 ± 120 Ma, (Chauvel and others, 1985). Chauvel and others (1985) also obtained a Pb–Pb isochron age on these samples of 2730 ± 30 Ma and a 2700 Ma model age for associated sulphides. They argue that the younger age represents the age of formation of the volcanic sequence and that the Sm–Nd age is a function of mixing of rocks from at least two isotopically distinct sources. Compston and others (1984a, 1984b) have found xenocrystic zircons with U–Pb ages of 3500 Ma, 3100 Ma, and < 2700 Ma. They interpret these zircons as relics of felsic rock assimilated by the basaltic magma; they are regarded as evidence of contamination of magma that was younger than 2670 ± 10 Ma. The volcanic sequence has been intruded by a mildly deformed phase of the Red Hill Granitoid Complex that has a U–Pb zircon age of 2660 ± 10 Ma (Compston and others, 1984b; Gresham and Loftus-Hills, 1981). A slightly older age is indicated by a Pb–Pb isochron age of 2720 ± 105 Ma obtained by Roddick (1984), which he suggests represents either a metamorphic event or the time of emplacement of the metabasalts. Further work is required to resolve the conflicting data. However, an Archaean age for the greenstones in the range 2600 to 2800 Ma appears likely. Greenschist metamorphism at Kambalda has been dated at 2610 ± 30 Ma using a Rb–Sr isochron (Roddick, 1984).

Metamorphosed granitoid and gneiss

Granitoid

Granitoid rocks (*Ag*) occupy about 15% of LAKE LEFROY and less than 20% of COWAN. On LAKE LEFROY the outcrop is concentrated in the southeast, and on COWAN in the west, mainly in the Widgiemooltha Monzogranite and the Pioneer Granitoid Complex. Granitoid is very poorly exposed and extensive areas are overlain by laterite and soil; it intrudes all parts of the greenstone sequence, except the Merougil beds. Despite sparse outcrop, Landsat imagery, physiography, vegetation patterns, and aeromagnetic maps indicate that most of the granitoid bodies are ovoid. This is true of the large Pioneer Granitoid Complex, Widgiemooltha Monzogranite, and the small bodies east of Kambalda and St Ives on LAKE LEFROY. Some granitoids, such as the Red Hill Granitoid Complex at Kambalda, are irregular in shape and consist of many small bodies within the greenstones.

Most granitoids are foliated monzogranite with minor amounts of syenogranite and granodiorite. They consist of quartz, oligoclase, alkali feldspar and biotite, with accessory apatite, sphene, zircon and opaque minerals. Microcline occurs as phenocrysts. Euhedral oscillatory zoning in plagioclase indicates that the granitoids are of magmatic origin. Many granitoids are composite and show recrystallization textures and tectonic fabrics due to the effects of regional metamorphism. Recrystallized biotite and quartz define foliations.

Small intrusions of syenogranite, aplite, monzogranite, and granodiorite *(Ag, Ai)*, monzogranite porphyry and granodiorite porphyry (*Agf*), pegmatite (*Agp*), and porphyritic syenite *(Ags)* are abundant in the greenstone sequences. They occur as dykes or irregular masses.

The poorly exposed Pioneer Granitoid Complex (*Agn*) is dominated by foliated biotite monzogranite with abundant pegmatite intrusions, quartz veins and zones containing xenoliths of gneiss. The Pioneer Granitoid Complex intrudes the Fifty Mile Tank Gneiss in the east, and greenstones and other granitoids in other parts.

The Red Hill Granitoid Complex (*Agrh*) crops out as small irregular bodies and dykes within the mafic and ultramafic rocks at Kambalda and to the north. It consists of syenogranite, monzogranite porphyry and granodiorite porphyry which show a variety of intrusive, cross-cutting relationships. Rocks of this complex have been affected by regional metamorphism, resulting in recrystallized biotite which defines a weak foliation (Ross and Hopkins, 1975; Gresham and Loftus-Hills, 1981).

The Widgiemooltha Monzogranite (*Agw*) is a foliated, and locally strongly lineated, biotite monzogranite with microcline phenocrysts. It has been deformed and metamorphosed along with the surrounding mafic–ultramafic rocks. Deformed dykes of the Widgiemooltha Monzogranite intruded high-Mg basalt on the northeast contact.

Pegmatite (*Agp*) and quartz veins (*q*) of several generations are a minor component of the granitoid rocks. They are also present within the mafic–ultramafic and sedimentary parts of the greenstones. Pegmatite is prominent on the eastern contact of the Fifty Mile Tank Gneiss in mafic–ultramafic rocks, and in metasedimentary rocks north and northeast of Binneringie homestead. They consist of quartz, feldspar and muscovite, with minor biotite, lepidolite, tourmaline, and occasionally tantalite, cassiterite and beryl. Less-deformed pegmatites consistently cut more-deformed pegmatites, suggesting that there were several episodes of pegmatite intrusion. Large aprons of broken quartz, generally associated with an outcropping vein, are ubiquitous in areas of both outcrop and cover material.

Age

The granitoid rocks on LAKE LEFROY and COWAN are Archaean. Most were deformed and metamorphosed with the greenstones. They are cut by undeformed Proterozoic dykes. Most of the Rb–Sr ages, ranging from 2700 to 2550 Ma (de Laeter and others, 1981; Groves and Lesher, 1982; Griffin, 1989) probably reflect metamorphism (Roddick, 1984).

At Kambalda, Gresham and Loftus-Hills (1981) consider that a "sodic granite" of the Red Hill Granitoid Complex was emplaced after one phase of deformation and metamorphism, and before another. This rock was given a U–Pb age of 2820 Ma (Compston, 1980) but was subsequently revised to 2660 ± 10 Ma (Compston and others, 1984b). Younger felsic dykes intrude the granitoid complex and Compston (1980) has dated one dyke at 2560 ± 30 Ma by zircon and total-rock U–Pb work.

Gneiss

Gneiss (*An*) is exposed on COWAN; the major body is the Fifty Mile Tank Gneiss (*Ang*). This crops out over an area 18 km long and up to 2.5 km wide, east of the Pioneer Granitoid Complex. Small areas of gneiss have also been mapped along the southwest margin of the Pioneer Granitoid Complex and are also associated with foliated granitoid on the edge of the greenstones 13 km west of Redross mine. The Fifty Mile Tank Gneiss is a component

of the Pioneer dome (Binns and others, 1976; Archibald and others, 1981; McCulloch and others, 1983). This dome is defined by generally poor outcrop of granitoid, surrounded by greenstones.

The Fifty Mile Tank Gneiss (*Ang*) consists of two components that have distinctive patterns on aerial photographs: areas of dense vegetation with streaky or banded appearance; and mottled areas that are poorly vegetated. They form broad, subparallel bands usually 100 to 300 m wide, parallel to the small-scale gneissic banding. On the ground the two components reflect different proportions of pegmatite veins, parallel and subparallel to banding, but the boundaries between them are indistinct. The pegmatite veins, ranging from a few centimetres to 4 m in width, are deformed; locally they make up more than 50% of the outcrop.

Gneissic banding consists of light and dark fine-grained quartzo-feldspathic units which are indistinct in weathered outcrops. A strong foliation, generally parallel to the gneissic banding and defined by prefered orientation of biotite and biotite-rich bands, appears to truncate at low angles earlier compositional banding. In some places banding is marked by parallel mafic layers, which are interpreted as deformed and recrystallized mafic dykes or sills. Strongly lineated gneiss, on the eastern margin of Fifty Mile Tank Gneiss, is attributed by Archibald (1979) to emplacement of gneiss by solid state diapirism. However, it is more likely that the foliation and lineation are related to fold interference structures resulting from structural movements that produced the Pioneer dome.

Five phases of deformed pegmatite *(Angp)* are recognized in the gneiss; aplite dykes and small monzogranite porphyry intrusions also occur. The early pegmatite dykes are parallel to, and partly define, the gneissic banding. These pegmatites are boudinaged; they contain alkali-feldspar augen, show grain-size reduction during deformation and metamorphism, and are folded. The youngest pegmatites are only weakly deformed. Some have been intruded at a high angle to the gneissic banding, and can be traced into the pegmatite dykes that intrude the greenstones.

Banding of the gneiss is discordant with the foliation of the greenstones to the east, and the gneiss is intruded by late granitoid. The contact with the main Pioneer Granitoid Complex to the west is not exposed.

It appears that the Fifty Mile Tank Gneiss may be either surrounded by faults or intruded by porphyritic monzogranite in the west. The porphyritic monzogranite that dominates the Pioneer Granitoid Complex lacks a foliation seen in the Widgiemooltha Monzogranite to the north, and thus may be a younger intrusion. The Fifty Mile Tank Gneiss is more strongly deformed than either the granitoids or the greenstones. It was probably emplaced tectonically into its present position and then deformed and metamorphosed during the latest regional tectonic and metamorphic events which also affect in the adjacent granitoids and greenstones.

Age

Several authors have considered the gneiss to be basement to the greenstones and granitoids (Archibald and Bettenay, 1977; Gee, 1979; Archibald and others, 1978, 1981). However, evidence about the age of the gneiss is inconclusive. It includes recent Sm–Nd and Rb–Sr isotope studies by McCulloch and others (1983) on samples from Fifty Mile Tank Gneiss, and gneiss from elsewhere in the Eastern Goldfields Province, and Pb–Pb studies by Bickle and others (1983) on rocks from the Diemals area 350 km northwest of Widgiemooltha. The rocks from Fifty Mile Tank Gneiss form a three-point Sm–Nd isochron that gives an age of 2800 ± 150 Ma, which agrees well with the Rb–Sr isochron age of 2780 ± 60 Ma derived from samples from a wide region of the Eastern Goldfields (McCulloch and others, 1983). McCulloch and others (1983) conclude that the gneiss could be part of a craton that had been stable for less than 100 Ma prior to formation of the greenstones at 2720 ± 30 Ma (Pb–Pb isochron; Roddick, 1984), or 2790 ± 30 Ma (Sm–Nd isochron; McCulloch and Compston, 1981). The field evidence is inconclusive. This does suggest that if the Fifty Mile Tank Gneiss is not basement to the greenstones but is derived from intrusive granitoid by heterogeneous strain around the margin, then it did not form in its present position because its eastern contact with the greenstones is tectonically discordant. Either it has been structurally emplaced or its margins have been modified by a later tectonic event in the east. Younger granitoid phases have intruded the gneiss and greenstones, destroying earlier contact relations in the west.

The following evolutionary models have been proposed for formation of the Fifty Mile Tank Gneiss:

(a) The Fifty Mile Tank Gneiss may represent sialic basement on which the greenstone supercrustals were deposited (Archibald and Bettenay, 1977; Archibald and others, 1978, 1981; Gee, 1979). Exposure of the rocks has resulted from folding, and minor faulting on the contact (Fig. 8a). Old xenocrystic zircons in the Kambalda ultramafic rocks indicate that sialic crustal material did exist at the time of extrusion of the greenstones (Compston and others, 1984a, 1984b).

(b) The gneiss may represent a thrust slice of either sialic basement, or highly strained early granitoid (McCulloch and others, 1983) (Fig. 8b).

(c) The gneiss may represent a zone of high strain associated with the intrusion of granitoid (possibly as sheet-like bodies) into deforming greenstones (Myers and Watkins, 1985). Later granitoid intrusion has isolated the early gneissic phase (Fig. 8c).

(d) The gneiss may represent exposure of a core complex in an extensional environment which developed in the area of the sole fault (Wernicke, 1985) located on the contact between greenstones and the sialic material below (Fig. 8d). The sialic material could be sialic basement to the greenstones, or represent early granitoid intrusion into the base of the greenstones.

In all models the gneiss has been affected by the intrusion of late granitoid and by the regional north-northwest compressional deformation. The range of alternatives is wide, yet the evolution of the gneiss has important implications for the tectonic development of the granite–greenstone terrane of the Eastern Goldfields. Detailed isotopic dating and structural work is required to place constraints on these evolutionary models.

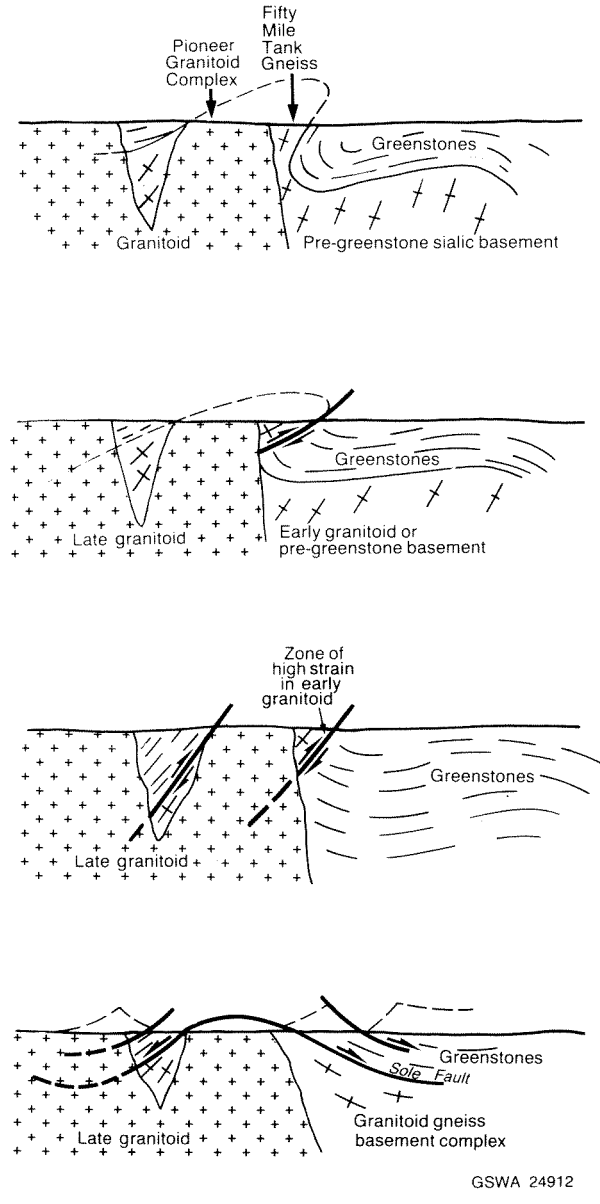


Figure 8. Schematic cross-sections illustrating models for the development of Fifty Mile Tank Gneiss:
(a) sialic basement,
(b) thrust slice,
(c) high strain zone associated with granitoid intrusion,
(d) exposed core complex in an extensional environment.

Geology of major areas of greenstone outcrop

This section describes the geology, and discusses the local stratigraphy and structure of the major exposures of greenstone on LAKE LEFROY and COWAN. Interpretation of structures has involved extensive use of aeromagnetic contour maps at 1:250 000 scale (BMR aeromagnetic survey, 1958) and 1:100 000 scale (Aerodata Holding Ltd, 1984–1985).

Kambalda

Interest in the greenstones at Kambalda has been stimulated by nickel and gold mining, and by the detailed geological work of Western Mining Corporation (WMC). Much has been written about Kambalda, as the type example of "volcanic peridotite" (komatiite) associated nickel deposits, and as the most intensively studied Archaean greenstones in the Yilgarn Craton (Ross and Hopkins, 1975; Gresham and Loftus-Hills, 1981; Marston, 1984; and many papers in Economic Geology, volume 76, no.6, 1981).

The most comprehensive discussion of the geology at Kambalda (Fig. 9) is by Gresham and Loftus-Hills (1981) and the geological outline that follows is based on that work.

The stratigraphy has been well established. It consists from the top downwards of: (a) fluvial Merougil beds at the top (Griffin, 1989), (b) clastic sedimentary rocks, (c) metamorphosed felsic volcanic rocks, (d) the hanging-wall metabasalts (split into lower and upper sequences separated by a black sulphidic slate horizon), (e) Kambalda ultramafics, (f) Kambalda footwall basalt.

Acid to intermediate intrusives are a minor component in the mafic-dominated units. Despite greenschist and some low-amphibolite metamorphism, enough primary textures and structures are preserved to allow igneous terminology to be used. A generalized stratigraphic column from Gresham and Loftus-Hills (1981) is illustrated in Figure 10.

Kambalda footwall basalt

The Kambalda footwall basalt is dominated by fine to medium-grained, dark-green, massive metabasalt, consisting of amphibole (actinolite–tremolite), chlorite, calcite and albite, with minor epidote and biotite. Pillow structures are abundant, vesicles are scarce, and flow-top breccia with carbonate-dominated matrix occurs locally. Variolitic and skeletal textures, typical of high-Mg basalt, are also present in some flows. Chemically the Kambalda footwall basalt is considered largely tholeiitic (Fig. 11) with MgO slightly greater than 8% (Gresham and Loftus-Hills, 1981).

Kambalda ultramafics

The Kambalda ultramafic rocks consist of a sequence of metakomatiite flows with MgO ranging from 15 to 48%. Three types are recognized: picrite (15–28% MgO); peridotite (28–36% MgO); and olivine peridotite (< 36% MgO) (Ross and Hopkins, 1975). The thickness of these rocks ranges from 0 to 1000 m. The lowest flows are the thickest (> 100 m), and contain nickel ore which is associated with the most magnesium-rich parts. In the non-ore areas, flows are less magnesium-rich and contain thin interflow metasedimentary rock horizons. Upper flows are generally thinner and less magnesium-rich and metasedimentary rock horizons are scarce. There is a broad trend of diminishing Mg-content upwards, although many reversals exist (Fig. 4).

Metamorphism and alteration are widespread and some relict chromite and rare cumulate olivine are preserved. Serpentine (antigorite), talc, chlorite and carbonate predominate. Chemical, textural and mineralogical profiles through komatiite flows at Kambalda are presented in Figure 4.

Interflow metasedimentary rocks

Thin metasedimentary horizons (< 5 m) are present on the contact between ultramafic rocks and the Kambalda footwall basalt, and between some flows in the lower part of the metakomatiite-dominated unit. The three main types present have been described in detail by Bavington (1979, 1981). The cherty and dark carbonaceous types are composed mainly of quartz and albite, and contain 15 to 20% pyrrhotite and pyrite. Alternating bands of sulphidic and cherty material make up some horizons. The less common chloritic metasedimentary rocks have small amounts of quartz and albite, but consist mainly of chlorite, biotite, tremolite, pyrrhotite and pyrite. These chloritic rocks are more common towards the ore environment. They may be stratigraphically equivalent to the cherty types (Bavington, 1981).

A massive, siliceous, albitic and variolitic zone occurs at the base of some interflow metasediments. The sediments are from mixed sources including both felsic and mafic–ultramafic volcanics, and an exhalative component which contributed sulphur (Bavington, 1981). The ocelli or varioles are similar to those common in many metamorphosed high-Mg basalts and may result from trapped immiscible sodium-rich and volatile-rich liquids from the underlying ultramafic flow (Bavington, 1981).

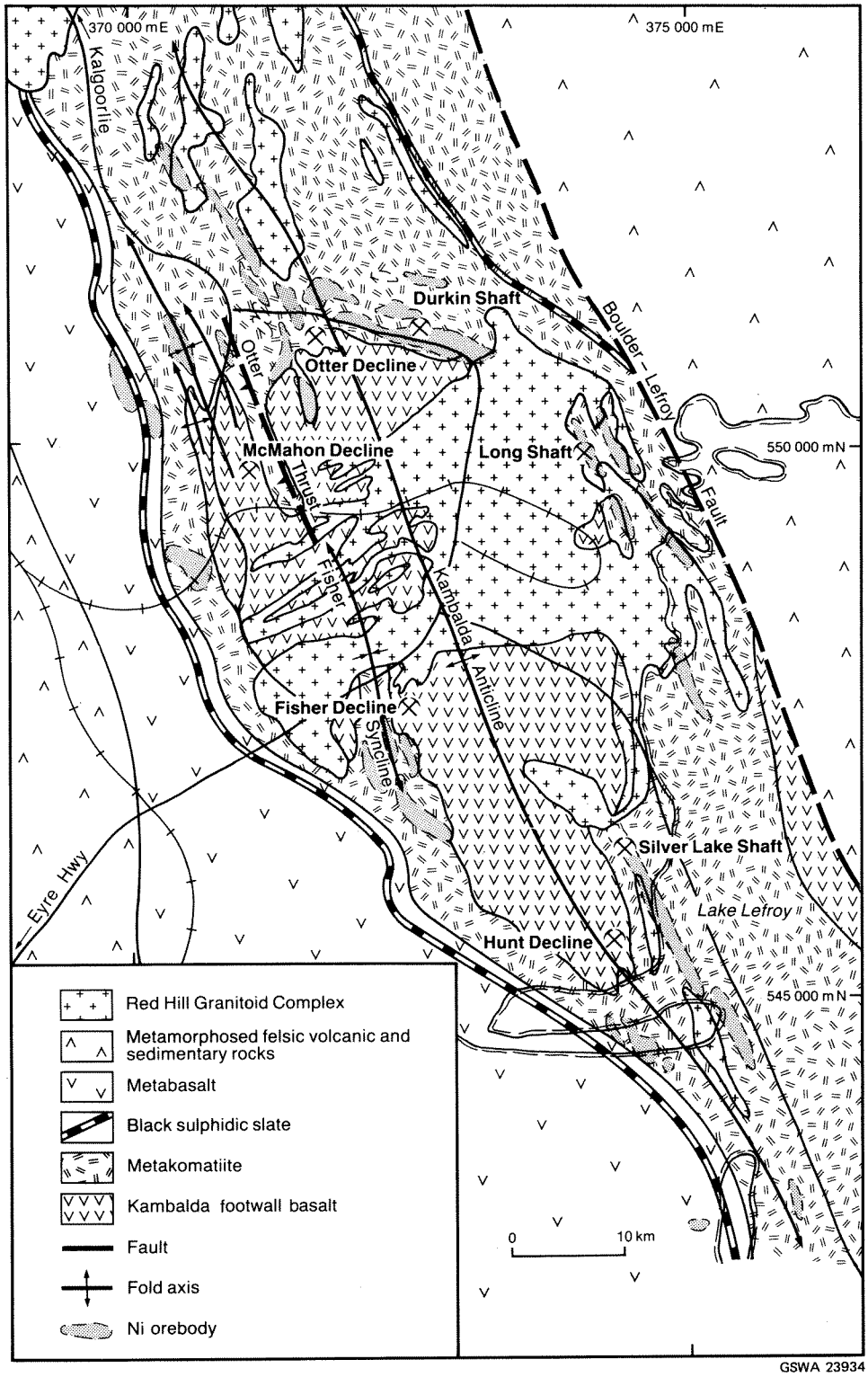


Figure 9. Geology of the Kambalda area (after Gresham and Loftus-Hills, 1981; Marston, 1984).

Hangingwall metabasalt

The hangingwall metabasalt is divided into an upper and a lower unit separated by a thin sulphidic metasediment (< 10 m thick) which includes siliceous chemical sediments and felsic volcanics (Bavington, 1981). The contact with the underlying ultramafic rocks is sharp at Kambalda. The lower unit is a 60 to 100 m thick sequence of metabasalt of high-Mg type with well developed pillows; felsic variolites are abundant. The upper part is rarely pillowed and variolites are less abundant. It also includes metamorphosed high-Mg basalt. Biotite is widespread and may indicate pervasive

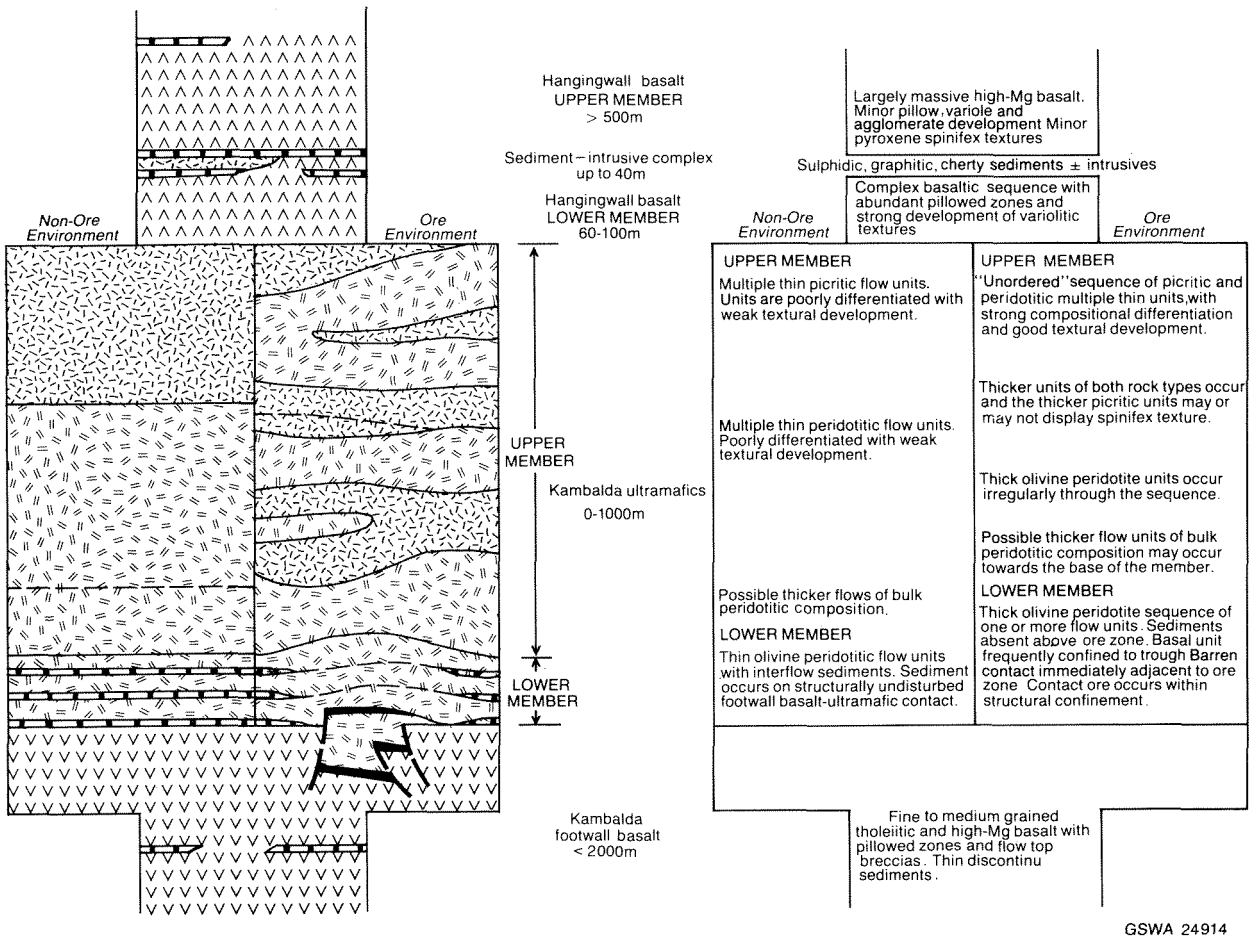


Figure 10. Stratigraphic column of greenstones at Kambalda including details of associated ore zones (from Gresham and Loftus-Hills, 1981).

potassic metasomatism, possibly associated with intrusion of felsic dykes (Gresham and Loftus-Hills, 1981).

Slate marker

The zone separating the lower and upper parts of the hangingwall metabasalt contains deformed meta-sedimentary rock and is intruded by acid and intermediate sills. Away from Kambalda the horizon is less well defined, such as in the Victory–St Ives area where the metasedimentary rock is distributed more widely through the metabasalt unit. The metasedimentary rocks are mainly the cherty type described earlier, and the main sulphide phases are pyrrhotite and pyrite.

The lower part of the hangingwall basalt has been included in the ultramafic unit on LAKE LEFROY, and on WIDGIEMOOLTHA 1:250 000 sheet (Griffin, 1989). Consequently the metasedimentary rock marker, equivalent to the Kapai Slate at Kalgoorlie (Fig. 3), is shown on the upper contact of the Kambalda ultramafic rocks.

Felsic volcanic rocks

Metamorphosed felsic volcanic rocks and associated clastic sedimentary rocks, up to 1000 m thick, are generally poorly exposed and overlie the mafic–ultramafic dominated sequence (Griffin, 1989).

Intrusives

Archaean intrusives at Kambalda include granitoids, acid and intermediate porphyries, and minor mafic dykes. These Archaean rocks are cut by undeformed Proterozoic mafic dykes. The coarse-grained, weakly porphyritic syenogranite, that dominates the Red Hill Granitoid Complex in the core of the Kambalda Dome, is an early phase that intrudes the greenstones. Rhyolite and dacite are present as porphyritic dykes and sills. Basaltic dykes are less common and generally pre-date the felsic dykes. Some felsic dykes intrude the syenogranite. Alteration haloes of biotite, chlorite and amphibole, around acid and intermediate intrusives, probably formed during regional metamorphism (Barrett and others, 1977; Marston and Kay, 1980).

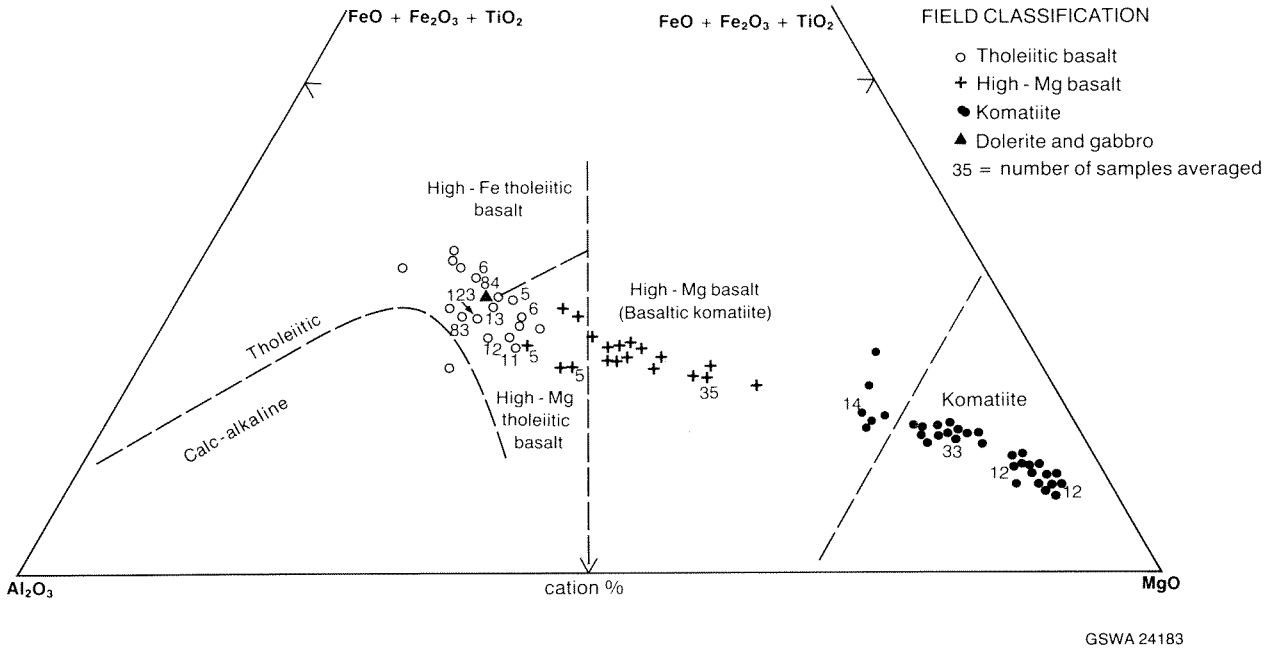


Figure 11. **Cation percent plot of metamorphosed mafic and ultramafic lavas at Kambalda. Data from Ross and Hopkins (1975), Gresham and Loftus-Hills (1981), and Redman and Keays (1985).**

Age

A "sodic" granodiorite from the Red Hill Granitoid Complex at Kambalda has been dated at 2660 ± 10 Ma using U–Pb on zircon grains (Compston and others, 1984b). This intruded the greenstone mafic–ultramafic sequence which is considered to be younger than 2670 ± 10 Ma (Compston and others, 1984a). The 3200 Ma age for the mafic–ultramafic sequence obtained by Claoué-Long and others (1984) (Sm–Nd whole rock isochron), is thought to be too old, and is the result of contamination by older crustal xenocrysts (Compston and others, 1984a; Chauvel and others, 1985; Bickle, 1984).

Nickel mineralization

Marston (1984) has reviewed the Kambalda nickel ores of the volcanic peridotite (komatiite) associated type and given details of all occurrences. The three main categories include:

(a) contact ore, occurring at the base of ultramafic rocks and usually lying directly on Kambalda footwall basalt in structural troughs that may have been original topographic troughs;

(b) hangingwall ore, ocurring in the lower part of the ultramafic rocks and usually stratiform; and

(c) offset ore, which has been structurally displaced from the contact or hangingwall positions.

Massive pyrrhotite, pentlandite, and pyrite are the common sulphides in the contact ore, and may be banded. Matrix ore, common in contact and hangingwall orebodies, has 40 to 80% sulphide; its interstitial silicates and sulphide mineralogy are similar to massive ore. Disseminated ore also occurs in contact and hangingwall orebodies with 10 to 40% sulphides. Contacts between ore types are generally sharp. Other rare ore types include blebby ore, spinifex ore, sedimentary ore, basalt breccia ore, and interpillow sulphide ore.

The nickel sulphide ore is thought to be of volcanic origin with segregation from the magma having occurred during vertical and horizontal transport. Deformation and metamorphism affected the ore; however, the extent of these processes is uncertain and contentious (Gresham and Loftus-Hills, 1981).

Gold mineralization

Gold has been mined in recent years at the Hunt nickel–gold mine on the southern end of the Kambalda Dome. The gold occurs as massive, vein-quartz ore at the contact between the Kambalda footwall basalt and the ultramafic rocks, and as disseminated ore in a sheared, quartz-veined and hydrothermally altered zone within the Kambalda footwall basalt (Phillips and Groves, 1982).

Structure

The major structure is the Kambalda Dome. This dome is part of the regional Kambalda Anticline; it extends

northwards for 60 km (past Kalgoorlie) and southwards for 55 km to the Republican–Democrat area. Dips to the west are 20 –50° but to the east they are steeper at 40 –70°; the anticline plunges to the north at about 35° and to the south at about 10°. Along its length there are various plunge reversals and faults that repeat the stratigraphy (Plates 1 and 2). On its western limb the sequence is repeated by folds and associated axial-plane faults—the Fisher Syncline and Otter Thrust (Fig. 9). Detailed rock relationships and structure for various parts of the dome are illustrated in Marston (1984, plate 2) and in Gresham and Loftus-Hills (1981). Numerous small faults and late felsic dykes disrupt the fold patterns and control the geometry of some ore shoots.

Geological history

The geological history of the Kambalda area is based on detailed and comprehensive work, primarily by WMC geologists. Many other areas of greenstones, particularly in the Widgiemooltha area, show lithological, stratigraphical, and structural similarities to those at Kambalda. The model outlined below probably has wide application therefore to greenstone belt development.

The model, presented in Figure 12, is based on the geological history proposed by Gresham and Loftus-Hills (1981). The most significant change from the account by Gresham and Loftus-Hills (1981) is the much younger revised age of 2660 Ma (Compston and others, 1984b) for the "sodic" granodiorite of the Red Hill Granitoid Complex, compared with the previous date of 2820 Ma (Compston, 1980). This removes much of the conflict relating to this felsic intrusive, which appears not to have been subjected to the full effects of the major metamorphism and deformation (see Gresham and Loftus-Hills, 1981). The "sodic" granodiorite was probably intruded during deformation and metamorphism.

The sequence of events at Kambalda was:

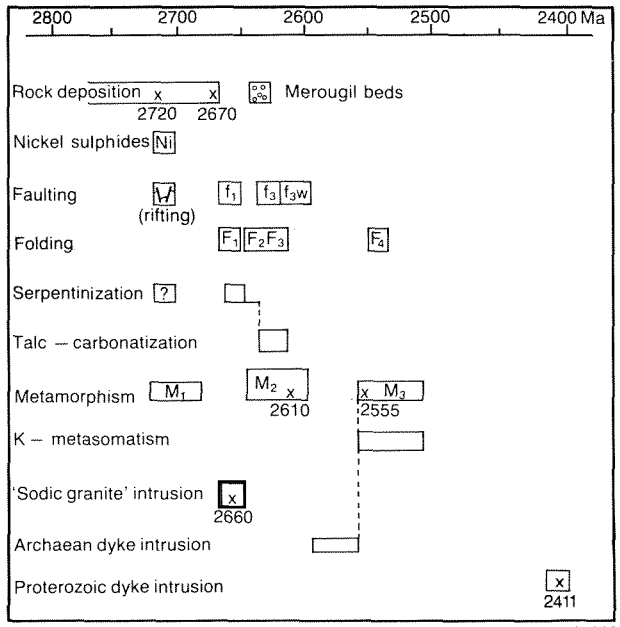
(1) deposition of the Kambalda supracrustals with modification by ocean-floor metamorphism/ alteration (M_1);

(2) deformation and development of f_1 thrusts and recumbent folds (F_1);

(3) (a) Commencement of second deformation,

(b) first peak of metamorphism (M_2) with talc–carbonate alteration, and

(c) intrusion of the Red Hill Granitoid Complex (the first granitoids intruded during the felsic volcanism and volcaniclastic sedimentation);



x Isotopic age data (Roddick, 1984; Compston and others, 1984 a, b, 1986; Fletcher and others, 1987)

Figure 12. Model for the geological history at Kambalda (after Gresham and Loftus-Hills, 1981).

(4) deposition of the Merougil beds containing clasts of mafic–ultramafic rocks, metasedimentary rocks, and granitoid;

(5) (a) north-northeast to northeast folding (F_3) forming the Kambalda Dome, and possible movement on the Lefroy Fault.

(b) emplacement of mafic, intermediate and felsic intrusives.

(c) onset of the second phase of regional metamorphism (M_3);

(6) dislocation of greenstones and intrusives by wrench faulting and associated folding (F_4);

(7) possible continued dyke emplacement; and

(8) intrusion of Proterozoic mafic dykes into stabilized crust.

White Hope–Hampton-Boulder (New Celebration)

The White Hope–Hampton-Boulder area straddles the highway between Kalgoorlie and Kambalda. The greenstones in this area are the northern extension of the Kambalda sequence, which on a regional scale, continue north into the Kalgoorlie sequence (Keats, 1987). Detailed work associated with mining operations at

Kalgoorlie and Kambalda suggest very close similarities in the stratigraphy of the two areas (Fig. 3) (Cowden and Archibald, in prep.). Consequently, it is appropriate to interpret the rocks in the White Hope–Hampton-Boulder area as having a similar stratigraphy and structural history. Poor outcrop and the absence of major mines results in a less well controlled interpretation of the geology (Griffin, and Hickman, 1988; and Plate 1) than at Kalgoorlie and Kambalda.

There is no substantial evidence for the existence of the lowest unit in the sequence, the Kambalda footwall basalt, despite the presence of fine-grained amphibolite as patchy weathered outcrops west of Hampton-Boulder. Metamorphosed high-Mg basalt is widespread, and characteristic variolitic textures, particularly in the lower parts, are also common. All outcrops of metabasalt are thought to be equivalent to the hangingwall sequence of high-Mg basalt at Kambalda, or its equivalent at Kalgoorlie (the Devon Consols Basalt and Paringa Basalt).

Black sulphidic shale, often silicified and bleached at the surface is present throughout the area; it may include more than one horizon close to the contact between metamorphosed high-Mg basalt and underlying metakomatiite. This is equivalent to the Kapai Slate (Fig. 3) at Kalgoorlie (Groves and others, 1982). Major sinistral wrench movement on the Boulder–Lefroy Fault (Swager, 1989), which cuts through the mafic–ultramafic rocks, disrupts the stratigraphy in the White Hope–Hampton-Boulder area.

White Hope

North of Kambalda the distinctive slate marker suggests that the north-plunging Kambalda Dome branches to several folds also with northerly plunges. The most prominent anticline, exposing the Kambalda ultramafics, swings north-northeast towards the White Hope mine where it is cut off by the Boulder–Lefroy Fault. The Otter Thrust/Anticline and the syncline to the west (Fig. 9) possibly extend north as more open structures. The slate marker is present as a disjointed unit, presumably folded and faulted, north of the Kambalda Dome, within a large area of monotonous metabasalt. Metagabbro is a prominent rock type in this area, whereas in the Kambalda area it is absent.

The western limit of the mafic–ultramafic rocks is faulted (Wildcatters Fault) in a zone containing attenuated folds that expose ultramafic schist and black slate adjacent to felsic schist.

The eastern margin of the mafic–ultramafic rocks is juxtaposed against extensively sheared felsic volcanics in the Boulder–Lefroy Fault. In the area of the White Hope gold mine the fault apparently branches, one part trends to the northwest (Boulder–Lefroy Fault), the other continues northwards into low country north of White Hope. The area is dominated by ultramafic rocks which pass into metamorphosed high-Mg basalt west of the fault, and metasedimentary rocks to the east. A north-trending upright anticline with northerly plunge is inferred within the ultramafics and metabasalt.

Hampton-Boulder (New Celebration)

The major regional anticline that joins Kalgoorlie and Kambalda is attenuated and faulted by the Boulder–Lefroy Fault in the Hampton-Boulder mine area, now the location of the New Celebration mine. Ultramafic schist and sheared felsic porphyry occupy the central part that contains the fault. To the west and east there are slate horizons and metamorphosed high-Mg basalt; metasedimentary rocks lie farther out. In a broad sense this relationship reflects the stratigraphy known at Kalgoorlie and Kambalda, and defines the regional anticline. To the east the outcrop indicates further regional folds. In detail the structure is complex with apparent strike faults.

Metagabbro sills are widespread and appear to disrupt the stratigraphy. However, they act as competent masses which resist deformation. Where exposed, contacts are usually faulted, such as on both the northern and southern contacts of the Stony Hill metagabbro, and deformation fabrics are very poorly developed within sills.

A western splay on the Boulder–Lefroy Fault continues south past Jubilee mine and separates metagabbro at Mount Goddard from metagabbro at Stony Hill.

West of Jubilee the ultramafic rocks are exposed in a south-plunging anticline with the structure partly defined by an ultramafic schist, slate and metabasalt sequence east of Mount Goddard.

Felsic intrusives, common in the Kambalda area, are not as abundant in the White Hope–Hampton-Boulder area. However, much of the gold mineralization in the Celebration to Golden Hope zone is associated with a sheared felsic porphyry in the Boulder–Lefroy Fault zone.

Undeformed Proterozoic mafic and ultramafic dykes cut the structures and have been dated at 2400 Ma (Turek, 1966; Fletcher and others, 1987). The most prominent are the Celebration Dyke in the north and Randalls Dyke in the south.

Victory–Defiance–St Ives

The Victory–Defiance–St Ives greenstones contain significant gold and nickel mineralization and host several important mines. The outcrop area is located 20 km across

the causeway south-southeast of Kambalda (Griffin and Hickman, 1988; and Plate 1).

The outcrop is generally poor, although low hills in the Jan mine and St Ives areas expose metabasalt, ultramafic schist and thin slate bands. These rocks outline a southeast-plunging anticline. The stratigraphy is correlated with that at Kambalda and Kalgoorlie (Gresham and Loftus-Hills, 1981; Clark and others, 1986).

St Ives

The ultramafic rocks contain platy spinifex textures in some areas. Talc and carbonate dominate the mineralogy with only minor antigorite. In the nickel mineralized areas, metakomatiite is less than 100 m thick, which is only half the thickness at Kambalda (Marston, 1984).

The metabasalt is generally heavily chloritized and includes high-Mg types with variolitic textures. The metabasalts immediately north of the ultramafic rocks in the core of the Kambalda anticline are fine-grained and heavily carbonated, and have been correlated with the Kambalda footwall basalt as they occupy the same stratigraphic position (Gresham and Loftus-Hills, 1981). These pass northwards into poorly exposed, coarse-textured metabasalt or metadolerite of the Victory–Defiance area, with a well-developed steep to vertical cleavage. A major fault has been interpreted to separate these rocks from the Kambalda footwall basalt to the south (Gresham and Loftus-Hills, 1981; Marston, 1984).

The Kambalda Anticline at St Ives has plunge reversals due to interference of a northeast-trending fold. This structure exposes Kambalda footwall basalt (Gresham and Loftus-Hills, 1981) and contains the Jan nickel mine in an anticline overturned to the northwest (Plate 1). Marston (1984) reports the possibility of a similar structure with a southeast-dipping axial plane just to the north on the faulted northeast limb of the open Kambalda Anticline. The area in between is faulted and attenuated.

The western limb of the Kambalda Anticline dips 45–70° southeast and contains abundant thin metasedimentary rock horizons, including one below the basal metakomatiite on the contact with the Kambalda footwall basalt. The nickel ore at Foster mine on this western limb is associated with the metakomatiite as a shallow, southeast-plunging shoot (Marston, 1984).

Victory–Defiance

The stratigraphy in the Victory–Defiance area is also equated with Kambalda and Kalgoorlie by recognition of the Kambalda ultramafics, lower hangingwall basalt, thin metasedimentary rock or chert marker horizon, and an overlying upper hangingwall basalt (Griffin and others, 1983b; Clark and others, 1986). A dolerite-textured phase is present in the hangingwall basalt, and hosts the Defiance gold lodes. The Victory mineralization is largely contained in a sulphide-rich part of a fine grained metasedimentary rock horizon within the hangingwall basalt (Clark and others, 1986). Outcrop is very poor and the structural interpretation (Plate 1) relies heavily on unpublished data from Western Mining Corporation.

Porphyritic felsic intrusives are present throughout the area as thin, sill-like bodies. They pre-date the gold mineralization which is largely associated with ductile to brittle deformation and quartz veining (Clark and others, 1986).

In an east–west traverse through the Victory and Defiance mines, the structure seems to include a north-trending syncline with an overturned west limb through the Defiance orebody. Anticlines are predicted to the east and west. These structures can be traced around a south-plunging anticline (possibly the Kambalda Anticline), across a fault into overturned folds with southeast-dipping limbs (similar to the structures on the northeast limb of the Kambalda Anticline at St Ives). Faults have disrupted these anticlines (Clark and others, 1986).

The deformation at Victory–Defiance includes early recumbent D_1 folds and regional F_3 folds. At St Ives the outcrop pattern reflects interference of F_3 folds on upright northeast F_2 folds (Plate 1).

Tramways

The Tramways greenstones are named after the Tramways group of prospects 40 km southeast of Kambalda across the causeway. Outcrop is poor and much of the geology, and resolution of the structure, relies on extensive drilling by WMC during nickel exploration (Gresham and Loftus-Hills, 1981; Marston, 1984).

Talc–carbonated metakomatiite and chloritized high-Mg basalt dominate the outcrop, They are associated with minor fine-grained metasedimentary rocks. In the southwestern part of the Tramways area porphyritic monzogranite intruded komatiite; it now forms resistant boulders. The best outcrop of metakomatiite is on the hornfelsed contact with a very poorly exposed east-northeast trending Proterozoic mafic dyke.

Thin metasedimentary beds within the mafic–ultramafic rocks are interpreted as discontinuous interflow units, deposited mainly during the transition from Kambalda footwall basalt to overlying metakomatiite. In the western part of the area, thin metasedimentary rock horizons are also present above the metakomatiite; these can be related to the chert marker

(Kapai Slate equivalent) above the thick metakomatiites at Kambalda. Gresham and Loftus-Hills (1981) correlate the whole sequence with that at Kambalda and consider that the outcrop pattern results from the interference of a northeast-trending anticline on regional north-northwest folds parallel to the Kambalda Anticline (Plates 1 and 2). The northeast-trending anticline swings sharply northwards in the east, where it is cut off by an extension of the the Boulder–Lefroy Fault. Surface continuity of this fault is lost west of granitoid bodies in the area of no outcrop between St Ives and Tramways.

Small faults thoughout the area produce complications of the general structure which makes nickel exploration difficult. Further complications arise from a recumbent anticline in the northeast which plunges southeast and appears to be refolded by the major north-plunging anticline. Parts of the sequence east of the anticline are repeated by faults (Marston, 1984). This is similar to the faulting and fold interference patterns in the Victory–Defiance–St Ives area.

South of the mafic–ultramafic rocks at Tramways are felsic volcaniclastics and argillaceous metasedimentary rocks. Felsic porphyries intrude the mafic–ultramafic rocks and are not obviously deformed, but they pre-date the cross-cutting Proterozoic mafic dykes. They may be comparable age to similar porphyry dykes at Kambalda.

Widespread nickel mineralization of metakomatiite is contained within southeast-plunging anticlines which dip about 45° (Marston, 1984). The dominant cleavage is vertical, striking north-northwest.

From extensive mapping and drilling, Western Mining Corporation correlate the Tramways sequence with the nickel-mineralized sequences at St Ives and Kambalda, where the nickel sulphides are concentrated at the base of the metakomatiites, on the contact with the domed Kambalda footwall basalt (Gresham and Loftus-Hills, 1981).

Bluebush–Republican

Bluebush and Republican are names given by the nickel explorers in the 1960s to hilly country north of the Binneringie Dyke. The Republican area is 30 km southeast of Widgiemooltha, and roughly midway between the old gold mining centres of Higginsville and Paris. Metakomatiite, metabasalt and laminated cherty metasedimentary rocks dominate the outcrop.

Bluebush consists of northwesterly trending thin units of mafic–ultramafic rocks which outcrop west of the Republican area. The belt continues north across the southern shore of Lake Lefroy to Lefroy Peninsula; this northern extension is discussed below.

The Bluebush and Republican mafic–ultramafic rocks define a southward-plunging antiform (Griffin 1988; and Plate 2) (see also Marston, 1984, Fig. 56; Gresham and Loftus-Hills, 1981).

Bluebush

There are two parts to the Bluebush mafic–ultramafic sequence. The eastern part is continuous with the Republican area and is narrower and better exposed than the western part, although laterite obscures much of the outcrop. The east Bluebush belt contains a range of ultramafic rocks including talc–carbonate schist, talc–chlorite–carbonate schist, tremolite–chlorite–talc schist, and serpentinized peridotite. The ultramafic sequence consists of a series of flows and has nickel mineralization at its base. The mineralized zone dips steeply westwards (Gresham and Loftus-Hills, 1981; Marston, 1984). Metabasalts to the east have variolitic textures and consist of tremolite–actinolite, chlorite, plagioclase, minor quartz and clinozoisite (Marston, 1984). A discontinuous chert unit, which consists of several thin bands, is present within these metamorphosed high-Mg basalts. The contact with the broad sequence of metasedimentary rocks farther east is not exposed.

The western contact of the east Bluebush ultramafic sequence is with metamorphosed high-Mg basalt which contains chert. Metasedimentary rocks occupy a syncline farther west. The stratigraphic sequence presented by Marston (1984, Table 34) is symmetrical about the ultramafic core zone of the east Bluebush belt. This apparent symmetry about the ultramafic sequence indicates a tight fold (an anticline) east of the syncline in the metasedimentary rocks to the west. Faulting in the core could explain the youngings and zoning of mineralization found from exploration drilling. Intense strike faulting within this belt (McDonald, 1976; Marston, 1984) accounts for the attenuation of the sequence to the northwest, and probably disrupted the primary stratigraphy.

The west Bluebush ultramafic sequence is less well exposed, and is not as continuous as the eastern part. This belt has also been affected by strike faulting (Gresham and Loftus-Hills, 1981). Geological information is based largely on rubble in soil, aeromagnetic data, and photo-interpretation of distinctive broad linear features. The ultramafic rocks include talc-carbonate schist, tremolite–chlorite–carbonate schist, and serpentinite. Spinifex textures, and the presence of chert representing interflow sedimentation, suggest an extrusive origin. Metabasalt with chert bands (McDonald, 1976), similar to that in the east Bluebush belt, is also present on the northeastern and southwestern margins, with metasedimentary rocks beyond. This symmetry of stratigraphy is attributed to an anticline by Gresham and

Loftus-Hills (1981); they show metasedimentary rocks in the faulted core area.

The metasedimentary rocks associated with the Bluebush mafic–ultramafic rocks are felsic volcaniclastic in origin, and contain quartz, feldspar and sericite with minor biotite. There is, however, a pelitic unit up to 700 m wide at the southeastern end of the ultramafic belt. It contains grey shale and laminated siltstone, metamorphosed to quartz–biotite schist, and minor felsic volcanic rocks and chert horizons.

The southern extension of the Bluebush belt is cut by the undeformed Binneringie Dyke (McCall and Peers, 1971) which post-dates all major deformation of the Archaean supracrustal rocks. The western belt maintains a southeasterly trend through a small outcrop of chert, and crops out adjacent to the Binneringie Dyke, just east of Cowan Hill. Across the dyke on the northern shore of Lake Cowan, and further to the southeast on islands in the lake, there are cherts associated with mafic rocks that may be an extension of the west Bluebush belt. A small area of tremolite–chlorite–carbonate–talc schist crops out with deformed laminated shale and chert on the lake shore, and a prominent ridge of mafic schist with variolitic and medium- to coarse-grained textures crops out to the north, forming a protrusion into the main Binneringie Dyke; all could be part of the west Bluebush belt. These and other metabasalts adjacent to the dyke may indicate that the west Bluebush belt is also folded by the Republican Anticline. Supporting this is the lack of a positive aeromagnetic anomaly over Lake Cowan. Aeromagnetic data along the lake shore are dominated by the Binneringie Dyke which attains its maximum width in this region.

Republican

The Republican area is dominated by a north-trending mafic–ultramafic sequence, 8 km long, on the eastern limb of the broad southeast-plunging Republican Anticline. It is continuous with the east Bluebush belt to the west and the Democrat area to the east. Outcrops of ultramafic schist are extensive because of local primary thickening of the sequence and the effects of folding (Marston, 1984).

Ultramafic rocks in the Republican area commonly have a hard silica and iron-rich cap-rock; the silica has a sugary texture that glitters in sunlight. Platy spinifex textures, fine cumulate textures and pillow structures are common. These features, along with cherty and laminated siliceous metasedimentary rocks within the sequence, indicate an extrusive origin for the ultramafics. Silicification of the rocks in some areas has preserved platy spinifex textures after olivine and variolitic textures in rocks which now contain more than 60% SiO_2. Serpentinite (antigorite) is abundant, although tremolite, chlorite, talc and carbonate often dominate.

Marston (1984) records picrite, peridotite, and olivine peridotite as primary lithologies. The lowermost unit is up to 150 m thick with nickel mineralization restricted to its basal part.

Chert bands usually crops out on both sides of the ultramafic mass, close to its contact with metabasalt which also has minor chert bands. Pillow structures, variolitic textures, and some minor doleritic-textured phases are common in these metabasalts. Metamorphosed high-Mg basalt with acicular tremolite–actinolite, chlorite, plagioclase and carbonate is abundant.

A significant difference between the current work and the interpretative map of Marston (1984, Fig. 56) is that he shows a granitoid intrusion in the core of the Republican Anticline. Gresham and Loftus-Hills (1981) show no granitoid, but allow for only a thin unit of metabasalt adjacent to the ultramafic. There is in fact a large area of medium to fine-grained, equigranular mafic schist consisting of actinolite, plagioclase, minor quartz, epidote, carbonate, and opaque minerals. This material is interpreted as thick basalt flows and dolerite sills above the ultramafic rocks. The cleavage, where developed, is vertical and strikes roughly north-northwest, parallel to the axial plane of the Republican Anticline.

Metasedimentary rocks, including both felsic and laminated pelitic types, crops out beyond the metabasalt. Laterite, and in some areas flat-lying semiconsolidated immature sandstone of possible Tertiary age, obscure the outcrop in areas adjacent from the mafic–ultramafic ridges.

Structure and stratigraphy

As with the east and west Bluebush belts, the successions in the Republican area are symmetrical about the ultramafic sequence, and define an early isoclinal anticline. An early layer-parallel cleavage, associated with the isoclinal anticline, has been deformed by the north-northwest upright Republican Anticline and associated minor folds and faults. This structure and associated stratigraphic interpretation places the major chert or slate band above the ultramafic sequence and below the mafic sequence—the same sequence observed at Tramways, St Ives, Kambalda, and Kalgoorlie. However, further detailed work is necessary on the whole sequence to confirm these relationships and to unravel the details of the structural development.

On the west limb of the Republican Anticline the early and late fabrics are parallel. However, on the north-trending eastern limb the cleavage is also north-trending, parallel to bedding and the axial plane of the isocline, and not parallel to the axial plane of the late Republican Anticline. As the mafic–ultramafic belt swings to the northeast into the Democrat area its cleavage also swings

east of north. Plunges on lineations are 20° south and are not related to the Republican Anticline which plunges to the southeast at 40°.

The contact between the metasedimentary and mafic rocks in the Republican–Bluebush area is interpreted as a fault that pre-dated formation of the Republican Anticline. The variation in the thickness of the mafic–ultramafic-dominated sequence and apparent termination of trends within the mafic rocks at the contact, indicate a fault. A fault in this position is consistent with the pattern at the St Ives and Tramways areas to the north.

Democrat

The Democrat area straddles the Binneringie Homestead–Widgiemooltha road, southeast of the road junction to Kambalda. It is the northeastern extension of the Republican belt, and also has large areas of ultramafic schist. These rocks surround metamorphosed felsic volcanics in the core of a dome. The broad area of ultramafic rocks consists of tremolite–chlorite schist with variable development of talc and carbonate that dominates the mineralogy in some areas. Platy spinifex texture has been observed in several areas, indicating that these rocks consist of metakomatiite flows.

The southern and western contacts of the ultramafic sequence are marked by a discontinuous, laminated, grey and black chert and slate unit. A chert and/or slate unit is present within the overlying metabasalt sequence that consists of feldspar-phyric metabasalts and variolitic textured tremolite–actinolite, chlorite, and plagioclase-bearing, metamorphosed, high-Mg basalt. Extensive development of laterite obscures exposures to the south.

The south-trending metabasalt and chert sequence differs from the main Democrat area because it lacks ultramafic rocks and has a wide zone of metabasalt on both sides of the chert units. Metadolerite or gabbro probably exist within this mafic schist as they are a major component farther east. These mafic schists crop out (often obscured beneath laterite) south to the Binneringie Dyke where they are hornfelsed on both the northern and southern contacts with the dyke. This large area of mafic schist may be a correlative of similar rocks in the core of the Republican Anticline. Both groups have chert at or close to the contact with a metakomatiite sequence. The fact that they are apparently on different sides of the ultramafic unit is consistent with the conclusion reached earlier for a major early anticlinal isocline in the Bluebush–Republican area.

The core of the Democrat dome contains felsic schist (not granitoid as indicated by Gresham and Loftus-Hills, 1981) with minor pelitic schist, chert and possibly granitoid porphyry. The felsic schist contains bipyramidal quartz and feldspar in a sericite and clay matrix, derived from either a felsic volcanic or proximal volcaniclastic sedimentary rock. Some fine-grained fragmental rocks containing felsic volcanic clasts are present. The laminated metasedimentary rocks are usually quartz-rich. Outcrop is deeply weathered and the only evidence of primary layering is the northwest-trending pelitic schist and chert in the centre of the area. Cleavages are vertical and trend north to north-northwest, consistent with the Republican and Democrat folds.

Various lithologies surround the felsic core of the Democrat dome. They range from brecciated ultramafics in the north, fine-grained metasedimentary rocks in the west, and ultramafic and mafic schist in the southeast. These indicate that the contact is a fault similar to the faulted contact in the core of the Republican Anticline. The rocks to the east are attenuated in the north-trending Paris area. The broad statigraphy comprises a basal metakomatiite unit, overlain by thin chert and slate units and metabasalt (predominantly high-Mg), which in turn is overlain by mainly metamorphosed volcaniclastic sedimentary rocks.

The association of metabasalt and thin chert units defines the south-southwest plunging Democrat Syncline which includes metamorphosed felsic volcaniclastics in its core (Plate 2). Cross-folding, on an open, upright east-northeast fold, could account for the mafic rocks on the east limb swinging around in the south towards the Republican area. The mafic–ultramafic rocks also define the Democrat Anticline to the northeast. The Democrat dome was produced by the interference of two upright folds, similar to those observed in the Tramways area. Because the east-northeast folds lack an associated axial-plane foliation they are assumed to represent a generally mild folding event pre-dating the north-northwest folds that produced the prominent cleavage. These folds were superimposed on earlier isoclinal folds in the mafic–ultramafic sequences as observed in the Bluebush–Republican area. Therefore, in the Bluebush–Republican–Democrat area three folding events are recognized:

(a) F_1—isoclinal and recumbent folds associated with a layer-parallel cleavage, orientation unknown. They were possibly associated with structural stacking of the greenstones. The major curved faults in the cores of the Republican and Democrat Anticlines are interpreted as F_1 folds;

(b) F_2—open, upright east-northeast trending folds;

(c) F_3—intense, dominant, upright, tight north-northwest trending fold associated with a prominent cleavage.

The unit most affected by this faulting is the metabasalt on either side of the ultramafic unit. It is thick in some areas

(e.g. the core of the Republican Anticline, and on the east limb of the Democrat Syncline), and absent in other areas. This mafic–ultramafic sequence defines an isoclinal fold that has been subsequently refolded and attenuated, producing the present distribution of rock types.

Lefroy Peninsula

Lefroy Peninsula is sand-covered and projects northwards into Lake Lefroy, northeast of Widgiemooltha (Griffin and Hickman, 1988). The northernmost part contained the now abandoned and largely dismantled Lefroy Salt mining operations; evaporating ponds on Lake Lefroy are still prominent.

The eastern shores of the peninsula have good exposures of the Merougil beds pebbly sandstone, with a small island to the east located in the core of the northwest-plunging Merougil Syncline (Griffin and Hickman; and Plate 1). Rocks cropping out on the western limb grade rapidly from pebbly sandstone to fine sandstone; a short distance farther west there are steeply west-dipping fine-grained metasedimentary rocks that contain slate bands. A fault contact is inferred between these rocks and the Merougil beds; the contact lines up with a series of quartz "blows" that persist across the lake to the south-southeast.

Farther southwest, mafic and ultramafic rocks crop out on the lake shore. A small island, just offshore, has abundant serpentinized and talc–carbonate ultramafic lavas including some with pillow structures. The adjacent shore contains low cliffs with excellent exposures of pillowed metamorphosed high-Mg basalt as well as brecciated pillows and interpillow hyaloclastite. A narrow, cherty, metasedimentary unit is contained within the metabasalts. These mafic and ultramafic rocks occupy the core of the northern extension of the Bluebush Anticline. Fine-grained metasedimentary rocks overlie the mafic–ultramafic rocks to the west and east.

Altered and weathered ultramafic schist occurs on the western shore of a small circular lake to the northwest, beneath a cap of Tertiary sediments. Some of the material is brecciated, and siliceous material with fibrous amphibole and serpentine is abundant. The weathered ultramafic rocks are possibly located in a fault zone, and appear to represent part of fault-bounded lenses of mafic–ultramafic rocks within metasedimentary rocks (Plate 1). Gresham and Loftus-Hills (1981, Fig. 1) present a similar interpretation for the geology of Lefroy Peninsula involving tight folding and major strike faulting. Thus the mafic–ultramafic and associated rocks of the Lefroy Pensinsula represent a low, narrow, fault-bounded extension of the Bluebush mafic–ultramafic sequence. Minor fault offsets are indicated by regional aeromagnetic contour maps.

Pilbailey Hill–White Dam

Pilbailey Hill

The Pilbailey Hill area is located 14 km south-southeast of Kambalda between the highway to Widgiemooltha and Coolgardie and the western shore of Lake Lefroy (Plate 1). A north–south ridge of black slate and metadolerite swings westerly then northwesterly in the south, and dominates the topography. The ridge defines an open, regional north-plunging syncline with metamorphosed felsic volcanics and epiclastics in its core. The metamorphosed feldspathic sandstone and siltstone, cropping out in low country south of the arcuate ridge, provides younging information from graded beds (and less commonly from trough cross-bedding) that indicates a syncline. However, a pattern of north-plunging anticlines and synclines repeated every 10 m indicates substantial minor folding in the metasedimentary rocks beneath the metadolerite and slate. These sedimentary rocks include graded coarse-grained and finely laminated beds. By the railway line small metagabbro bodies crop out as dismembered parts of a larger unit. They are in an area that contains folded and attenuated slices of felsic schist adjacent to the metadolerite and slate unit.

Undeformed east–west Proterozoic dykes crop out in the southern part, intruding both metadolerite and slate and adjacent metasedimentary rocks.

The contacts between the ridge-forming slate and metadolerite are complex. A strong cleavage in the slate parallels the contact in the core of the regional syncline. It is interpreted as belonging to an earlier folding event that folded the metadolerite and slate into a tight syncline that can now be traced around the open regional syncline. Limited mineral zoning in the metadolerite, in the hinge of the regional structure, is the only evidence for the early fold being synclinal. Refolding of the early syncline by the later regional syncline is responsible for the complex distribution pattern of the slate and metadolerite, particularly on the east limb around Pilbailey Hill. Further detailed work is needed to resolve this complex structure.

The contact between the metadolerite and slate unit, and the felsic schist to the east, is sharp; it marks an abrupt termination of slate and metadolerite trends and is interpreted as a faulted contact, folded in the south by the regional syncline.

One kilometre east of Pilbailey Hill there is a narrow (< 300 m wide) discontinuous zone of mafic and ultramafic rocks within metasedimentary rocks. Although offset by cross-faults, it appears to extend from 10 km south of Pilbailey Hill northwards to an area 2 km east of Cave Rocks gold mine, and possibly beyond. It consists of metakomatiite, metamorphosed high-Mg basalt,

metadolerite, metagabbro, and slate. The relationship with adjacent metasedimentary rocks is unclear. The belt is interpreted as a faulted slice of a more extensive mafic–ultramafic greenstone sequence, tectonically emplaced into the metasedimentary rocks.

The major east–west fault between the Pilbailey Hill area and the White Dam area to the north is inferred from: an air-photo lineament; a mismatch of the western contact and attitude of the Merougil beds; and apparent lack of continuity of rock trends on either side of the fault between the Pilbailey and White Dam areas.

White Dam

Rocks of the northern and central parts of the White Dam area are exposed in low hills. The northern part is faulted against the Yilmia area with the apparent displacement greatest in the west. The outcrop exposes thin, generally north–south striking units of chert, metamorphosed variolitic textured high-Mg basalt, metadolerite, ultramafic schist and felsic schist. The ultramafic schist, containing serpentine–talc–carbonate–chlorite–tremolite, is very poorly exposed. Komatiite is indicated by spinifex-textured chips from shallow exploration drill holes through colluvium. Porphyritic felsic schists are medium grained, with phenocrysts of quartz and feldspar in a felsic groundmass containing recrystallized biotite. They form wide masses which possibly represent high-level, subvolcanic intrusives. The felsic schist cuts across the adjacent rocks and appears intrusive, although contacts parallel to the strike indicate that it may have been partly sill-like. The White Dam area has a strong vertical north–south cleavage with an anastomosing pattern in the coarser parts of the felsic schist.

Yilmia–Cave Rocks

The Yilmia– Caves Rocks area contains several low, steep hills of mainly mafic and ultramafic rocks (Griffin and Hickman, 1988). It is dominated by the layered mafic Yilmia Sill (McCall and Doepel, 1969) and broad areas of ultramafic schist. The eastern part contains metadolerite and slate faulted against the metasedimentary rocks farther east. A similar relationship exists to that in the Pilbailey Hill area to the south.

Two thick layered bodies comprise the Yilmia Sill (Plate 1) that was described in detail by McCall and Doepel (1969) and discussed in general terms, along with similar layered intrusives in the Eastern Goldfields, by Williams and Hallberg (1973). McCall and Doepel (1969) have interpreted two separate intrusions with similar differentiation. Eastward youngings, interpreted from mineralogical and chemical zoning, predominate. However, the eastern margin becomes more mafic as the contact with the ultramafic flows is approached, suggesting that the eastern sill defines a synclinal structure. It is possible that the western limb has been repeated by faulting to form the western sill (Griffin and others, 1983b). Float of sheared gabbro is present in the area of dislocation.

The basal zone of the sill (on the western contact) is described by McCall and Doepel (1969) as an aggregate of chlorite and tremolite with relict bronzite and olivine, probably after harzburgite. Generally, the rocks are rich in chlorite with varying amounts of talc, tremolite and actinolite. Cumulus textures can be recognized (olivine in poikilitic orthopyroxene), along with original pyroxene, possibly clinopyroxene. The norite zone contains cumulus bytownite and orthopyroxene, and is above a zone containing bronzite and intercumulus labradorite (McCall and Doepel, 1969). The central gabbro is rhythmically layered and now consists of plagioclase-rich and actinolite-rich layers. The cores of large amphiboles can be seen to represent original igneous pyroxene grains. Orientation of plagioclase is probably due to settling or flow, not tectonism. The most differentiated rock is coarse-grained ferrogabbro with vermicular intergrowths of albite and quartz, plus amphibole (possibly ferroactinolite).

The metamorphosed high-Mg basalt in the west, at Yilmia Hill, is generally fine grained with variolitic textures, and consists of pale-green amphibole, feldspar, and chlorite. Minor biotite, clinopyroxene, epidote, and magnetite have been observed in thin section. At the base of both parts of the sill in the northwest is metamorphosed high-Mg basalt breccia, an uncommon rock type, that has been displaced by faulting (Griffin and others, 1983b).

The lack of strong metamorphic fabric in the Yilmia Sill is characteristic of layered mafic sills throughout the region, even though they are often folded. The folds are usually open, with the enclosing metakomatiite and metasedimentary rocks absorbing the major part of the stress, expressed as strong planar fabrics in these rocks. The Yilmia Sill is closely associated with thin slate and chert bands near its margins—another characteristic feature of the mafic sills. The metadolerite at Cave Rocks mine has a similar relationship, and is also interpreted as occupying a synclinal core. Steep shear zones are prominent in this tightly folded sill.

The eastern contact with the metasedimentary rocks contains thin slivers of ultramafic and mafic schist as well as chert and metasedimentary rocks. It is possibly a strike extension of the faulted contact seen at Pilbailey Hill to the south.

The western contact of the Yilmia mafic–ultramafic rocks is marked by a thin chert and slate unit, and possibly

a fault adjacent to metasedimentary rocks. A narrow strip of chert and metamorphosed high-Mg basalt, farther west within the tightly folded metasedimentary rocks, is possibly a faulted repetition of rocks on the western contact. The metasedimentary rocks are andalusite (locally chiastolite) – biotite–quartz–feldspar schist, with foliation defined by secondary biotite. There is evidence in thin sections of a later, coarse, random, biotite overprint, suggesting that the metamorphic peak post-dated the deformation.

The central Yilmia–Cave Rocks area is dominated by ultramafic schist (metakomatiite) that generally has poor outcrop. Spinifex textures are abundant in chips from many shallow drill holes. To the north are metabasalts and discontinuous thin chert and slate units, together with small areas of felsic schist. Folding within this central zone can account for the broad expanse of ultramafic rocks and the presence of metabasalt and chert in synclines. The Yilmia Sill is apparently faulted against the mafic and ultramafic rocks in the north.

The felsic schist, along with the other rocks, is strongly foliated and could represent small subvolcanic intrusions similar to, but less well developed than, the larger porphyritic felsic schist in the White Dam area to the south.

Interpretation of the stratigraphy places ultramafic rocks low in the sequence, with thin chert and slate above, followed by metamorphosed high-Mg basalt, then metasedimenary rocks. Metadolerite and metagabbro are most abundant at the metakomatiite–metamorphosed high-Mg basalt contact, which often contains a thin slate unit. This sequence is similar to that in the Kambalda Anticline. Contact relationships between the Yilmia–Cave Rocks mafic–ultramafic rocks and surrounding metasedimentary rocks have not been observed. However, faulted contacts are indicated in many areas by the termination of trends and rapid attenuation of units. The clastic metasedimentary rocks, including the Merougil beds, stratigraphically overlie the mafic–ultramafic dominated sequence at Yilmia. This is contrary to the view of Gemuts and Theron (1975) which is based on a simplistic structural model that did not recognize the Merougil Syncline and its partly overturned and faulted western limb.

The rock units and their relationships in the Yilmia–Cave Rocks area appear to continue to the north, although offset by northeast-and southeast-trending faults.

No. 1 Dam–Hurtles Dam

The No. 1 Dam–Hurtles Dam area in northeast LAKE LEFROY (Plate 1) consists of a wide range of greenstone lithologies including metakomatiite and metamorphosed felsic volcanics. Trends are north to north-northwest. The relationship with the White Hope–Hampton-Boulder area to the east is uncertain, because of poor outcrop in an area apparently dominated by metasedimentary rocks. These areas also include areas of metabasalt that are recognized mainly from aeromagnetic maps. Outcrop is dominated by a narrow ridge-forming belt of ultramafic schist, metadolerite, and chert. Metamorphosed felsic volcanics crop out on western LAKE LEFROY.

The mafic–ultramafic rocks in the Hurtles Dam area form a wide belt which is broadly continuous with the Yilmia–Cave Rocks area; the large areas of metakomatiite occupy a regional anticline. Lithologies and structure on the eastern limb in particular form a complex pattern, offset by northeast and southeast faults. These faults are deduced from lack of continuity along strike, on both geological and aeromagnetic maps, and air-photo lineaments. A zone of metabasalt in the west trends northwestwards into the Mount Marion area on the adjacent YILMIA 1:100 000 sheet (Hunter, in press b).

The western belt of ultramafic rocks, metadolerite and metagabbro, and slate is an attenuated continuation of the rocks to the south at Cave Rocks. Its structural setting in relation to surrounding metasedimentary rocks is uncertain, and its boundaries appear to be faults along its full length.

Metasedimentary rocks are well exposed in breakaway country in the northwest corner of LAKE LEFROY. Tight upright folding is widespread in graded, fine- to medium-grained, quartzo-feldspathic sandstone and laminated siltstone. A steep to vertical, axial-plane cleavage striking north-northwest is well developed. Plunges are generally shallow to the southeast.

The felsic schist to the west is fine to medium grained and contains feldspar and quartz phenocrysts. The rocks are deformed and contain an anastomosing cleavage largely defined by chlorite after biotite. Coarse fragmental rocks, finely laminated felsite, and homogeneous felsic porphyry indicate that extrusive, as well as subvolcanic, processes were responsible for these rocks. Hunter (in press b) has been able to further subdivide these metamorphosed felsic volcanic rocks. They form part of a large felsic volcanic pile that was possibly a major source area for the detritus in adjacent metasedimentary rocks.

The mafic–ultramafic rocks in the No. 1 Dam–Hurtles Dam area are an extension of those in the Yilmia–Cave Rocks area. The stratigraphy is broadly similar to that in the Kalgoorlie–Kambalda belt to the east. These two belts can be correlated from their complex folding and strike faulting on north to north-northwest trend, as illustrated by Keats (1987) for the area just north of LAKE LEFROY.

Spargoville nickel mine

A belt of tightly folded, faulted and attenuated mafic–ultramafic rocks and chert occurs on a ridge on the western boundary of LAKE LEFROY, 20 km southwest of Kambalda (Plate 1). The details of the belt as a whole are covered by Hunter (in press b). The eastern contact with metasedimentary rocks is interpreted as a fault. This accounts for the structural complexity encountered during nickel exploration drilling in ultramafics north of Spargoville nickel mine (Andrews, 1975), and for the cross-cutting nature of the contact between the mafic–ultramafic rocks and the sedimentary and felsic volcanic sequence. A similar example of a discordant contact is present in the mafic belt further west (Griffin and others, 1983b, Fig. 6).

The ultramafic rocks contain spinifex-textured metakomatiite, mainly consisting of tremolite, chlorite and talc. Nickel mineralization is richest at the base of the komatiite flows, in contact with the underlying metabasalt (Marston, 1984). Metasedimentary rocks close to the contact with ultramafic rocks are laminated, micaceous, quartzo-feldpathic siltstones with varying amounts of biotite, which defines a moderate foliation generally parallel to bedding.

The metamorphosed felsic volcanics to the east form a prominent exposure of volcanic and subvolcanic rocks. The unit has been deformed, and has suffered low-grade recrystallization with the generation of a weak foliation that has not disrupted the phenocrysts. Coarse, angular, fragmental, agglomeratic textures are present. Both the pale clasts and darker matrix are interpreted as metadacite containing phenocrysts of quartz, microgranular quartz, feldspar, chlorite after biotite, carbonate and muscovite. Coarse felsic porphyries form a major part of the exposure and probably represent subvolcanic intrusions into the volcanic pile. An anticlinal axis in the north is indicated by a thin, folded, slate band in the volcanic rocks and by the outcrop pattern around metagabbro (Plate 1).

Widgiemooltha

The geology of the Widgiemooltha area, on the boundary between LAKE LEFROY and COWAN (Griffin and Hickman, 1988; Griffin, 1988) contains a wide range of greenstone lithologies at greenschist to middle amphibolite metamorphic grade. Metakomatiite hosts widespread nickel mineralization (Dalgarno, 1975; Gemuts and Theron, 1975; Willett and others, 1978; McQueen, 1979; Marston, 1984) which is mined at Mount Edwards. Gold is mined from sheared metamorphosed high-Mg basalt at the Mount mine near Mount Morgan. Prominent chert and slate units provide important stratigraphic marker horizons. Metamorphosed felsic volcanic rocks show a range in textures, and grade to thick metamorphosed volcaniclastic sedimentary sequences. Significant high-level subvolcanic porphyry intrusions are scarce in comparison with the Spargoville nickel mine area to the north. Cross-faults disrupt direct correlation along strike.

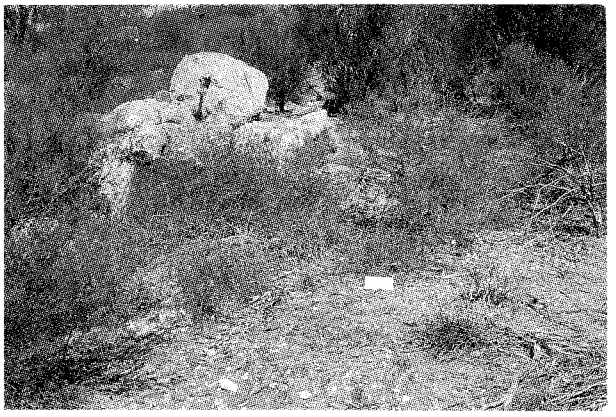
The mafic–ultramafic belt extends to the south-southeast into the Lake Zot area, and around the Widgiemooltha Monzogranite to the Wannaway area.

Development of hornblende in amphibolite-grade metabasalts makes discrimination of either tholeiitic or high-Mg basalts difficult in hand specimen. The rocks are hornblende–oligoclase or andesine amphibolites containing minor quartz, biotite, diopside, cummingtonite, almandine, clinozoisite, sphene, chlorite, prehnite, and carbonate. Pillowed, amygdaloidal, and brecciated textures are common in some areas, such as north of Mount Edwards mine.

Textures and mineralogy vary widely in the ultramafic rocks; metamorphic olivine, anthophyllite and enstatite have retrogressed to serpentine, talc and chlorite. Talc–carbonate alteration appears to be superimposed on earlier metamorphic assemblages. Marston (1984) suggested that carbon-dioxide metasomatism could have taken place during either a prograde or retrograde metamorphic event. The thicker flows are towards the base of the ultramafic unit and are commonly less than 50 m thick. Nickel mineralization is usually contained in the basal flows, although these flows are thinner than the basal nickel-bearing komatiites at Kambalda.

Thin metasedimentary rock horizons are associated with mafic–ultramafic units, and at the contacts with other rocks. They are commonly silicified at the surface and consist at depth of cherty material, but include black and grey slate, often with finely disseminated pyrite. Felsic volcanic material is also associated with some of the fine-grained laminated units (Archibald, 1979). Repetitions of thin, fine-grained metasedimentary rock units probably reflect both deformation and primary distribution. In many places they are complexly deformed and were possibly the loci for much of the tectonic movement that caused slaty cleavage and transposed layering (Archibald, 1979).

The felsic rocks have been described in detail by O'Beirne (1968) and McCall (1969). The volcanics include flows, crystal and lithic tuff, agglomerate, and subvolcanic porphyry. Metamorphic recrystallization make the distinction of the various lithologies difficult in rocks ranging in composition from dacite to rhyolite. Both proximal and distal volcaniclastic metasedimentary rocks can be recognized, associated with the felsic volcanics.



GSWA 24913

Figure 13. Porphyritic Widgiemooltha Monzogranite showing development of cleavage.

GSWA 24922

Figure 14. Deformed dykes of Widgiemooltha Monzogranite in ultramafic schist on the northwestern contact of the Widgiemooltha Monzogranite.

Where contact relationships are exposed on the northwestern margin of the Widgiemooltha Monzogranite, porphyritic monzogranite occurs as apophyses within the ultramafic and mafic metavolcanics. All rock types have been affected by later deformation that produced a well-developed steep, north to north-northwest cleavage (Fig. 13). The Widgiemooltha Monzogranite has clearly cut across the lithological trends of the greenstones on the eastern margin (Fig. 14).

Strong north to northeasterly fabrics and trends predominate, although the lithologies are folded to trend east–west around the northern end of the Widgiemooltha Monzogranite. The Widgiemooltha Monzogranite occupies the core of a regional anticline that plunges northeast, west of Widgiemooltha.

The sequence of north-dipping rocks dominated by metakomatiite is folded in the east by a northwest-plunging syncline to form a northerly trend that contains the Mount Edwards nickel mine. To the west, outcrop is poor and includes a granitoid stock and probable mafic intrusives. To the east, the complex association of lithologies forms the steep north-northwest trending ridges around Widgiemooltha. The northern extension of the mafic rocks in this belt appears to occupy an anticlinal structure (Archibald, 1979; Marston, 1984). To the southeast, through Widgiemooltha, the structure broadens. Archibald (1979) recognized four generations of folding in this area and he includes upper and lower ultramafic sequences to resolve the structure (Fig. 15). In addition to folding, fault stacking could also played a major role during early deformation. It could control the present distribution of lithologies that cause repetitions of sequences.

From recent work and review of available data it appears that many of the lithological boundaries are faulted. It may be appropriate to regard the mafic–ultramafic rocks as part of essentially one complex lithostratigraphic unit, with metakomatiite predominant at the base. The metavolcanic and slate–chert horizon is stratigraphically above, and passes upwards, and laterally into, metamorphosed felsic volcaniclastic and pelitic sedimentary rocks. The complex distribution now seen results largely from the deformation which gave rise to fault-bounded slices of mafic–ultramafic rocks at various levels within the overlying sedimentary–volcanic succession. This model is presented as an alternative to the cyclic model of Gemuts and Theron (1975) for this area, because as Martyn (1985, personal communication) states "there seem to be no clear reasons why they (the cycles) should have been regarded as separate, apart from their apparent superposition".

Regional metamorphism reaches middle amphibolite facies in the Widgiemooltha area, with andalusite and sillimanite present in pelitic rocks (Bickle and Archibald, 1984). The metamorphism in the west produced a dynamic, lower to middle amphibolite zone, which passes eastwards through a 5 km wide, transitional, lower amphibolite zone, to a static upper greenschist zone (Bickle and Archibald, 1984). This observation is consistent with earlier work by Binns and others (1976) and Archibald and others (1978) which showed that this southwestern margin of the Eastern Goldfields Province has dynamic high-grade zones along the contact with the granitoid–gneiss areas to the west. Bickle and Archibald (1984) attributed the higher grade of metamorphism to superposition of the thermal aureole, associated with granitoid intrusion, on regional metamorphic conditions similar to those in the lower grade areas.

Lake Zot–Redross

Prominent north–south ridges on the western shore of Lake Zot on COWAN expose a major sequence of mafic–ultramafic rocks with minor metasedimentary rocks and metamorphosed felsic volcanics. The highway

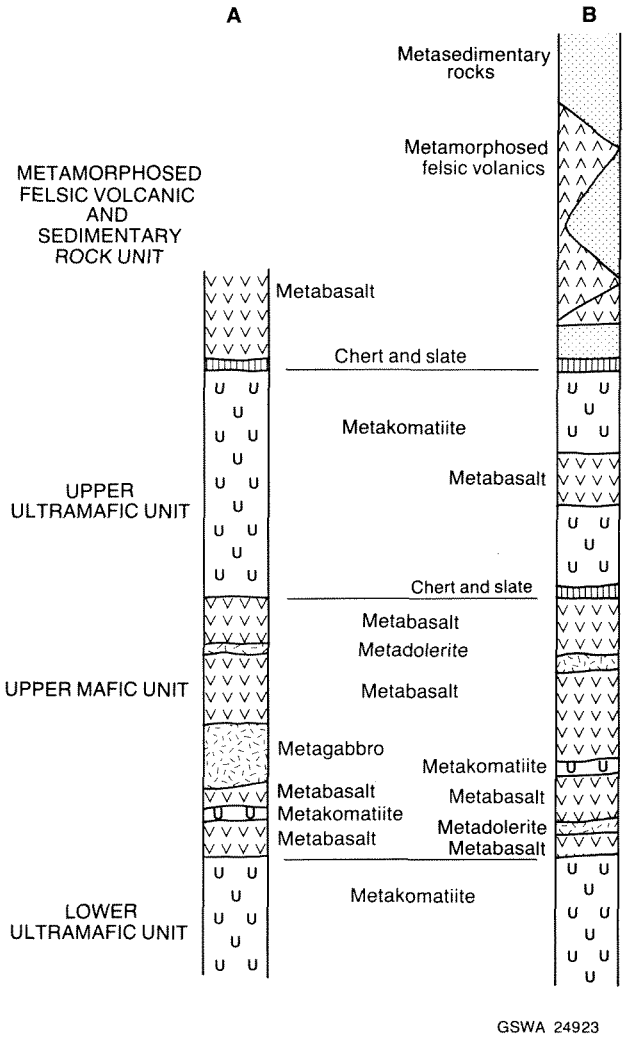


Figure 15. Diagrammatic stratigraphic section for greenstones in the Widgiemooltha area: A. 2 km south of Mount Edwards mine, B. 4 km southeast of Widgiemooltha (from Archibald, 1979).

between Widgiemooltha and Norseman crosses the southwestern part of the belt, 15 km south of Widgiemooltha. The greenstones are intruded in the west by the Widgiemooltha Monzogranite, and are partially terminated to the north by a medium- to fine-grained granitoid intrusion (Plate 2). Nickel exploration drilling and ground magnetic studies indicate that this sequence continues beyond the small granitoid, to the mafic and ultramafic rocks at Widgiemooltha (Marston, 1984).

The tremolite–chlorite–carbonate–talc schist (metakomatiite) at the granitoid contact west of Lake Zot is up to 1 km wide and contains felsic porphyry dykes. Near the contact it is intruded by monzogranite dykes of the Widgiemooltha Monzogranite, up to 5 m wide and generally parallel to the cleavage in the schist. All rocks are strongly foliated. The contact with the Widgiemooltha Monzogranite is not exposed, but hornblende amphibolite near the contact suggests possible hornfelsing.

A prominent ridge east of the highway is dominated by metamorphosed high-Mg basalt; variolitic textures are common in a rock comprising tremolite–actinolite, plagioclase and carbonate. Hornblende amphibolite is also present and seems to be spatially related to granitoid dykes, which are abundant close to the small granitoid intrusion in the north.

The next unit to the east is foliated metakomatiite that consists of talc, tremolite and chlorite, with varying amounts of carbonate and serpentine. Contact with the metamorphosed high-Mg basalt to the west dips 45° east. Nickel mineralization occupies an embayment in this contact at the Dordie Rocks North deposit (Dalgarno, 1975; Marston, 1984). Marston (1984) reported the ultramafic unit to be 300 m thick, and to consist of picritic to peridotitic flows. The basal mineralized flow is about 20 m thick. Steep east-dipping quartz–feldspar porphyry dykes are common and are possibly responsible for localized metasomatic reaction in the ore environment (Marston, 1984).

The upper or eastern contact of the mineralized metakomatiite unit is marked by a discontinuous band of metasedimentary rocks comprising metasiltstone, slate and scarce chert. Metamorphosed high-Mg basalt occurs east of the metasedimentary rock. Coarse mafic schist, possibly metadolerite, crops out close to the contact. In a low area of the main promontory into Lake Zot minor metamorphosed felsic volcanic rocks occur with the metasedimentary rocks. Lithologies include: laminated biotite schist; quartz-rich metasandstone and metasiltstone; coarse fragmental biotite-rich schist; metaconglomerate with flattened clasts up to 10 cm across; coarse felsic fragmental rocks with subrounded clasts of feldspar porphyry 30 cm across (occasionally 1 m across), and interbeds of slate. The fragmental rocks have a quartzo-feldspathic matrix and some are clast supported. Bedding is parallel or subparallel to cleavage and dips eastwards at about 60°.

The eastern extremity of the promontory is dominated by variolitic and pillow-textured amphibolite derived from high-Mg basalt. Eastward youngings indicated by pillow lava structures were observed on the island 500 m south of the promontory. Some of the metabasalt is vesicular with quartz infillings. All exposures of this eastern metamorphosed high-Mg basalt on Lake Zot have slate and laminated metasiltstone at the western contact. Youngings based on graded beds at two localities are eastward, and at one locality westward. Metasedimentary rocks adjacent to mafic schist are intensely deformed and contain isoclinal folds and a well developed cleavage that strikes 20° west. The second island, 2 km south of the

promontory, contains a major fault zone with a chaotic mixture of sheared, metamorphosed high-Mg basalt, metasedimentary rocks and felsic schist that is intruded by granitoid dykes.

This metamorphosed high-Mg basalt unit can be correlated with the metabasalt ridge west of the talc–carbonate schist that hosts the Redross nickel mine. It crops out on the promontory and the island to the south and can be followed along strike to the south, through a hill of metamorphosed high-Mg basalt south of Lake Zot. Unpublished nickel-exploration reports confirm this correlation, because the mineralized ultramafic unit at Redross can be traced northwards and is found to be mineralized at Anomaly A and Mariners (nickel deposits located beneath lake deposits on Lake Zot) (Marston, 1984). Mariners deposit has been drilled from a causeway extending from the southern shore of Lake Zot. The mineralized ultramafic rock, 40 to 120 m thick, is a talc–carbonate schist with minor chlorite and tremolite, probably derived from serpentinized komatiite with interflow sediment horizons (Dalgarno, 1975). The mineralization is at the base of the ultramafic unit and the contact dips about 60° east (Marston, 1984). This ultramafic unit extends northwestwards, east of metamorphosed high-Mg basalt on the Lake Zot promontory, and into the Widgiemooltha area.

Metamorphosed clastic rocks occur to the east of the Redross mafic–ultramafic rocks before the northern extension of the Higginsville mafic–ultramafic belt is reached (Gemuts and Theron, 1975; Archibald, 1979).

In a stratigraphic model published by Marston (1984, Fig. 57), based on work by Archibald (1979), the "lowermost" ultramafic unit in contact with the Widgiemooltha Monzogranite can be traced in an anticlockwise direction around the granitoid 2.5 times until it becomes the uppermost ultramafic. This is obviously nonsense, and highlights the problems of correlation throughout the greenstones in this area of the Goldfields.

It is proposed that the prominent ridges of metamorphosed high-Mg basalt, greater than about 500 m wide and with an overlying unit of metakomatiite, represent the only original statigraphic succession of this type. Thus the two, eastward-younging sequences in the Lake Zot area are the result of structural stacking, not original cyclic statigraphy as proposed by Gemuts and Theron (1975). The nickel-mineralized belt at Lake Zot that contains the Mariners and Redross nickel deposits is a faulted repetition of the western belt containing the Dordie prospect. Strong planar fabrics and possible fault breccia are present on parts of the eastern margin of the metamorphosed high-Mg basalt ridge in the Lake Zot area.

Wannaway–Mount Eaton

The Wannaway–Mount Eaton mafic–ultramafic rocks form a 20 km long belt that is relatively well exposed and almost continuous, on the southwestern margin of the Widgiemooltha Monzogranite. A prominent ridge of metamorphosed high-Mg basalt, 300 to 1000 m wide, runs the length of the belt, with ultramafic schist (metakomatiite) on either side. At Lake Eaton, a second, short, roughly parallel ridge of metamorphosed high-Mg basalt is present to the northeast. Ultramafic schist crops out between these two mafic ridges.

The rocks of the mafic ridges are dominated by massive, metamorphosed, high-Mg basalt. Pillow structures are obvious in the southern part, although a consistent younging direction was not obtained. Variolitic textures are present throughout. There are some medium- to coarse-textured rocks that could be either metadolerite sills or coarse-grained basalt flows. Interflow metasedimentary rocks are rarely seen, but some crop out near Wannaway mine close to the western contact with the ultramafics. The metabasalt consists of tremolite– actinolite, chlorite, plagioclase and carbonate, although in the southern part hornblende occurs, indicating that metamorphic grade was higher in this area.

The prominent mafic ridge is separated from the Widgiemooltha Monzogranite by metakomatiite consisting mainly of tremolite, chlorite and carbonate. The ultramafic schist has a strong vertical cleavage that trends parallel to the granitoid contact. Foliated apophyses of the Widgiemooltha Monzogranite, plus later less deformed pegmatite dykes, intrude the ultramafic schist. Both phases are parallel or subparallel to the foliation (Fig. 14).

Rocks immediately west of the main metabasalt ridge are also metakomatiite, with thin interflow metasedimentary rock units. The outcrop is generally poor, but in an area in the southern part of the belt characteristic platy spinifex texture is seen in a tremolite–chlorite–talc–carbonate schist. Small lenses of deformed laminated chert or slate are present just west of the mafic ridge. The nickel-mineralized metakomatiite consists mainly of tremolite, chlorite, carbonate and magnetite; talc and serpentine are abundant locally. Mineralization at Wannaway mine occupies a shallow depression near the base of the ultramafic unit (Dalgarno, 1975; Marston, 1984). This ultramafic unit comprises four or five sub-units separated by fairly persistent laminated, sulphidic, carbonaceous slate and quartzite bands. Marston (1984) notes that there are at least nine komatiite flows, ranging in composition from picrite to olivine peridotite. The lowest unit is 20 to 50 m thick and is the most Mg-rich (Groves and Hudson, 1981).

The geology of this belt is complex in detail, consisting of thin short lenses of metabasalt, slate and metadolerite, with no consistent pattern from north to south.

The western ultramafic and mafic units, and the contact with the metasedimentary, units, are poorly exposed and largely covered by laterite. The northern extensions of these units cross onto BOORABBIN 1250 000 where they are lost beneath alluvium; on aeromagnetic evidence they terminate against granitoid. The main ridge of metamorphosed high-Mg basalt, and its flanking ultramafic schist belts adjacent to the Widgiemooltha Monzogranite, continue northwards on aeromagnetic evidence and are correlated with the rocks of the Widgiemooltha area, around the northwest-plunging Widgiemooltha Dome.

The metasedimentary rocks west of the mafic–ultramafic rocks in the Wannaway–Mount Eaton belt are predominantly laminated metasiltstone and fine metasandstone which are poorly exposed around breakaways of laterite and flat-lying Tertiary sediments. In the north there are chert and slate beds as well as biotite schist. To the south the metasedimentary rocks are feldspathic and are apparently derived from felsic volcanic material. Small granitoid plugs have intruded these metasedimentry rocks. The steep cleavages in all rock types are sub-parallel to the lithological contacts, including the granitoid contact. The ubiquitous north-northwest trending fabric is present in the Mount Eaton area away from the granitoid contact. This fabric is assumed to be later than a layer-parallel fabric, and later than the intrusion of granitoid. It is related to the major regional north-northwest deformation event that produced the foliation and cleavage in the Widgiemooltha Monzogranite. Where the early fabric is subparallel to the later event it seems likely that the earlier fabrics have taken up the strain, rather than a new fabric developing at a low angle, although some crenulations are present.

A westward-younging sequence in the thin, middle ultramafic unit at Wannaway is indicated by structures in the flows observed in drill cores and in mining (Marston, 1984). The units dip 65–70° to the west in this area. Archibald (1979) recorded southwestward-younging, metakomatiite in the Mount Eaton area between the main ridges of metamorphosed high-Mg basalt. The dismembered intrusive sill farther west also seems to be westward-younging, from compositional layering. This is consistent with the broad regional structure dominated by the Widgiemooltha Anticline. However, lack of lithological continuity in this belt suggests that the structure is more complex in detail.

Extension of the Wannaway–Mount Eaton mafic–ultramafic belt around the southern end of the Widgiemooltha Dome, and to the southeast, is deduced from aeromagnetic maps and isolated oucrops. Correlation with the Lake Zot sequence is uncertain. The belt apparently terminates within metasedimentary rocks to the southeast in the vicinity of the Binneringie Dyke. A regional syncline in the metasedimentary rocks to the west appears to repeat the Wannaway–Mount Eaton rocks in the narrow Franks Find belt, adjacent to the extensive area of granitoid to the west.

Franks Find

The southern part of the Franks Find mafic–ultramafic belt is on COWAN; the better exposed northwestern part is on BOORABBIN 1:250 000 sheet (Hunter, in press a). Outcrop on COWAN is in low hills about 6 km west of Mount Eaton (Griffin, 1988). The rocks include: platy spinifex-textured tremolite–chlorite–talc–carbonate schist derived from komatiite flows; variolitic-textured tremolite-actinolite–chlorite–plagioclase–carbonate schist derived from high-Mg basalt; similar coarser grained material possibly derived from dolerite and gabbro intrusives, and minor pelitic metasedimentary rock horizons. There are also fine-grained, hornblende–plagioclase amphibolites that are similar to the other mafics but reflect contact metamorphism by the adjacent granitoid intrusions. Minor granitoid and pegmatite dykes intrude the mafic–ultramafic units and some epidote alteration of mafics has occurred.

To the east is the wide metasedimentary rock unit separating Franks Find mafic–ultramafic rocks from those in the Wannaway–Mount Eaton area.

On the western contact the mafic–ultramafic rocks are intruded by a foliated, fine-grained equigranular biotite monzogranite. This granitoid has also intruded a small area of banded gneiss which contains coarse feldspar augen in some bands. Later pegmatites, also foliated, cut the monzogranite and gneiss. The granitoid–mafic contact in the north close to the sheet boundary is strongly sheared.

If the eastward younging obtained from the metasedimentary rocks is typical of the whole sequence, then this belt is probably equivalent to the Wannaway–Mount Eaton belt, in having a syncline through the area of metasedimentary rocks. Alternatively, the younging may be on the limb of a minor fold and not representative of the regional structure. If this is so, the Franks Find mafic–ultramafic belt could either be a faulted repetition of the Wannaway–Mount Eaton belt, or, as Gemuts and Theron (1975) have suggested, a younger sequence of mafic–ultramafic rocks than at Wannaway.

From limited outcrop and aeromagnetic maps the Franks Find belt extends southwards into the mafic–ultramafic rocks of the West Pioneer area (Plate 2). A medium-grained biotite monzogranite intrudes the

greenstones in this area. It is generally unfoliated, indicating that it may be a relatively late intrusion. On the eastern margin of this monzogranite there is a prominent area of metamorphosed high-Mg basalt and metakomatiite. The outcrop is midway between the extensions of the Franks Find and Wannaway–Mount Eaton mafic–ultramafic belts. The metakomatiite characteristically contains a brown silicified cap, and occupies a central zone with metabasalt on both sides. The belt appears to be folded on an east–west fold axis to the south and is entirely surrounded by metasedimentary rocks. The mafic–ultramafic rocks possibly represent the exposure of rocks in the core of a refolded early anticline.

West Pioneer

The mafic and ultramafic rocks on the western margin of the Pioneer Granitoid Complex crop out in two areas on the western edge of COWAN (Griffin, 1988). Access is by forestry and mineral exploration tracks from the highway south of Fifty Mile Rocks.

The southern area is less well exposed, consisting of mafic schist (biotite, amphibole, plagioclase, and carbonate), ultramafic schist (tremolite, chlorite, and carbonate) and variolitic-textured metamorphosed high-Mg basalt. The northern area is better exposed and occupies prominent ridges but, as in the south, laterite again obscures much of the outcrop. Exploration for nickel has been carried out in this area. Metamorphosed high-Mg basalt and metakomatiite sequences are abundant in the west. They are hornfelsed by adjacent granitoid, and locally silicified. Strongly foliated quartz–feldspar–sericite schist and metasiltstone dominate the area adjacent to the Pioneer Granitoid Complex. No indicators of younging were observed. The sequence has a strike length of 8 km and both northern and southern parts have significant outcrops of metadolerite; these possibly represent small sills interlayered with the mafic flows. The west Pioneer area trends north–south then northeast in the north.

Aeromagnetic data and rubble associated with laterite along the broad extension of the belt indicate that mafic rocks are more extensive than the outcrop suggests (Cox and Tyrwhitt, 1975). This is despite the occurrence of small outcrops of granitoid and gneiss close to the greenstone contact, and an extensive cover of granitic sand. Continuity of the southern part of the mafic–ultramafic belt to the sheet boundary is also indicated by aeromagnetic data.

Granitoids occur as small stocks and dykes in the metasedimentary rocks and mafic schist. All these rocks have been intruded by pegmatite (graphic intergrowths of quartz and clay-altered feldspar, muscovite and, in some places, lepidolite, biotite, and tourmaline). Deformation fabrics occur in all the rocks, although some pegmatites post-date deformation. Fabrics are steep, striking 330° in the south swinging to 030° in the north.

The existence of high strain indicates that this area of greenstones is an attenuated zone, or screen, between granitoid to the west and the Pioneer Granitoid Complex to the east. These granitoids was intruded prior to, or during, the last major deformation event. The small areas of gneiss could represent even older granitoid material, or material from an intensely deformed zone.

East Pioneer

The East Pioneer area is a narrow (< 1 km wide) zone of mainly mafic and ultramafic schist just west of the Coolgardie–Esperance highway on the eastern margin of the Pioneer Granitoid Complex; it trends roughly north-south (Griffin, 1988). The Fifty Mile Tank Gneiss to the west is faulted against the greenstones in a zone dominated by strong north–south cleavages and pegmatite dykes in both the gneiss and greenstones. The East Pioneer area extends north from the southern COWAN boundary for about 20 km; its northern end terminates against granitoid, but it is not clear whether this contact is intrusive or faulted.

The mafic rocks are dominated by tremolite-actinolite–chlorite–plagioclase–carbonate schist with a variable grain size, possibly indicating derivation from dolerite intrusions as well as basalt flows. Biotite and hornblende are minor phases of the mafic rocks. The ultramafic rocks are interbanded with the mafic schist and include tremolite–chlorite–carbonate–talc schist and talc–carbonate schist. Minor thin metasedimentary rock horizons present include biotite schist, sericite schist, slate and chert. Groves and Gee (1980) record pelitic rocks containing garnet, andalusite and sillimanite. Amphibolite-facies rocks are widespread. Hornblende–biotite–plagioclase schist with a variable grain size is generally found closest to the gneiss and granitoid contact; presumably it reflects higher temperatures in this zone. Some primary igneous textures are preseved.

Cox and Tyrwhitt (1975) interpret the belt as an eastward-younging sequence, because of zoning in the metakomatiite that is mineralized with nickel in its base.

The Fifty Mile Tank Gneiss (Griffin, 1989) preserves a more complex history of dyke intrusion and intense deformation than is evident in the mafic–ultramafic rocks. All the rocks are strongly deformed with a well developed cleavage that is generally parallel to the strike.

East of the East Pioneer mafic belt there is a wide area of pelitic and psammitic metasedimentary rocks. Sparse outcrops are found on low ridges and breakaways. The

northeast extension of these, adjacent to the Pioneer Granitoid Complex, offers the best exposure. The metasedimentary rocks consist of metamorphosed siltstone, fine-grained sandstone, and slate. Some have significant plagioclase and quartz and are probably derived from felsic volcanics; their mineralogy is dominated by quartz, sericite, feldspar and biotite. One cleavage is well developed, and is generally parallel to the steeply dipping bedding lamination in these tightly folded metasedimentary rocks.

Small metadolerite bodies crop out within the metasedimentary rocks. Farther east, thick mafic–ultramafic sills of the West Lake Cowan area intrude the metasedimentary rocks. They could all be part of the same general mafic sill phase that includes the Mount Thirsty and Mission Sills on NORSEMAN 1:250 000 (Doepel, 1973). Tight folding in the metasedimentary rocks, and apparent dislocation of the West Lake Cowan mafic rocks, makes possible structural repetition of at least some of these metadolerite and gabbro bodies along with the enclosing metasedimentary rocks.

Higginsville

Higginsville is an old mining centre on the Eyre Highway between Widgiemooltha and Norseman (Plate 2). It is now the site of extensive gold exploration and small-scale mining— open pit, underground, and heap leaching.

The area is dominated by a 5 km wide belt of metamorphosed high-Mg basalt and minor metakomatiite flows. Doleritic and gabbroic bodies have intruded the sequence, apparently disrupting some of the thin, interflow metasedimentary units. Metamorphism and weathering have made it difficult to distinguish the intrusives from extrusives that originally may have been coarse-grained. Gold mineralization appears to be associated with quartz veins, in zones containing mafic intrusions which have probably been further modified by metasomatic processes associated with mineralization. At Two Boys mine, where the outcrop on the western side of the belt is dominated by an extensive laterite sheet, mining has concentrated on gold-bearing east–west quartz veins in chlorite schist. The Fairplay mine to the southwest is in metagabbro.

Exposures in the west of the belt include talc–carbonate altered komatiite adjacent to chert bands. These were investigated for nickel mineralization in the early 1970s. This part of the belt is dominated by tremolite-actinolite–chlorite–carbonate–plagioclase schist, often with a coarse acicular amphibole texture indicative of high-Mg basalt. Metamorphosed intrusive mafic rocks are common, and some of the massive serpentinized ultramafic rocks are possibly parts of differentiated mafic sills.

Metasedimentary rock outcrop is sparse in the east and includes chert, pelitic schist and metamorphosed fine-grained, fragmental, felsic volcaniclastic rocks. These possibly relate to the metamorphosed felsic volcaniclastic rocks in the north of the mafic–ultramafic belt, north of the east–west Binneringie Dyke. Malachite and azurite are present in limonite veins and as small irregular masses in weathered metasedimentary rocks that contain fragments of pelitic schist and felsic volcanic material. Copper has been recovered from a small mining operation at this locality in the past. Other outcrops of metamorposed felsic volcaniclastic rocks are present west of the old copper mine area, associated with metamorphosed high-Mg basalt, metagabbro and metadolerite.

Outcrop of the southern extension of the Higginsville belt is obscured by an extensive laterite sheet that continues to the Hayes Hill area. An oblique fault (Plate 2) appears to separate these two areas on aeromagnetic maps. The Higginsville belt is defined by north-south trends, despite the north-northwest cleavage in some parts. The eastern side has metamorphosed high-Mg basalt adjacent to a wide zone of metasedimentary rocks. The thin band of mafic–ultramafic rocks further west, contained entirely within the metasedimentary rocks, appear to continue north through Redross mine to the easternmost mafic–ultramafic belt of the Lake Zot area. Lithologies in the south include metamorphosed high-Mg basalt, metakomatiite, thin cherty metasedimentary rocks, and metagabbro.

The distribution of lithologies across the Higginsville greenstone belt could represent a single thick mafic–ultramafic volcanic pile incorporating thin metasedimentary rocks and intruded by mafic sills. Alternatively, the possibility of structural repetition of various units by folding and faulting cannot be ruled out. The rocks have been affected by the regional north-northwest deformation superimposed on rocks with a pre-existing layer-parallel fabric; at Two Boys mine it is crenulated.

Hayes Hill

The Hayes Hill area is on the western shore of Lake Cowan, 10 km south of Higginsville, and is dominated by mafic–ultramafic rocks in a roughly circular area 6 km across (Plate 2). These rocks produce a prominent and complex positive anomaly on aeromagnetic maps. They are dominated by serpentinized ultramafic schist, talc–carbonate schist, tremolite–chlorite–carbonate schist with occasional spinifex textures typical of metakomatiite flows, and variolitic-textured tremolite-actinolite–chlorite–plagioclase–carbonate schist derived from high-Mg basalt. Discontinuous units of medium- to coarse-grained amphibolite indicate that the

mafic–ultramafic flows have been intruded by dolerite, gabbro and pyroxenite sills. The metamorphosed high-Mg basalt and komatiite flows contain discontinuous, finely laminated, cherty interflow sedimentary rocks.

The central ridge of metagabbro and metapyroxenite, with Hayes Hill on the western end, has a discontinous silicified laminated siltstone along its southern contact. This metasedimentary unit is most prominent where the sill is folded to the south; dips in the unit are steep to the east and northeast. Adjacent to the metasedimentary unit is a foliated quartz–feldspar schist, which follows the trend of the metasedimentary rocks; it is most likely a porphyry dyke that intruded the contact between the metasedimentary unit and the fine-grained ultramafic schist farther west. An early foliation in the porphyry is deformed and follows other lithological trends as it changes from a north–south trend to an east–west trend. Later steep cleavages strike north-northwest in the east–west trending outcrops of slate, felsic porphyry and ultramafic schist. No fabrics were recognized in the metamorphosed intrusive sills.

Southward and westward youngings, based on differentiation of the large central sill, are towards the low-lying poorly exposed areas south of Hayes Hill. They indicate a synclinal structure through the centre of the Hayes Hill area. The old gold workings are located on a chert band, with metadolerite to the south and metabasalt to the north on the vertical southeast limb.

The eastern intrusive units also outline a syncline with the same stratigraphic sequence on its eastern limb. The rocks in the fold closure to the south are differentiated indicating it is northward younging. Metasedimentary rocks interlayered with the sills have a steeply dipping, layer-parallel cleavage. The rocks on the western limb of this eastern syncline have been disrupted by faults.

The rocks in the north include metamorphosed high-Mg basalt that forms an almost circular pattern, apparently due to plunge reversals on the central syncline which may be the result of interference folding. This folding is consistent with an early, steep roughly east–west F_2, and a later steep, roughly north–south F_3. Orientation of these structures has moved clockwise with rotation of the central Hayes Hill area between faults (Plate 2). The D_1 event is represented by the folded cleavage mentioned above. Movement on faults, particularly the one north of the area, which is based on both abrupt geological and aeromagnetic changes during D_3, has left the rocks less intensely folded than those further west at West Pioneer.

This sequence of mafic–ultramafic-dominated rocks at Hayes Hill appears to extend into the Higginsville area to the north. To the south the rocks appear to terminate close to the lake shore. The nature of this break is unknown but may be related to the early D_1 event.

West Lake Cowan

Massive serpentinized ultramafic schist forms prominent ridges on, or near, the southwestern shore of Lake Cowan on COWAN (Plate 2). The belt, which is deformed and discontinuous, consists of several units up to 1 km across, and extends 17 km northwards from the southern sheet boundary.

The major rock type is a metamorphosed, fine-grained, serpentinized equigranular peridotite. In areas with well-developed cleavage, mineral assemblages are dominated by tremolite, chlorite, serpentine, carbonate, and talc. There are narrow bands of metapyroxenite and metagabbro which are parallel to the serpentinite ridges. The areas between the ridges have sparse outcrops of slate and felsic schist. No evidence for an extrusive origin for the ultramafic rocks was observed. This sequence of metamorphosed mafic and ultramafic rocks represents mainly ultramafic sills with minor differentiation. The large outcrop in the north contains a westward-younging differentiation sequence.

In the central part of the belt, metagabbro and metapyroxentite are tightly folded, with vertical contacts and cleavage trending north-northwest. Felsic schist and slate occupy the fold core. Differentiation seen in the sill youngs westwards, indicating a syncline to the west (Plate 2). Lack of continuity along the belt indicates major structural disruption caused by folding and faulting.

The southern extension of this belt is into the Mount Thirsty Sill, and possibly the Mission Sill on NORSEMAN 1:250 000 (Doepel, 1973; Gemuts and Theron, 1975). The West Lake Cowan belt terminates in the north in an area of poor outcrop dominated by metasedimentary rocks. Several small outcrops of metadolerite and metagabbro within these metasedimentary rocks may be related to the larger intrusive masses to the south.

Eundynie

The Eundynie area is a prominent peninsula on the western shore of Lake Cowan (Plate 2). It is dominated by mafic sills, metakomatiite and metamorphosed high-Mg basalt. Metamorphosed variolitic-textured high-Mg basalt is abundant in the east. Varioles up to 2 cm across make some metabasalts appear porphyritic. Metamorphosed high-Mg basalt is composed of tremolite–actinolite (often acicular in form, after original pyroxene), chlorite, plagioclase and minor carbonate. These metamorphosed high-Mg basalts lack interflow

metasedimentary rocks that are common in many other areas of LAKE LEFROY and COWAN.

The structure in the Eundynie area is dominated by a folded, metamorphosed, dolerite, gabbro and pyroxenite sill. Differentiation of the sill indicates it is southeastwards younging at the northwestern contact. A tightly folded sequence 1.5 km east of Eundynie mine contains metakomatiite and finely laminated chert. Younging, based on the distribution of platy spinifex textures in the metakomatiite, indicates that the top is to the north, towards the chert. These two observations on both sides of the sill indicate that the sill occupies a synclinal core within metamorphosed high-Mg basalt. This syncline has been refolded by a north-plunging anticline to form an open structure (Plate 2). The syncline represents the first phase of deformation (D_1), that involved tight to isoclinal folding. The major sill unit may have been repeated by folding to form the sill outcrops southwest of Eundynie mine. The distribution of finely laminated metasiltstone, felsic schist and serpentinized ultramafics in this area is consistent with a complex structural history that involved interference folding.

A possible extension of the west limb occupies an area between Eundynie and Hayes Hill, and is apparently separated from both areas by faults. The area is dominated by ultramafic schist which has, in the south, thin discontinuous chert bands close to its contact with metabasalt. In the north the chert is highly brecciated, possibly in a fault zone at the contact with metasedimentary rocks to the north that are largely obscured by laterite.

The geology in the southwest is poorly exposed and includes felsic schist and chert associated with mafic–ultramafic schist. Some of these rocks have a north-striking vertical cleavage. Similar north-trending fabrics are present in the area around Eundynie mine; they are accompanied by ubiquitous north-northwest cleavage of the D_3 event.

Archibald (1979) has also recognized three deformation events in this area, although his F_2 and F_3 are subparallel. The structural data indicate an early D_1 isoclinal folding event, with faults parallel to lithologies—indicative of tectonic interleaving or thrust faulting—that disrupted the primary stratigraphy. D_2 was a mild event that formed some of the generally east–west folds in the pelitic metasedimentary rocks north of Eundynie, and was responsible for plunge reversals on D_3 folds. D_3 is the pervasive regional event that produced upright north-northeast folds and cleavage. A late D_3, or D_4, folding event has given rise to the upright north-trending folds and cleavages. These may be related to movement on a sinistral wrench fault, as suggested by Swager (1989) for the Kalgoorlie area. The fault passes through a carbonated breccia zone in metakomatiite west of Eundynie mine and trends north-northwest; the structure continues to the south-southeast through the northern part of Polar Bear Peninsula (Plate 2).

Polar Bear Peninsula

Greenstones crop out on the eastern shore of the Polar Bear Peninsula that protrudes northwards into Lake Cowan from the southern boundary of COWAN (Plate 2). Felsic schist derived from felsic volcanics, volcaniclastic sedimentary rocks, and probably porphyry intrusives, dominate in the south. Cleavage and stratigraphy strike roughly north–south. In the southeastern part the felsic schist and chert are folded to strike east–west, then southeast, parallel to the mafic belt at Killaloe described below. In the southern part of the Polar Bear Peninsula a finely laminated chert and silicified slate unit overlies a thick metabasalt (Gemuts and Theron, 1975). Variations in thickness of the chert can be attributed to tight folding and faulting within the unit. In some east–west trending outcrops the layering strikes north–south in domains up to 10 m across separated by several metres of breccia. Immediately beneath the chert the poorly exposed metabasalt is silicified or strongly carbonated.

Felsic schist horizons less than 1 km wide, composed mainly of quartz, feldspar, sericite, and carbonate, crop out above the chert marker. Several discontinuous chert–slate units appear to represent sedimentary sequences within this sequence of volcanic rocks; they have been disrupted by deformation or, by intrusion of subvolcanic sills. The felsic schist includes metamorphosed flow-banded rhyolite, tuff, volcanic-derived sedimentary rocks, and subvolcanic porphyry with phenocrysts of quartz and feldspar up to 1.5 cm across. Some finely laminated volcaniclastics contain limonite nodules (after pyrite) up to 2 cm across. This metamorphosed volcanic sequence generally has a north–south trend up to the "Polar Bear's front paw" (a small promontory on the eastern side of Polar Bear Peninsula).

North and east of the metamorphosed felsic volcanic rocks is a discontinuous sequence of metamorphosed slate and sandstone, with ultramafic schist farther east. Carbonated ultramafic rocks are often preserved by surface silicification. Many of the ultramafic rocks are talc–carbonate schist, and some rocks have platy "spinifex" textures, indicative of komatiite flows. Tremolite, chlorite and serpentine are also abundant consituents of the ultramafics. Minor metabasalt, metagabbro, and dolerite intrusives are associated with the ultramafic schists.

A south-plunging syncline is exposed in laminated grey slate on the contact between the felsic and ultramafic rocks, north of Hinamoa mine. Younging is determined

from grading and scouring. Between the laminated slate beds there are 0.5 m wide coarse-grained, green, fuchsite-rich, metasiltstones with strong, north-trending, vertical cleavage. On the lake margin, 500 m to the south, the slate contains flattened fragments of mafic–ultramafic material immediately above ultramafic schist. The slate is carbonaceous in places and contains malachite. West of the slate is a highly sheared felsic schist with bipyramidal quartz. On the basis of the association and structure in this small area it appears that the sequence youngs westward, i.e. the slate overlies the ultramafic rocks, and the felsic volcanic sequence overlies the slate. If this evidence is combined with the stratigraphic information on the western side of the felsic volcanics, where the sequence youngs eastwards, then the felsic volcanics lie in a north-plunging syncline. The chert is equivalent to the slate, and the underlying metabasalt sequence in the west has associated ultramafic rocks in the east. This syncline in the felsic volcanics has minor north-trending folds along its margins and in its core, together with minor faults that offset the stratigraphic succession. It has been folded in the southeast by later north-trending folds. These may be related to movement on a possible wrench fault to the east (c.f. Swager, 1989).

A prominent ridge of mafic–ultramafic rocks with a northwest trend outcrops southwest of Polar Bear Peninsula. The metagabbro and dolerite sills appear to have resisted deformation. However, slate and chert associated with the metakomatiite northwest of the gabbroic intrusives are complexly deformed and cut across the strong northwest fabric.

The geological features in the northern part of Polar Bear Peninsula strike northwest, and are aeromagnetically and structurally an extension of the Killaloe area. Metakomatiite flows contain minor interflow metasiltstone. Aeromagnetic maps indicate a major break between the strongly magnetic ultramafic zone on the Killaloe trend and the area completely masked by Lake Cowan to the southwest (Plate 2). This break is possibly a major structural lineament that continues northwest through the western Eundynie area. The poorly outcropping, mainly pelitic, metasedimentary rocks in the centre of Polar Bear Peninsula are apparently above the chert marker and metabasalt in the south, and could be a facies equivalent of the felsic volcanics in the southeast of the area.

Killaloe

The geology of the Killaloe area in southeast COWAN (Plate 2) is dominated by a northwest-trending sequence of mafic and ultramafic rocks that forms a 2 km wide ridge extending into Lake Cowan. These ultramafic rocks consist of fine-grained massive equigranular serpentinite, foliated tremolite–chlorite–serpentine schist, tremolite–chlorite–carbonate schist, and talc–carbonate schist. Coarse, platy, spinifex texture after olivine, and narrow bands of finely laminated siliceous metasedimentary rock, indicate this to be a sequence of steep to vertically dipping metakomatiite flows with interflow metasedimentary rocks. The ultramafic rocks were investigated for nickel mineralization in the early 1970s.

East of the ultramafic rocks are foliated tremolite-actinolite–carbonate schists, with variolitic textures that are particularly common in the northern outcrops. They are regarded as metamorphosed high-Mg basalt flows. In the south, around old shafts of the Killaloe mining area, exposure is poor and rocks are deeply weathered. The surface is littered with rubble from quartz veins which were apparently targets for early gold mining. Remnant textures suggest that metadolerite may be associated with the mafic schist.

Immediately east of the weathered mafic schist is a ridge of mainly pelitic metasandstone and metasiltstone. These rocks are laminated and contain both feldspar fragments and fuchsitic mafic clasts, suggesting that they are derived from a mixed mafic and felsic source. Mafic material in the sediments might indicate that the sequence youngs eastwards, with the sedimentary rocks overlying the mafic and ultramafic rocks to the west. Occasional cherty slate beds are present. The vertical cleavage is parallel to bedding, and strikes north-northwest.

Sedimentary rocks farther east include conglomeratic beds with angular clasts of quartz–feldspar porphyry, sandstone, siltstone and basalt, in a matrix of quartz, feldspar, sericite and biotite. Foliation, well-developed in all rocks except the massive sandstone beds, dips 50 –70° to the west and strikes north-northwest.

Close to the southeastern boundary of COWAN there is a north–south sequence of slate interbedded with siltstone, mafic schist containing variolitic-textured metamorphosed high-Mg basalt, and minor metadolerite. The stratigraphic position of these rocks is unknown; they could be basal to the felsic schist and exposed in an anticline or fault slice, or part of a minor basaltic volcanic sequence within a mainly felsic volcaniclastic sequence. The felsic schist is more pelitic and mature to the northwest, while to the southeast it contains abundant bipyramidal quartz and is considered to be more proximal.

West of the main Killaloe ultramafic ridge is a 3.5 km wide belt of poorly exposed mafic schist (tremolite-actinolite–chlorite–feldspar–carbonate schist). Cleavage strikes north-northwest, consistent with regional trends. Aeromagnetic maps suggest that a fault separates these rocks from the better exposed metakomatiite,

laminated slate, and metagabbro of the Polar Bear Peninsula area (Plate 2).

Mount Martin–Carnilya

The Mount Martin– Carnilya mafic–ultramafic rocks define the Carnilya Anticline between the White Hope–Hampton-Boulder area to the west and the Mount Monger area to the east (Plate 1).

Mount Martin, 37 km south southeast of Kalgoorlie, is on the western end of a belt of mafic and ultramafic rocks that trend north-northwestwards. The eastern part of the belt has a dominant east–west trend; the Carnilya nickel mine is near its eastern end, 52 km southeast of Kalgoorlie. The Mount Martin gold mine is reached via the Kalgoorlie–Kambalda road, whereas the Carnilya mine has an all-weather road link to Kambalda because the mine operations are based, and ore is treated, at Kambalda. The geology of the Mount Martin– Carnilya area is based primarily on work for nickel exploration (Marston, 1984).

The eastern, or Carnilya, area is dominated by the Carnilya Anticline, which has a southerly dipping overturned northern limb. The core of the fold is occupied by foliated metabasalt containing a variety of minerals including hornblende, biotite, actinolite, epidote, quartz, plagioclase, and carbonate. Metamorphism varies from greenschist to lower amphibolite. Pillow structures, breccia, and variolitic textures are present. This sequence of metabasalt can be correlated with the Kambalda footwall basalt.

Ultramafic rocks surround the metabasalt, with metasedimentary rocks beyond. These define an elongate dome plunging to the east at Carnilya mine, and to the north and northwest in the Mount Martin area (Plate 1). The ultramafic rocks contain spinifex textures and are interpreted as metakomatiite, with typical zoned MgO contents similar to those at Kambalda (Fig. 4). They are associated with thin chert and cabonaceous or sulphidic metasedimentary horizons (Marston, 1984). These metakomatiites are dominated by picritic compositions; the mineralogy is tremolite and chlorite with minor serpentine, talc, carbonate and magnetite. Individual flows have been recognized; nickel mineralization is present as sulphides in the lower part of the sequence. They are volcanic peridotite (komatiite) associated deposits, comparable to hangingwall ore at Kambalda in style and setting but not in size (Marston, 1984).

Tight folds involving ultramafic rocks are present on the northern limb of the Carnilya Anticline (e.g. at Carnilya Hill). Folding and faulting play a major role, possibly along with primary features, in determining the thickness of the ultramafic units around the Carnilya structure. Marston (1984) suggested that there may be a fault along the northern contact of the ultramafic rocks with strong deformation and metasomatism in the attenuated ultramafic rocks, in the east at Carnilya Mine. The rocks exposed indicate that this pattern of tight folding and faulting on the steep northern limb of the Carnilya Anticline continues into the metabasalt and metasedimentary rocks to the north.

The outcrop patterns of ultramafic rocks and metabasalts, and air-photo lineaments on the southern limb of the Carnilya Anticline, indicate that east–west lithological trends are disrupted by generally north–south faults with differential rotation of the blocks between the faults (Plate 1). The Carnilya Anticline is rotated in the west to become a series of north-northwest plunging folds that parallel the major structures in the Mount Martin area.

Correlations north and northeast of Carnilya mine into the Mount Monger greenstone belt, through an area of metasediments and poor outcrop, are most uncertain (see section on Mount Monger). The two areas are interpreted to be separated by the Mount Monger Fault (Williams, 1970), a major lineament defined largely by a broad valley with no outcrop.

It is possible that the greenstones at Carnilya extend into the Mount Hogan area, and also into a narrow belt of magnetically anomalous material, possibly metabasalts, in the southeast. However, the Mount Hogan area does contain a different lithological sequence which includes significant banded iron-formation and metamorphosed felsic volcanic rocks.

The ultramafic rocks that dominate the Mount Martin area can be traced into, and correlated with, those at Carnilya. The best exposure is west of the Kents Dam Syncline on LAKE LEFROY (Plate 1), where north-northwesterly striking units of talc–carbonate, talc–chlorite, serpentine, and amphibole–chlorite rocks are interspersed with metasedimentary units. This relationship is interpreted as resulting from tight folding with minor faulting parallel to the fold axes, with all units dipping west.

Foliated, pelitic and siliceous metasedimentary rocks are present west and south of Mount Martin and in the central area of the Kents Dam Syncline to the east. These schists contain mainly quartz and sericite with minor biotite and albite. Some in the Mount Martin area, including Kyanite Hill to the north, are unusual in containing abundant kyanite as well as fuchsite, andalusite and chloritoid. Purvis (1984) interprets these rock as metamorphosed weathered komatiites; however, Martyn and Johnson (1986) interpret a similar suite of rocks from the Menzies area as having developed from intense metasomatism of layered rocks of komatiitic composition, possibly immature sediments.

The nickel and gold mineralization at Mount Martin is largely within the siliceous schist, it is closely associated with komatiite. The nickel mineralization is classed as a vein-type auriferous-arsenical deposit by Marston (1984), because gold or auriferous minerals occur with, or near, the nickel arsenide minerals which make up the bulk of the nickel resource. The deposit is in a strongly deformed zone that has been substantially metasomatized (dominated by carbonate alteration) and consists of a complex system of quartz–carbonate–sulphide–arsenide veins oriented along strike.

The Kents Dam Syncline is an open structure defined by a slate horizon in the north. An early cleavage has been folded by this syncline, and it is likely that much of the isoclinal folding on the western limb of the Kents Dam structure is also the result largely of an early deformation event with the structures tightened by D_3.

The Mount Martin mafic–ultramafic rocks trend northwards and cross LAKE LEFROY boundary into the Duplex Hill area (Keats, 1987). Continuity of the various units into the Carnilya area is disrupted by complex structures resulting from at least two phases of tight folding and faulting.

Mafic dykes, such as the Parkeston Dyke (Keats, 1987), most of which are known largely from aeromagnetic anomalies, are assigned a Proterozoic age based on dating of similar dykes, and because they post-date the deformation of the greenstones (Griffin, 1989).

Mount Monger

The Mount Monger greenstones are located 55 km by road southeast of Kalgoorlie. Only the western half of this prominent belt of mainly mafic rocks is on LAKE LEFROY (Plate 1), cropping out as an arcuate range of low hills that define the western limb of a broad regional southeast-plunging anticline, the Bulong Anticline. The whole area has been the subject of a recent study by Hickman (1986). The northern part, or core of the fold, contains metamorphosed intermediate and felsic volcanic and volcaniclastic sedimentary rocks in a low-lying, poorly exposed area. The low rubble-covered hills, that contain the mafic rocks and thin units of fine-grained clastic metasedimentary rocks, are mainly strike ridges separated by areas of colluvium.

The mafic rocks represent basaltic lava flows, generally high-Mg types, and mafic and ultramafic sills (Hickman, 1986; Williams, 1971). Quartz–feldspar porphyry intrudes the layered sequences, as both conformable and cross-cutting dykes. Fine-grained clastic metasedimentary rocks appear to overlie the mafic rocks in the west, where the outcrop is obscured by laterite with a surface that dips towards the major drainage line.

Hickman (1986) noted the difficulties of carrying out detailed structural work because of limited outcrop and recognition that much outcrop consists of disoriented blocks. On a regional scale the mafic rocks of the Mount Monger area are folded around the Bulong Anticline which has a steep plunge to the southeast (Plate 1). Dips on the limbs and in the core range from 50 to 80° with an average of about 60° (Hickman, 1986). Younging indicators in metasedimentary and mafic rocks, plus the vergence and plunge of minor folds, indicate that the structure is upward facing.

The observed cleavage on the western limb is consistent with the Bulong Anticline; however, a north-trending cleavage, parallel to bedding, is present on the eastern limb and probably represents an isoclinal folding event prior to the formation of the Bulong Anticline. Hickman (1986) suggests that this early event is related to the Peters Dam isoclinal fold on the eastern limb and possibly also to the Carnilya Anticline in the west.

The outcrop pattern of the various units in the mafic dominated sequence in the Mount Monger area (Hickman, 1986, Plate 2, interpretive geology) is not representative of a simple stratigraphic sequence of mafic flows and sediments intruded by mafic–ultramafic sills. The discontinuous nature of units, and variation in thickness over short distances, is indicative of isoclinal folding and attenuation on strike faults prior to the Bulong Anticline fold event.

A north–south fault through the centre of the fold, on the boundary of LAKE LEFROY, apparently displaced the two limbs of the Bulong Anticline. In particular, the various units in the mafic sequence cannot easily be traced across this area of no outcrop. Correlation across it is ambiguous, with apparently no displacement of the felsic–mafic contact, and possibly 3 km of displacement if the thickest gabbro sill units are matched.

Tight folding is indicated by the felsic rocks and associated thin chert band in the extreme northeast—much tighter than the Bulong Anticline which is defined by the mafic rocks. The possibility of an early faulted contact, between the felsic rocks in the core of the Bulong Anticline and the mafic sequence should not be overlooked. Later felsic porphyries may have obscured the original relationship.

A fault separating the Mount Monger area from the Carnilya and Mount Hogan areas is shown on Plate 1 in an area of no outcrop; it is proposed because of differences in lithological sequences and structures between the areas. It has been called the Mount Monger Fault by Williams

(1970). Northwest of the Mount Monger area there is an indication that the pelitic metasedimentary rocks that overlie the mafic rocks extend southwards through a syncline with a northwest trend, and reappear on the northern limb of the Carnilya Anticline where they again overlie mafic rocks. However, the stratigraphy at Carnilya contains a thick sequence of mafic rocks below the ultramafic rocks, and not felsic rocks as at Mount Monger. A faulted contact, between felsic rocks in the core of the Mount Monger Anticline and the mafic sequence at Mount Monger, as suggested above, could provide an explanation.

Structural interpretation of the area south of the Mount Monger greenstones is complicated by a narrow belt of northwest-trending, magnetically anomalous material that has no outcrop. This magnetic material is between Mount Monger and the mafic rocks and BIF with chert at Mount Hogan (Plate 1). It could be either mafic rocks or BIF, possibly a narrow extension of the Carnilya greenstone belt.

Mount Hogan

The Mount Hogan greenstones, 12 km south of Mount Monger, have been the site of small-scale gold mining, and more recently, nickel and gold exploration. The geology in this area is complex; there are generally narrow units of metabasalt, metakomatiite, metasedimentary rocks, metamorphosed felsic volcanics, slate, and metamorphosed banded iron-formation, all with a north-northwest trend (Plate 2). Continuity along strike cannot be demonstrated; consequently the interpretative geology (Plate 1) shows that east-northeast faults are responsible for the disruption along strike.

The rocks are metamorphosed to upper greenschist facies, with many primary structures preserved. These include: vesicles, varioles, pillows, and flow-top breccias in the metabasalt; spinifex textures in the tremolite, chlorite, talc and carbonate dominated metakomatiite; and fine flow-banding in the metamorphosed felsic volcanics. Lithic tuff, crystal tuff and agglomerate are present in the metamorphosed felsic volcanics. Felsic porphyry intrusions are represented in the felsic schist.

The structure of the area is complex and some fold closures have been identified. The most prominent is a north-plunging syncline in the southeast. The closure is exposed on an island at the western end of Lake Randalls, where magnetite-rich banded iron-formation overlies laminated siltstone and biotite metasandstone. Grading in these metasedimentary rocks indicates northwards younging and the fold plunges 20° north.

Detailed relationships between the various units throughout the Mount Hogan greenstone belt could not be determined, but the thickness, variety of rock types and repetitions across strike indicate significant structural control on their distribution, involving tight folding and strike faulting (Williams, 1972).

An unusual feature, representing a later intrusive event, is the abundance of northwest-trending syenite dykes in metamorphosed high-Mg basalt on the northwest shore of Lake Randalls. A similar relationship exists to the west on the north shore of Lake Lefroy, southeast of Stans Dam.

The Mount Hogan greenstones contain too much felsic volcanic material to be directly correlated with the Carnilya or Mount Monger areas; however, there is a broad similarity which indicates that they could be correlated with the eastern margin of the Parker–Yalca area and the Paris area.

Parker–Yalca

The Parker–Yalca area is located 5–10 km east of the Victory–Defiance–Tramways belt. It consists of low hills dominated by mafic schist separated from the mafic–ultramafic belt to the west by low country with poor outcrop of granitoid and metasedimentary rocks. The eastern contact is also with granitoid and metasedimentary rocks (Plate 1).

At Yalca Hill, the northerly trend from the Paris area is split into two by a granitoid pluton. The major arm swings to the northwest, then north-northeastwards to Parker Hill. The easterly arm, that contains metamorphosed felsic volcanics and volcaniclastics in the south, appears to continue across strike through an area of very sparse outcrop, to the Mount Hogan area.

Amphibolite is the dominant rock type and consists mainly of actinolite, hornblende, biotite, chlorite, plagioclase and carbonate. Metamorphic grade is upper greenschist to lower amphibolite. The size of grains is variable, indicating possible derivation from both dolerite sills and basalt flows. There are rare exposures of pillow structures and variolitic textures. Metagabbro and metapyroxenite have been recognized, and some talc-rich schists may have been derived from komatiite.

Thin, laminated, cherty bands are widespread, occurring as discontinuous and deformed units within amphibolite. They are probably derived from interflow sedimentary material, although some may be silicified tectonites.

All rocks have a strong cleavage. The strike is generally parallel to the trend of the belt and does not reflect the regional north-northwest fabric.

No systematic stratigraphy was recognized which could assist in understanding the structure, or the correlation with other mafic belts such as the Victory–Defiance–Tramways belt. The northern extension of the mafic rocks at Parker Hill appear, on aeromagnetic maps, to cross Lake Lefroy and to extend into the prominent outcrop of metamorphosed high-Mg basalt in the area of Stans Dam. This area is unusual, as it contains small plugs and dykes of syenite similar to dykes in metabasalt east of Mount Hogan. The mafic rocks terminate in metasedimentary rocks before reaching the Mount Martin–Carnilya mafic–ultramafic rocks (Plate 1).

The southern extension of the magnetically prominent Parkeston Dyke, east of Kalgoorlie (Keats, 1987), appears on magnetic evidence to follow the trend of the Stans Dam–Parker Hill mafic belt.

On aeromagnetic evidence, the mafic schist in the Parker Hill area broadens to the west, and includes metagabbro within sand dunes northeast of the Victory–Defiance mine. An anomalous zone, on aeromagnetic evidence, extends across Lake Lefroy into the apparently isolated mafic rocks at Cutters Luck, and may continue to the Mount Martin area.

Paris

The Paris area is 40 km east-southeast of Widgiemooltha and west of the Tramways and Democrat areas on LAKE LEFROY and COWAN. The dominant trend of the rocks and fabrics is north. Two rock types characterize this area: metadolerite–metagabbro and metamorphosed felsic volcanics. The felsic rocks are best exposed in the south, on the north shore of Lake Cowan.

Although the rocks form low hills throughout the belt, contact relationships are rarely seen. Lower amphibolite metamorphism and well developed cleavage have destroyed most primary features. Only rarely do the intrusive mafic phases exhibit a mineral zoning indicating way-up. These intrusive sill-like bodies may have post-dated an early tight folding event and thus further disrupted the primary layering.

Even within the felsic schist no clear trends towards proximal material are evident. The best-exposed rhyolite with distinctive flow banding is in the south. Here the metamorphosed felsic volcanic rocks are interlayered with metabasalt and it is not clear whether the relationship is primary, or due to tectonic interleaving.

In general, the Paris area is at a slightly higher metamorphic grade than the greenstones to the west. It has a strong north–south trend with no clear fold structures. The Paris area mafic rocks appear, on magnetic maps, to terminate abruptly to the south. In the north they extend into the Parker–Yalca area. The felsic rocks on the east side persist to the north. The contact to the east is thought to be intruded by granitoid, whereas the western contact is faulted against the rocks of the Democrat area.

Salina

The Salina area is located 20 km north of the old Killaloe mine area, on a small saline lake system east of the main part of Lake Cowan on the eastern boundary of COWAN (Plate 2). Access is from the east along exploration tracks. This area contains most elements seen in other greenstone sequences. It is exposed beneath poorly consolidated, iron-rich, flat-lying, Tertiary sandstone, laterite, and gypsiferous dune deposits in breakaway country.

Tightly folded slate, and repetition of units across strike, indicate intense deformation caused by folding and faulting. The slate is associated with ultramafic schist containing tremolite, chlorite, carbonate, talc, and serpentine, and metamorphosed high-Mg basalt in the centre of the area. Metadolerite, felsic schist with bipyramidal quartz and felsic porphyry, crop out west and east of the mafic rocks. Metasiltstone and slate are associated with the felsic schist in the marginal areas.

A well-developed steep cleavage is present throughout the area, and strikes north-northwest. Quartz veins, generally parallel to the main fabric, are abundant.

Correlation for this isolated area is northwestwards, through a weak aeromagnetic anomaly across Lake Cowan, into the metabasalt south of the Republican–Democrat area.

Merougil

Sedimentary rocks, the Merougil beds (Asw), are well exposed in the southeast-plunging Merougil Syncline, 6 km west of Kambalda (Plate 1). The western limb of the syncline is steep and overturned in the south. Further outcrop is found to the southeast on the east side of Lefroy Peninsula. The Merougil beds comprise a 2300 m thick unit of metamorphosed, trough cross-bedded, pebbly sandstone and siltstone.

The basal unit of the Merougil beds is 300 m thick and consists of schistose interbedded sandstone and siltstone. The rock is a spotted quartz schist with feldspar, biotite, and chlorite. The spots (2–4 mm) consist of quartz and minor feldspar surrounded by biotite, and possibly replace andalusite. This unit has a sheared basal contact that overlies a strongly cleaved, coarse metaconglomerate, dominated by felsic volcanic clasts. The schistose, spotted siltstone is overlain conformably by a succession of metamorphosed, trough cross-bedded, pebbly sandstone

and conglomerate. The sandy component is poorly sorted, with clasts of quartz, feldspar and small rock fragments in a fine-grained matrix of quartz, muscovite and biotite. Rounded pebbles and cobbles generally occur at the base of thick-bedded units, which grade upwards to a fine-grained metasandstone that contains primary and metamorphic biotite. The clasts include porphyry, granodiorite, chert, metasedimentary rocks, and less abundant mafic and ultramafic volcanics (McCall and others, 1970). More than half the pebbles are feldspar–quartz–biotite schist of metasedimentary origin. Sedimentary structures include graded bedding, cross-bedding, scour channels and ripple marks.

Deformation fabrics are not obvious in the coarse metamorphosed sandstones and pebbly sandstones, but in some places the pebbles are aligned parallel to the regional cleavage, which dips steeply west and strikes north-northwest.

The sedimentary structures indicate that the Merougil beds were deposited in a shallow-water, fluvial environment. The clasts are from a mixed provenance indicating major uplift and erosion of pre-existing greenstones and granitoid. They overlie a highly deformed metamorphosed felsic volcanic sequence that crops out on headlands and islands on Lake Lefroy south of Kambalda (Fig. 16). This volcanic sequence includes metamorphosed dacitic volcanics and metamorphosed felsic volcaniclastic sandstone and conglomerate (Groves and Gee, 1980). The Merougil beds in this report differ from the definition proposed by McCall and others (1970) and adopted by Griffin and others (1983b), by excluding all metamorphosed felsic volcanic units. The transition from a felsic volcanic environment to a fluvial environment with a polymictic source area is sharp, and indicates that the sheared base of the Merougil beds is located on a disconformity.

The polymictic clasts indicate that the Merougil beds were formed relatively late in the development of the greenstones, post-dating the accumulation of earlier greenstones that included pelitic and psammitic sediments, granitoid intrusion and erosion, yet pre-dating at least the last strong regional north-northwest deformation.

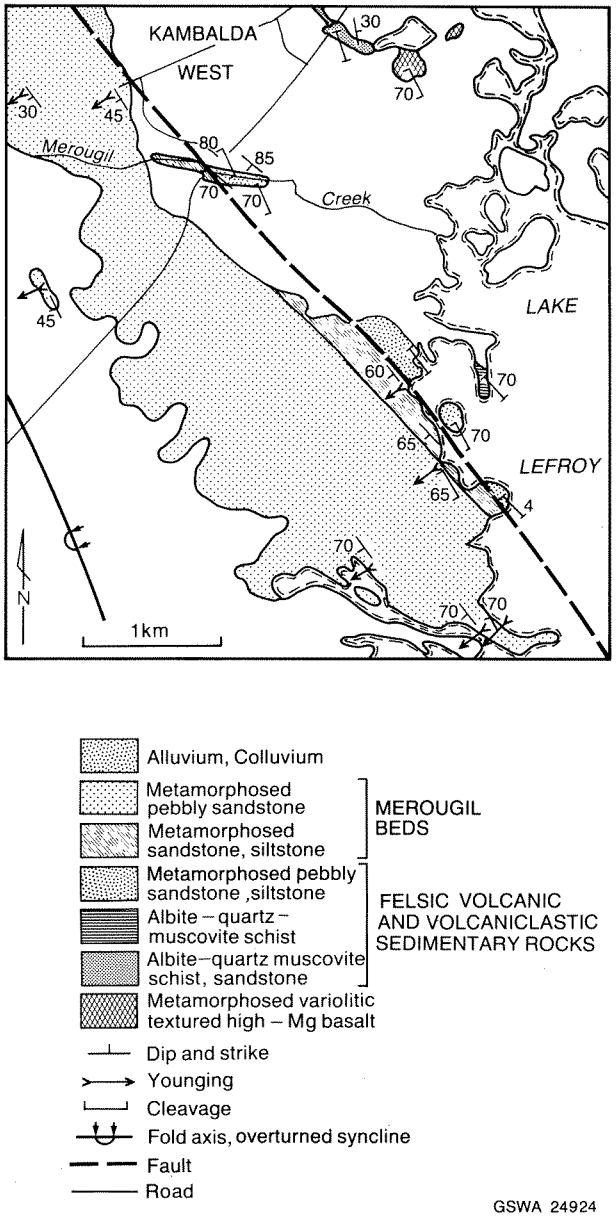


Figure 16. Geology of the eastern contact of the Merougil beds south of Kambalda (after McCall and others, 1970: Griffin and others, 1983b).

The Merougil beds are possibly a correlative of the Kurrawang beds, west of Kalgoorlie. Both sequences are fluviatile and include a wide range of well-rounded clasts. However, the Kurrawang beds are distinctive because they include an horizon rich in BIF clasts of unknown provenance (Groves and Gee, 1980; Hunter, in press b).

Conclusion

Stratigraphy

The basement to the greenstones is unknown. Old zircon xenocrysts, recently identified from the Kambalda mafic–ultramafic sequence, indicate that a sialic basement containing rocks up to 3500 Ma old was present during extrusion of the komatiite and basalt (Compston and others, 1984a, 1986).

The 2800–2600 Ma old greenstones on LAKE LEFROY and COWAN consist of a sequence of ultramafic, mafic and felsic lavas; clastic sediments largely derived from felsic volcanics; minor fine-grained siliceous sediments; mafic and ultramafic sills; and felsic porphyries. In most areas the stratigraphy is complex, and has been multiply deformed; relationships between areas are unclear, particularly across strike. However, the rocks can be assigned into a generalized stratigraphic succession (Fig. 17).

The first greenstones to form in this part of the southern Eastern Goldfields Province were a thick sequence of mafic–ultramafic rocks. Komatiite is generally overlain by mainly high-Mg basalt but in the Kambalda Anticline basalt also underlies komatiite. Thin shale beds occur at all levels except in the Merougil beds. They are abundant at or near the contact between the komatiite and the overlying basalt. A thick sequence of felsic volcanic rocks, dominated by dacite and rhyodacite and associated felsic-volcanic derived sediments, overlies the mafic–ultramafic rocks. Fluviatile pebbly sandstone of the Merougil beds unconformably overlies the felsic volcaniclastic sediments.

Banded iron-formation, a major component in the adjacent Southern Cross Province and areas marginal to the Norseman–Wiluna zone (Williams, 1975), is a very minor component of the greenstones of LAKE LEFROY and COWAN. Similarly, tholeiitic basalt is not abundant and high-Mg basalt predominates.

Structure

Folding

All Archaean rocks, except some of the small late granitoid intrusions and quartz veins, are deformed. They contain foliations, cleavages and lineations with a variety of orientations, which are dominated by a steep north-northwest trend. Mesoscopic folds are generally tight to isoclinal, and are particularly well preserved in pelitic metasedimentary rocks and fine-grained laminated siliceous units.

A generally weak cleavage, parallel to bedding, has been folded by subsequent deformation in many areas. Folds of regional scale are clearly defined by lithological trends on LAKE LEFROY and COWAN; such examples are the Kambalda Anticline, Carnilya Anticline, Republican Anticline and Widgiemooltha Anticline (Plates 1 and 2). Plunges on these structures range from moderate to steep, with formation of prominent domes caused by cross-folding, as at Kambalda, Democrat and Widgiemooltha. The major structural feature from areas of greenstone outcrop are summarized in Figure 18.

Recumbent folding (D_1) is the earliest of four deformation event recorded by Archibald and others (1978) from the Widgiemooltha area, Gresham and Loftus-Hills (1989) from the Kambalda area, and Swager (1989) from the Kalgoorlie area. Gresham and Loftus-Hills (1981) recorded a weakly developed, layer-parallel fabric, S_1. The most prominent D_1 structure is an anticline in the Republican–Bluebush area that has been refolded by a later event that produced the prominent north-northeast trending folds, such as the Republican Anticline.

D_2 was a mild, generally large wavelength event that produced a steep east- to northeast-trending axial plane. Any fabrics that were formed by this event appear to have been masked by later strongly penetrative deformation. D_2 folds are present at Tramways, Hayes Hill, and in greenstones north of the Pioneer Granitoid Complex. D_2 may be equivalent to some of the F_3 structures of Gresham and Loftus-Hills (1981). They suggested that these are asymmetric, with the northern limbs of anticlines steeper than the southern, and that they post-dated the regional north-northwestern event. The overturned Carnilya Anticline is possibly a D_2 structure.

D_3 was an intense, tight-folding event with a steep north-northwest trending axial plane. It dominates the regional structures and has produced a well developed S_3 fabric, present in all local Archean rock types. Interference with D_2 has caused the plunge reversals of these north-northwest-trending folds. D_3 interference on D_2 was also responsible for the pattern of domal, ovoid areas of granitoid surrounded by greenstones, particularly the Widgiemooltha Dome in west COWAN. Alternatively, Archibald and others (1981) argued that the fabrics in the Widgiemooltha Dome and adjacent greenstones resulted from solid-state diapiric emplacement of granitoid. However, the strong lineations that Archibald and others (1981) use to support their model are associated with well developed tectonic foliation, and are consistent with interference folding that involved D_2 and D_3. F_3 is equivalent to F_2 of Gresham and Loftus-Hills (1981), and D_3 of Archibald and others (1978). The

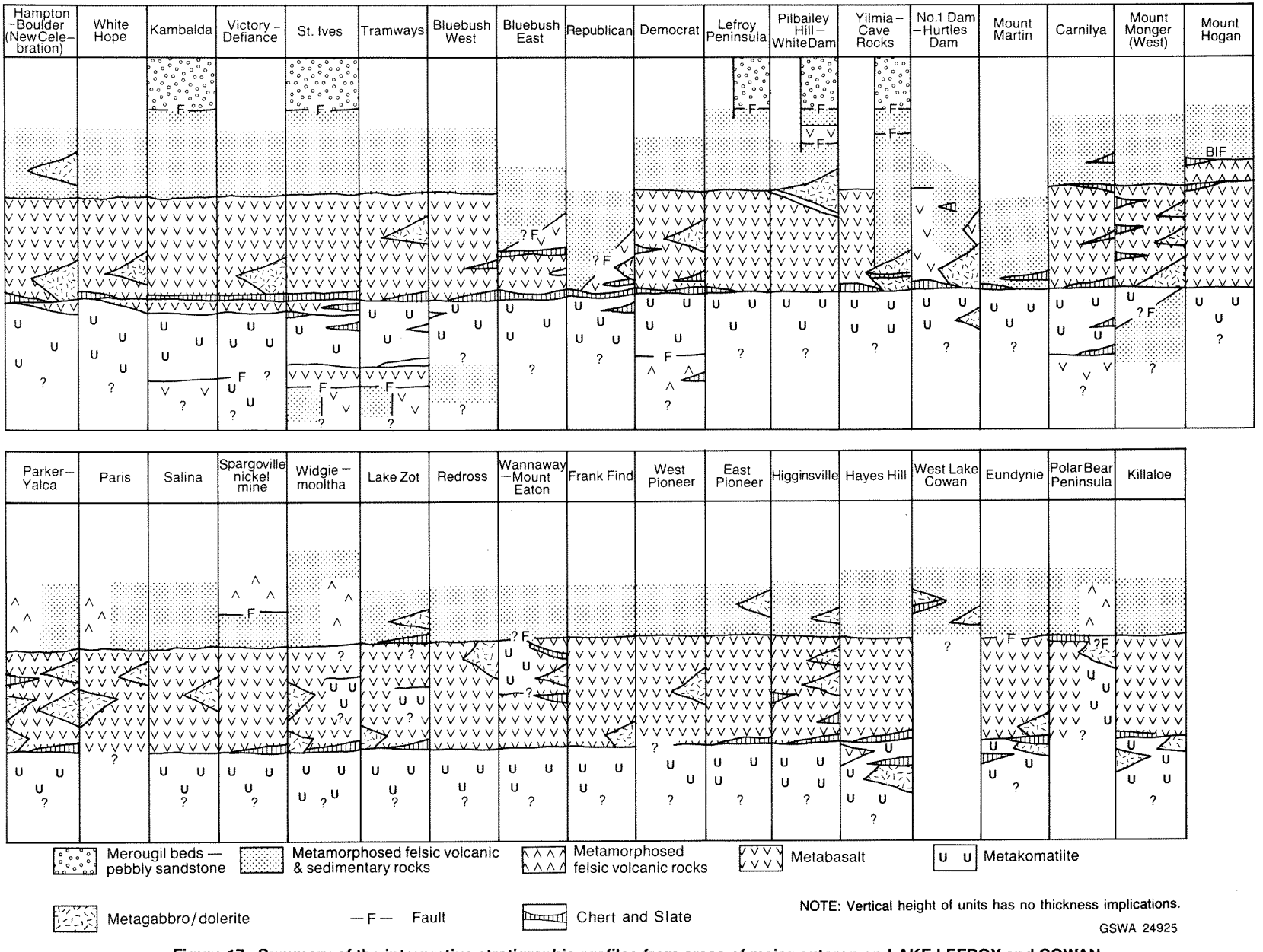


Figure 17. Summary of the interpretive stratigraphic profiles from areas of major outcrop on LAKE LEFROY and COWAN.

	COWAN & LEFROY	VICTORY—DEFIANCE	KAMBALDA	WIDGIEMOOLTHA — NORSEMAN	COOLGARDIE	KALGOORLIE	NORSEMAN
	This report	Clark and others, 1986	Gresham and Loftus – Hills, 1981	Archibald and others, 1978; Archibald and Bettenay, 1977	Hunter, in press b	Swager, 1989	Spray, 1985
	? D_4 — Localized folding related to faulting	D_4 — N S_4 — zones dip steeply E & W	D_4 — N — upright open folds	S_4 — crenulation cleavage adjacent to granitoid		Post D_4 — E — weak cross folding, small scale, localized	D_4 — ENE — upright open folds S_4
			D_3 — ENE, NE — upright, open folds				
MAIN REGIONAL EVENT	D3 — NNW (N,NW) — upright, open to tight folds S_3 — major regional fabric	D_3 — NNW — upright open to tight folds S_3 — well developed	D_2 — NNW — upright, open to tight folds S_2 — well developed	D_3 — NNW — upright open tight folds, synkinematic granite doming S_3 — well developed	D_3 — N, NW — upright, open to tight folds S_3	D_3 — NW, NNW — upright close to tight folds S_3 — well developed	D_3 — NNW — upright close tight S_3 — well developed
	D_2 — E, NE — open, upright folds	D_2 — tight to isoclinal recumbent folds S_2		D_2 — N, NNW — mesoscopic folds	D_2 — ENE, NE — upright open to tight folds	D_2 — NW, NNW — upright open folds	D_2 — NNE — upright, large scale folds — refolded by D_3
	D1 — tight to isoclinal recumbent folds — thrusts S_1	D_1 S_1 — mineral foliation	D_1 — tight to isoclinal recumbent folds S_1 — weak	D_1 — isoclinal recumbent folds	D_1 — tight to isoclinal ?recumbent folds S_1	D_1 — NE — recumbent folds to fold nappes — large thrust sleets	D_1 — intrafolial folds S_1 — mylonitic, shallow dipping

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Figure 18. Summary of structural features recognized from areas of major outcrop on LAKE LEFROY and COWAN.

relative timing of D_2 and D_3 is unclear; the two events may have been closely related, which would mitigate against development and preservation of D_2 fabrics, particularly if D_2 was mild.

From work at Kalgoorlie, Swager (1989) recognized steep north-trending folds which he attributed to sinistral movement on the Boulder–Lefroy Fault during the early part of D_3. North–south folds on LAKE LEFROY and COWAN may be similarly related to faulting, particularly those adjacent to the Boulder–Lefroy Fault in the north.

Subsequent deformation is recognized at Kambalda by Gresham and Loftus-Hills (1981), in the form of upright F_4 folds with south-plunging axes. In west COWAN and southwest LAKE LEFROY, Archibald and others (1978) recognized two folding events that trend north-northwest. Planar fabrics associated with these are steep, and generally parallel to lithological layering. They probably include both S_1 and S_3, with much of the variation in direction due to interference by D_3 on S_1. However, crenulation of S_3 does occur in some high-strain areas adjacent to the granitoid margins, indicating a post-D_3 event roughly parallel to D_3.

The folding history, recognizable throughout LAKE LEFROY and COWAN (Fig. 18), shows the similarity between the various areas of exposure. The pattern is comparable with that proposed by Gresham and Loftus-Hills (1981) for the Kambalda area, Archibald and Bettenay (1977) and Archibald and others (1978) for the Widgiemooltha area, Spray (1985) for the Norseman area to the south, Clark and others (1986) for the Victory–Defiance area, Swager (1986) for the Kalgoorlie area to the north, and Hunter (in press b) for the Coolgardie area to the northwest (Fig. 19). Differences relate to the recognition of a pre-D_3 event, its orientation, and the type and extent of D_1 and post-D_3 deformation.

Faulting

The most prominent fault is the Boulder–Lefroy Fault that extends from Kalgoorlie southeastward to beyond the St Ives area (Plates 1 and 2). It is not well exposed, but is identified by shear zones and sharp terminations of lithological trends. In the Hampton-Boulder (New Celebration) mine and Jubilee mine areas, the Boulder–Lefroy Fault is a zone of shearing, up to 300 m wide, that includes gold mineralized porphyry and

D_1 — recumbent folding (F_1) and thrusting (f_1) — layer parallel cleavage (S_1)

D_2 — mild upright folds, ENE — E (F_2)

D_3 — NNW — N, upright, steep, tight folds (F_3) — cleavage (S_3), faults (f_3) — wrench faults (f_w), N – wrench folds (F_{3W})

D_4 — mainly faulting (f) — localized folding

	Hampton Boulder (New Celebration)	White Hope	Kambalda	Victory – Defiance	St. Ives	Tramways	Bluebush West	Bluebush East	Republican	Democrat	Lefroy Peninsula	Pilbailey Hill White Dam	Yilmia – Cave Rocks	No.1 Dam – Hurtles Dam	Mount Martin	Carnilya	Mount Monger (West)	Mount Hogan
D_4	f — ENE									f — WNW f — N	f — NE	f — ENE	f — ENE f — NE	f — NE f — NW	f — NE f — NW f — N f — E	f — NE f — N	f — N	f — NE
D_3	f_w F_{3W} F_3 S_3	f_w F_3 S_3	f_w F_3 S_3	f_w $?f_3$ F_3 S_3	f_w F_3 S_3	f_w F_3 S_3	 $?F_3$ S_3	 S_3	 F_3 S_3	$?f_3$ F_3 S_3	$?f_3$ $?F_3$ S_3	f_3 F_3 S_3	f_3 F_3 S_3	$?f_3$ F_3 S_3	 $?F_3$ S_3	 	 F_3 S_3	$?f_3$ F_3 S_3
D_2			F_2		F_2	F_2				F_2					F_2	F_2		$?F_2$
D_1			$?F_1$	f_1 $?F_1$ S_1	f_1 S_1	f_1 S_1	$?F_1$ S_1	f_1 F_1 S_1	f_1 F_1 S_1	f_1 S_1	f_1 $?F_1$ $?S_1$	f_1 $?F_1$ S_1			 $?F_1$ S_1	$?f_1$ $?F_1$ S_1	$?f_1$ $?F_1$ S_1	$?f_1$ $?F_1$ S_1

	Parker – Yalca	Paris	Salina	Spargoville nickel mine	Widgie – mooltha	Lake Zot	Redross	Wannaway – Mount Eaton	Frank Find	West Pioneer	East Pioneer	Higginsville	Hayes Hill	West Lake Cowan	Eundynie	Polar Bear Peninsula	Killaloe
D_4		f — E		f — E f — NE	f — NE f — NW	f — NE					f — NW		f — NW f — NNW		f — NW	f — NNW	
D_3	f_3 — N, NNW F_3 — N, NNW S_3	$?f_3$ — N F_3 — N S_3	$?f_3$ F_3 S_3	$?f_3$ — N F_3 — N S_3	$?f_3$ F_3 S_3	$?f_3$ — N, NNW F_3 — N, NNW S_3	$?f_3$ — N F_3 — N S_3	$?f_3$ F_3 S_3	F_3 S_3	 F_3 — N, NNW S_3	$?f_3$ — N F_3 — N S_3	$?f_3$ — N F_3 S_3	$?f_3$ F_3 — NNE S_3	$?f_3$ — N, NNW F_3 — N, NNW S_3	f_3 F_3 S_3	 F_3 — N S_3	$?f_3$ F_3 S_3
D_2								F_2 — NE		F_2 — E			F_2 — ESE		$?f_2$ — N F_2	$?f_2$ — N $?F_2$	
D_1				$?f_1$ S_1	$?f_1$ F_1 S_1	$?f_1$ $?F_1$	$?f_1$ $?F_1$	$?f_1$ F_1			$?f_1$ $?F_1$	$?f_1$ $?F_1$	$?f_1$ $?F_1$ S_1		$?f_1$ F_1 S_1	F_1 S_1	

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Figure 19. Regional metamorphic subdivisions on LAKE LEFROY and COWAN (after Binns and others, 1976; Bickle and Archibald, 1984) [Ky = Kyanite].

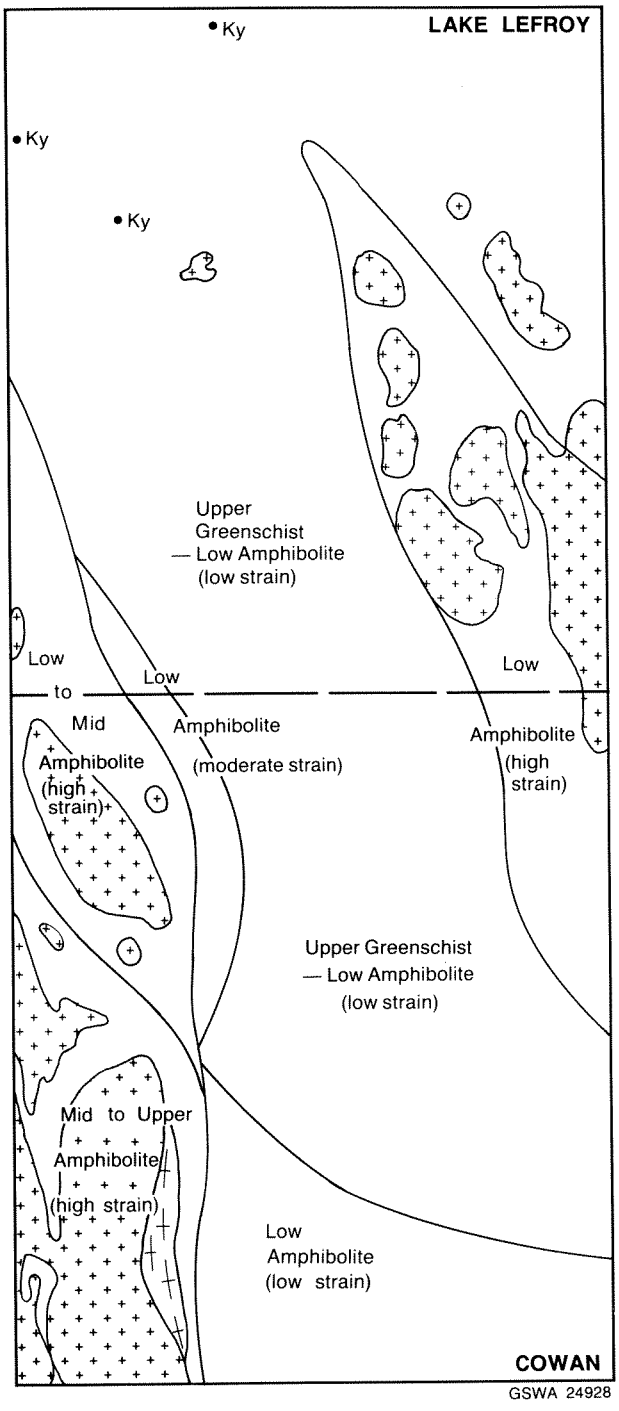

Figure 20. [Regional folding histories from areas of greenstones relevant to LAKE LEFROY and COWAN].

ultramafic schist containing quartz veins. Sinistral movement of 10 km has been determined on this fault, and it has been interpreted by Swager (1989) as a major wrench structure at about the time of the strong D_3 event. Less extensive north-northwest trending faults occur in other areas (Plates 1 and 2).

An early suite of faults, folded by D_2 and D_3 folds, is recognized. The faults are most prominent in the open D_3 Kambalda Anticline, north of Jan nickel mine, and in the Republican–Democrat area. In both areas they are parallel to early tight to isoclinal folds, intepreted as D_1 (recumbent), and have been folded along with the D_1 folds and S_1 cleavage. Consequently these faults represent early thrust faults associated with the D_1 event. Other areas that may include D_1 thrusts are indicated in Figure 18.

Late faults, generally at high angles to the lithological trends, cause minor offsets (Plates 1 and 2).

Metamorphism

Reviews of metamorphic evolution of the Eastern Goldfields granite–greenstone terrane (Binns and others, 1976; Archibald and Bettenay, 1977; Archibald and others, 1978, 1981; Bickle and Archibald, 1984) have incorporated detailed work from the Widgiemooltha area on LAKE LEFROY and COWAN. Two main divisions are recognized. Areas of "static metamorphism" contain rocks metamorphosed to prehnite–pumpellyite, greenschist, and lower amphibolite facies with little internal strain. Primary lithologies are easily recognized. Areas of "dynamic metamorphism" contain rocks metamorphosed to greenschist, amphibolite and occasionally lower granulite facies, in high strain zones. These dynamic zones are shown by Binns and others (1976) to be marginal to greenstones, adjacent to granitoid, and interpreted as loci of deformation and heating.

Mineralogy in low-grade metasedimentary rocks is dominated by quartz, albite, muscovite and chlorite. As the grade increases, andalusite and biotite are succeeded by garnet, cordierite, staurolite, calcic plagioclase and sillimanite. In the mafic rocks albite, epidote and tremolite-actinolite are replaced by biotite, hornblende, andesine and garnet. Kyanite has been observed in the Mount Martin area (Purvis, 1984), where it probably reflects Al-enrichment in intensely metasomatized rocks (Martyn and Johnson, 1986), and at two localities in northeast LAKE LEFROY (Fig. 20) where it occurs in deformed kyanite–muscovite–quartz schist. The texture of the kyanite indicates that it grew in an unstrained environment.

The distribution of metamorphic grades is shown in Figure 20 which is based on a regional overview after Binns and others (1976), rather than on detailed work, apart from that of Bickle and Archibald (1984).

Binns and others (1976) in their review suggested that the metamorphic pattern developed during a single thermal event. However, in detail it appears to be polyphase. Gresham and Loftus-Hills (1981) described the history at Kambalda as beginning with early ocean-floor metamorphism and serpentinization. A first peak was associated with D_3, the main regional deformation that involved talc–carbonate alteration, and a

late phase of potassic metasomatism affecting intrusives by replacing chlorite with biotite.

Significant retrogressive mineralogy and textures in ultramafic rocks are described from the Spargoville mine area by Groves and Gee (1980). Archibald and others (1978) described a local low-grade metamorphic fabric prior to the main regional event. To the south in the Norseman area, Spray (1985) has suggested a polyphase history for the greenstones, with some events quite localized and related to intrusion or deformation.

Bickle and Archibald (1984) suggested that the higher grade of metamorphism close to the granitoid in the west reflects superposition of a thermal aureole on regional metamorphic conditions that were similar to those in the lower-grade areas.

Evolution of the granite–greenstone terrane

The granite–greenstone terrane in the LAKE LEFROY– COWAN region has evolved over nine main stages:

(1) Formation of sialic crust at 3500–3200 Ma. These rocks have not been directly recognized in the Eastern Goldfields.

(2) Accumulation of a thick greenstone sequence consisting of: ultramafic, mafic, and felsic volcanics; ultramafic, mafic and, felsic intrusives; thin, fine-grained siliceous units; and sedimentary rocks (turbidites) largely derived from felsic volcanic material. These rocks accumulated without significant tectonism. The greenstones appear to have a broad primary stratigraphy that began with mafic–ultramafic rocks and passed upwards through felsic volcanics to thick sedimentary sequences. There is no compelling evidence that these rocks formed as a multicyclic succession, as suggested by Gemuts and Theron (1975).

(3) Recumbent folds and thrust faults interleaved and repeated the stratigraphy.

(4) Intrusion of granitoid and possibly further deformation.

(5) Erosion of greenstones and granitoids and deposition of fluviatile Merougil beds.

(6) Major regional deformation (D_3) forming tight folds, steep north-northwest cleavage, and wrench faulting. Further intrusion of granitoid.

(7) Further faulting and minor deformation.

(8) Intrusion of Proterozoic dykes (2400 Ma).

(9) Erosion prior to deposition of post-Archaean sedimentary rocks (Griffin, 1989).

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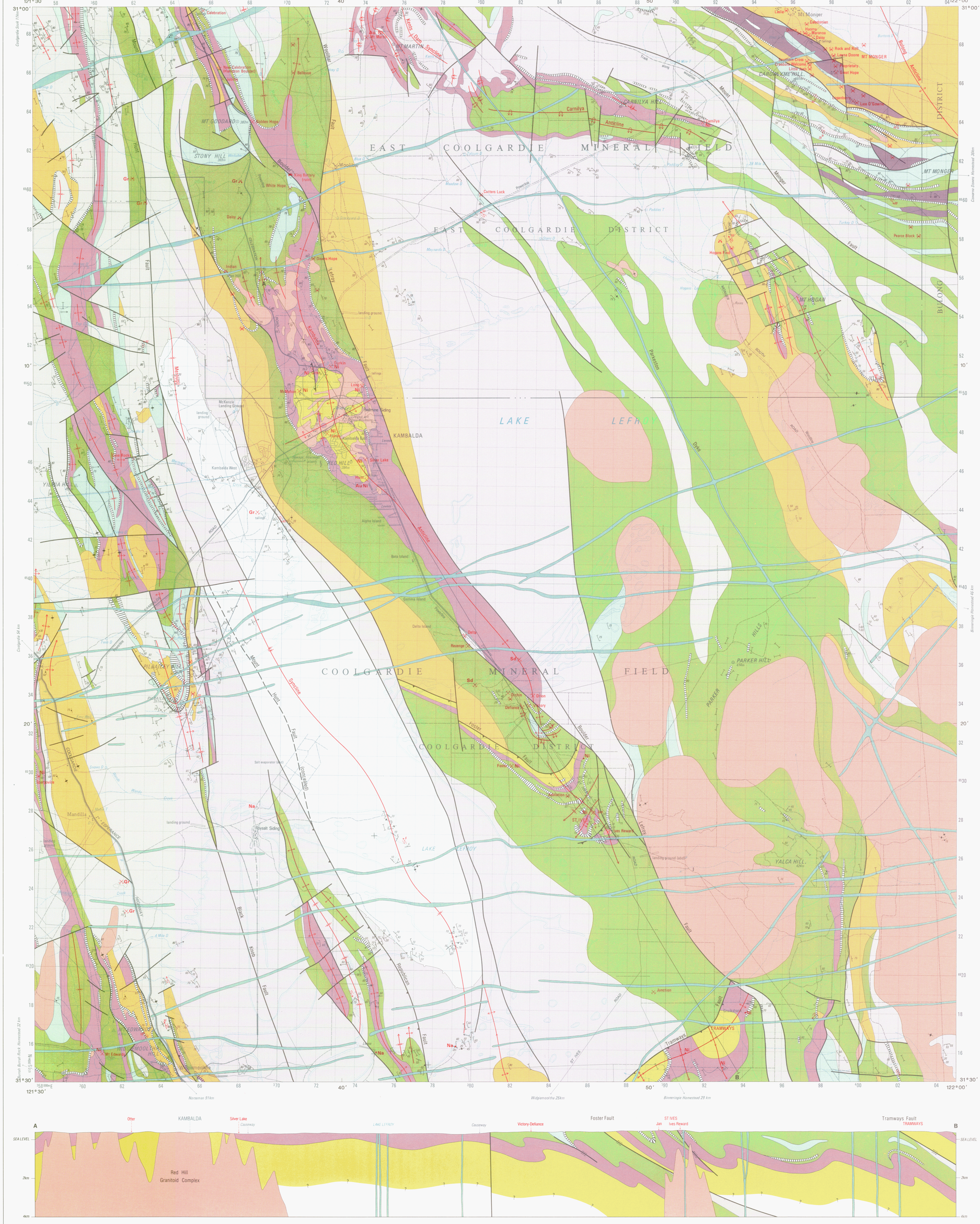
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

REPORT 32 PLATE 1



PROTEROZOIC

- Mafic and ultramafic dykes

ARCHAEAN

- Granitoid rocks, partly recrystallized
- Merougil beds: metamorphosed fluviatile pebbly sandstone
- Metamorphosed dolerite and gabbro, and minor ultramafic rocks
- Metasedimentary rocks; largely derived from felsic volcanics
- Metamorphosed felsic volcanic rocks
- Slate, metamorphosed shale and banded iron-formation, and "chert"
- Metabasalt (predominantly high-Mg) and mafic sills
- Metamorphosed ultramafic rocks
- Metakomatiite
- Kambalda footwall basalt: metamorphosed tholeiitic and high-Mg basalt

- Geological boundary
- Unconformity
- Fault
- Thrust fault
- Fold showing plunge
  - anticline
  - syncline
  - overturned anticline
  - overturned syncline
  - minor fold
  - M vergence
- Bedding
  - inclined
  - vertical
  - horizontal
- Way-up indicator
  - sedimentary
  - graded bedding
  - differentiated intrusion
- Cleavage
  - inclined
  - vertical
  - strike coincident with bedding
  - with lineation
- Foliation, metamorphic
  - inclined
  - vertical
- Joint
  - inclined
  - vertical
- Trace fossil locality
- Highway with national route marker
- Formed road
- Track (many exploration and logging tracks not shown)
- Railway, railway abandoned
- Townsite gazetted
  - pop. 1000 – 10000 — KAMBALDA
  - pop. less than 1000 — Widgiemooltha
- Homestead — Mandilla
- Locality — Kambalda West
- Horizontal control, major, minor
- Microwave repeater site, building
- Lake margin
- Watercourse, ephemeral
- Pipeline
- Playa lake, fresh — brackish
- Dam ; tank
- Mining locality — ST IVES
- Mine, mining area (gold unless otherwise indicated) — Victory
- Mine, abandoned
- Alluvial workings, abandoned
- Mineral occurrence
  - Gold — Au
  - Nickel — Ni
  - Salt — Na
  - Pit
  - Gravel — Gr
  - Sand — Sd

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MOUNT MALCOLM 2956	DUNDAS (E) 3056	KALGOORLIE 3156	KANOWNA 3256	KURNALPI 3356	IRON 3456
BOORABIN 2955	MOUNTS GANGE 3055	YILMIA 3155	LAKE LEFROY 3255	MOUNT BELCHER 3355	FRAYMAN 3455
BOORABBIN			WIDGIEMOOLTHA	
SH 51-13			SH 51-14	
LAKE PERCY 2854	DIAMOND ROCK 3054	CAVE HILL 3154	COWAN 3254	YARDINA 3354	YARDILLA 3454

1:100 000 SERIES — GWYHERIC
1:250 000 SERIES — BOORABBIN

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MINISTER FOR MINES
D.R. KELLY, DIRECTOR GENERAL OF MINES

P.E. PLAYFORD
DIRECTOR, GEOLOGICAL SURVEY
OF WESTERN AUSTRALIA

SCALE 1:100 000

1000 0 1 2 3 4 5 6 7 8 9 10
Metres Kilometres

TRANSVERSE MERCATOR PROJECTION
Grid lines indicate 1000 metre interval of the Australian Map Grid Zone 51

Geological interpretation by: T.J. Griffin 1986

Based on geology by Griffin (1988: Lake Lefroy 1:100 000 Geological Series — sheet 3235, Geological Survey of Western Australia), and aeromagnetic colour plot at 1:100 000 scale (contour interval — 25 nano Tesla) by Aerodata Holdings Limited (1985).

Cartography by the Surveys and Mapping Division, Department of Mines, Western Australia.

Topographical base supplied by the Australian Survey and Land Information Group, Department of Administrative Services (1975)

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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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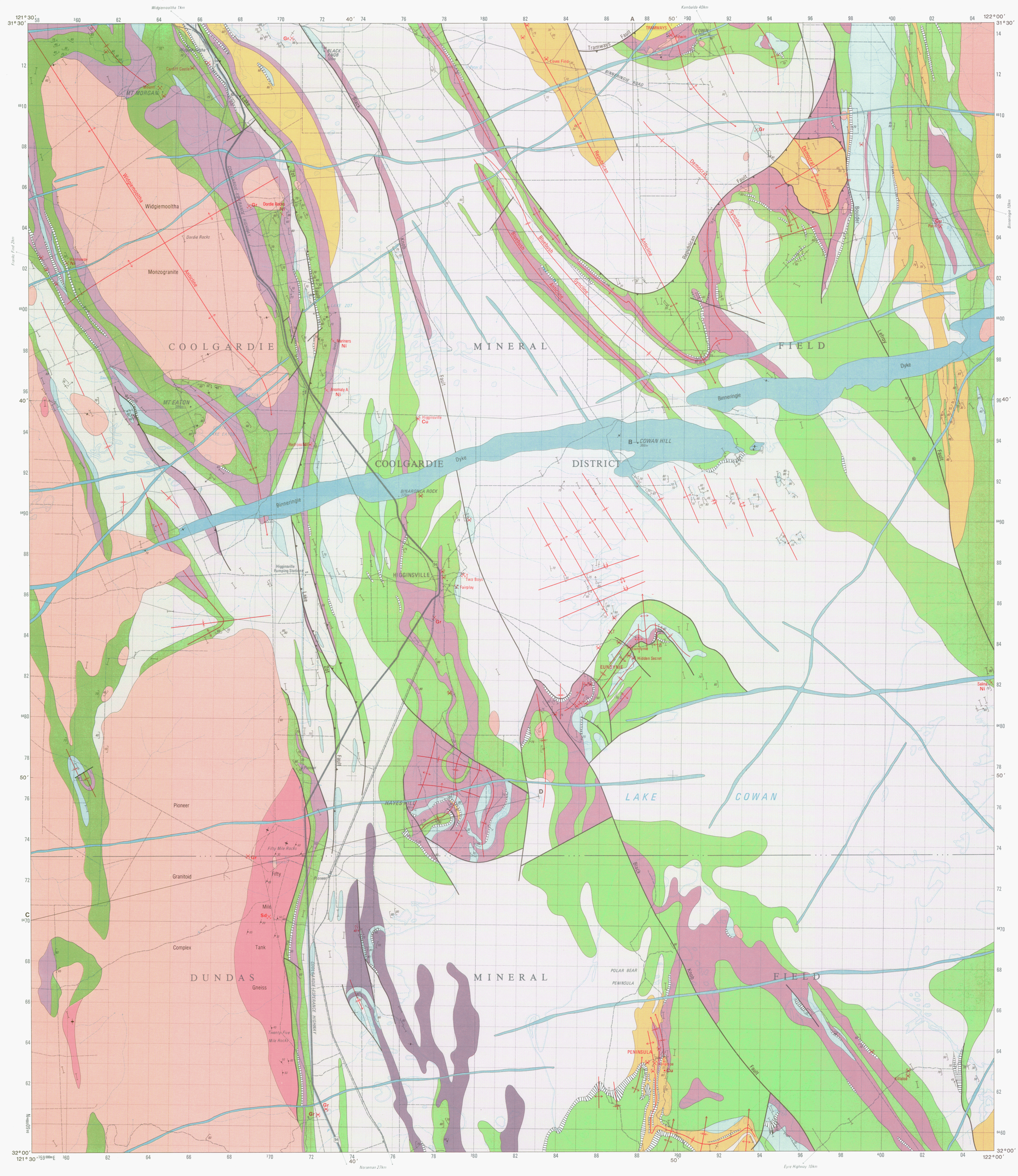

PROTEROZOIC

- Mafic and ultramafic dykes

ARCHAEAN

- Granitoid rocks, partly recrystallized
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- Metamorphosed ultramafic rocks
- Metakomatiite
- Kambalda footwall basalt: metamorphosed tholeiitic and high-Mg basalt

Geological boundary
Fault
Thrust fault
Fold showing plunge
- anticline
- syncline
- overturned anticline
- overturned syncline
- minor fold

Bedding
- inclined
- vertical
- horizontal

Way-up indicator
- sedimentary
- graded bedding
- igneous pillows
- differentiated intrusion

Cleavage
- inclined
- vertical
- strike coincident with bedding
- with lineation

Foliation, metamorphic
- inclined
- vertical

Joint
- inclined
- vertical

Macrofossil locality

Highway with national route marker
Formed road
Track (many exploration and logging tracks not shown)
Railway, with siding
Railway, abandoned
Fence
Townsite gazetted, pop. less than 1000 — HIGGINSVILLE
Microwave repeater site, building
Lake margin
Watercourse, ephemeral
Pipeline
Playa lake, fresh — brackish
Dam, tank
Mining locality — EUNDYNIE
Mine, mining area (gold unless otherwise indicated) — Killaloe
Prospect
Mine, abandoned
Tailings retreatment plant
Mineral occurrence
- Copper — Cu
- Nickel — Ni

Pit
- Gravel — Gr
- Sand — Sd

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1:100 000 SERIES — YILMIA
1:250 000 SERIES — BOORABBIN

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SCALE 1:100 000

1000 0 1 2 3 4 5 6 7 8 9 10
Metres — Kilometres

TRANSVERSE MERCATOR PROJECTION
Grid lines indicate 1000 metre interval of the Australian Map Grid Zone 51

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