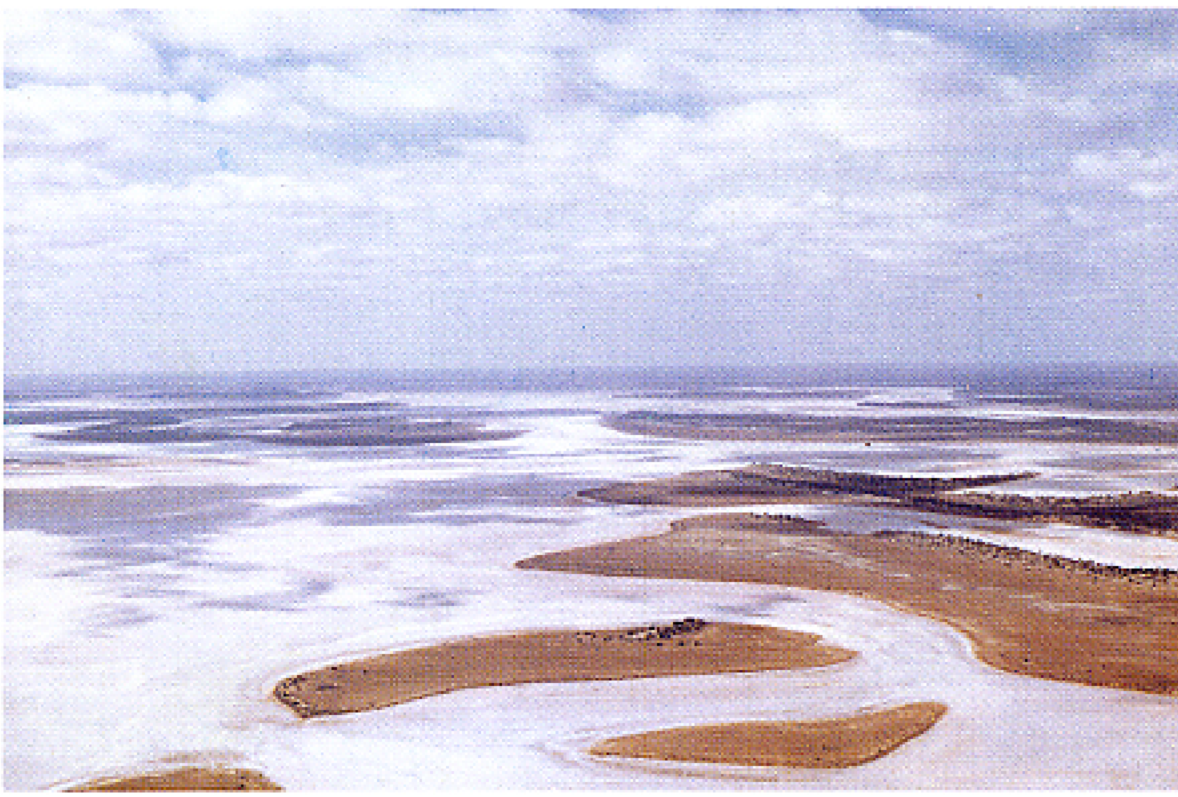
XPLANATORY NOTES

GEOLOGY OF THE KURNALPI 1:100 000 SHEET

by C.P. SWAGER



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DEPARTMENT OF MINERALS AND ENERGY

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGY OF THE KURNALPI 1:100 000 SHEET

by
C. P. Swager

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MINISTER FOR MINES
The Hon. George Cash, J.P., M.L.C.

ACTING DIRECTOR GENERAL
L. C. Ranford

DIRECTOR, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
Pietro Guj

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Cover photograph:
Aerial view of Lake Yindarlgooda, which covers much of the northwest portion of the Kurnalpi 1:100 000 sheet

Contents

Appendix

Figures

Tables

Geology of the Kurnalpi 1:100 000 sheet

by

C. P. Swager

Summary

The KURNALPI 1:100 000 sheet area is underlain by volcano-sedimentary greenstone sequences with granitoids mainly restricted to the eastern and northern parts of the sheet. Four stratigraphic–structural domains are distinguished.

The Juglah Domain in southwest KURNALPI lies on the east limb of a regional anticline. A felsic to intermediate volcanic sequence in the core of the anticline is overlain by a mafic volcanic sequence which becomes thinner and changes in composition (high Mg to tholeiitic) from south to north. The Randell Shear separates the Juglah Domain from the Mount Belches Domain in the south and the Jubilee Domain in the north.

The Mount Belches Domain contains a rather monotonous, intensely folded greywacke sequence with minor banded iron-formation.

The Jubilee Domain is separated from the Mount Belches Domain by the Railway Shear. It contains a complex sequence of basalt, komatiite (including massive peridotitic–gabbroic layers), sedimentary rock and minor felsic volcanic rock. At least four major ultramafic horizons, interleaved with the other rock types, can be clearly distinguished, and may indicate repeated ultramafic volcanism or structural repetition. The sequence is disrupted by intrusive granitoids along the northern boundary of KURNALPI. The volcano-sedimentary rocks are successively younger to the southwest and overlain by conglomerate and sandstone, possibly as part of a later syntectonic sequence. Characteristic wedge-shaped, faceted pebbles and boulders suggest a glacial origin.

The Avoca Shear separates the Jubilee Domain from the Karonie–Yindi Domain, which is dominated by an apparent regional synform. The lower part of the sequence contains complexly interleaved basalt and sedimentary rock, with some komatiite along the contact with the overlying felsic volcanic complex and associated epiclastic rocks including banded iron-formation. Intrusive granitoids (Bulyairdie Monzogranite, Yindi Monzogranite) have disrupted the volcano-sedimentary succession.

Structural–stratigraphic relationships between the various domains require further study.

Metamorphic grade generally increases from west to east with low- to mid-amphibolite facies conditions attained in the Karonie–Yindi Domain.

Regional structures are dominated by the inferred domain boundary faults, by major (both gently and steeply plunging) folds within the domains, and by the complex granitoid–greenstone geometry along the northern sheet boundary.

Modest historical gold production on KURNALPI occurred at three small mining centres (Jubilee, Kurnalpi, and Transfind).

KEYWORDS: Eastern Goldfields Province, Yilgarn Craton, regional geology.

Introduction

The KURNALPI* 1:100 000 map sheet (SH51-10-3336) occupies the central southern part of the KURNALPI 1:250 000 sheet, and lies between latitudes 30°30'S and 31°00'S and longitudes 122°00'E and 122°30'E. The first edition of the KURNALPI 1:250 000 geological map sheet (Williams, 1970) was prepared and published before the nickel and gold exploration booms in the 1970s and 1980s respectively.

KURNALPI is part of a series of 1:100 000 scale maps covering the Eastern Goldfields (Fig. 1). Mapping was carried out between April 1989 and June 1990 using 1:25 000 colour aerial photographs. Greenstone terrain has

* Capitalized names in these notes refer to standard map sheets.

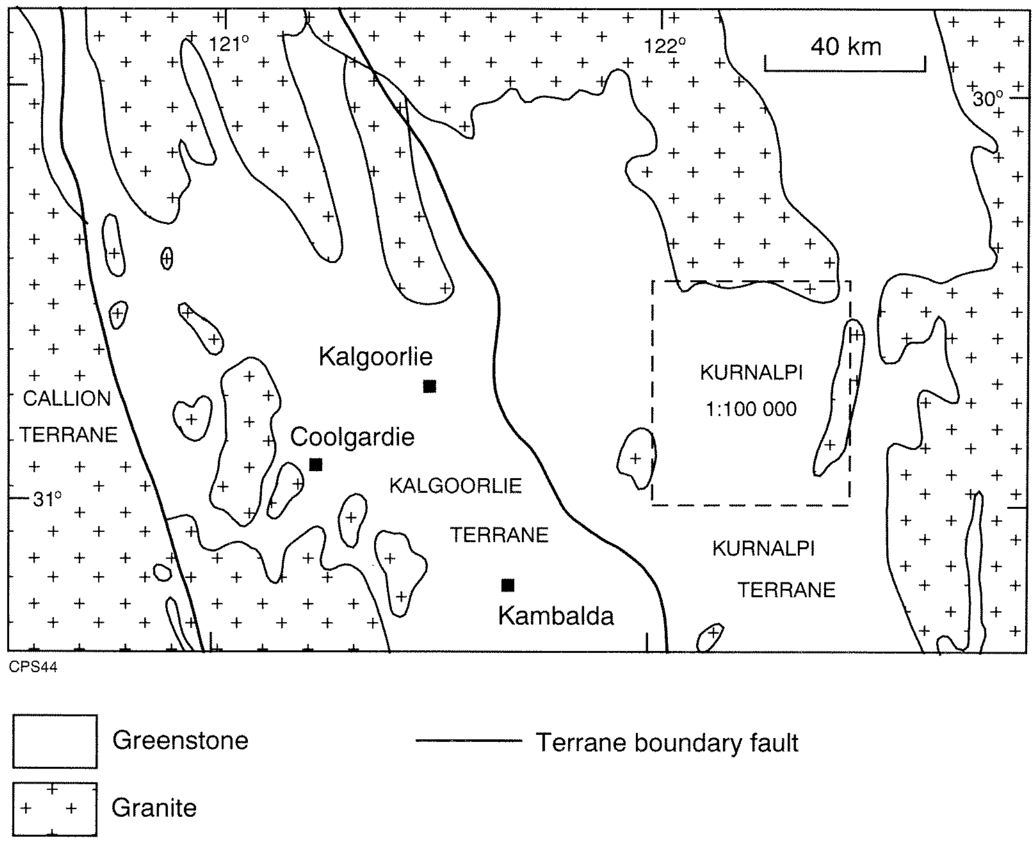

Figure 1. Location of KURNALPI within the southern Eastern Goldfields Province. Structural–stratigraphic terranes and their boundary faults from Swager et al. (1990)

been systematically mapped at photo scale, along tracks, fence lines and numerous foot traverses. Degree and quality of outcrop vary from reasonable to very poor.

Early publications include descriptions of gold mines around Kurnalpi township (Montgomery, 1906; Jutson, 1914). A regional survey of host rocks, alteration assemblages and structural setting of all gold-producing mines is planned.

Williams (1970, 1974, 1976), in a major contribution to the understanding of Eastern Goldfields geology, recognized a regional stratigraphy based on the 1:250 000 mapping program. Williams proposed a stratigraphic succession consisting of five associations of alternately mafic volcanic and felsic volcanic/volcaniclastic nature. These associations or formations were interpreted as constituting three cycles, each characterized by a progressive change from mafic to felsic volcanic and clastic rock types.

The only other recent publication on the area is a petrological study of Proterozoic dykes 10 km north of Avoca Downs (Purvis and Moeskops, 1981).

Several substantial mineral exploration reports on KURNALPI are held on open file by the Geological Survey of Western Australia (WAMEX Open File system).

Access, physiography and Cainozoic geology

Major, unsealed access routes are the Transline road adjacent to the Trans Australian Railway in the south, and the Kanowna–Pinjin road in the north (Fig. 2). Numerous pastoral tracks and fencelines provide access away from the major east–west roads. Sheep farming is based on Hampton Hill Station in the west and northwest, Mount Monger in the southwest, Avoca Downs and Cowarna Downs in the southeast, and Yindi Station in the northeast.

The physiography reflects to a large extent the underlying geology. Areas underlain by mafic volcanics are characterized by low rolling hills with open eucalypt growth, whereas areas underlain by sedimentary and felsic volcanic rocks form open low-lying grasslands with some lateritic plateaus. Granitoid areas form sandy plains covered by dense acacia growth and some low outcropping inselbergs. Lake Yindarlgooda is a major easterly trending feature bordered by kopai dunes.

Eight types of Cainozoic deposits are distinguished.

Laterite (*Czl*) and deeply weathered rocks form plateaus and more-subdued areas of reworked products including pisolitic soils.

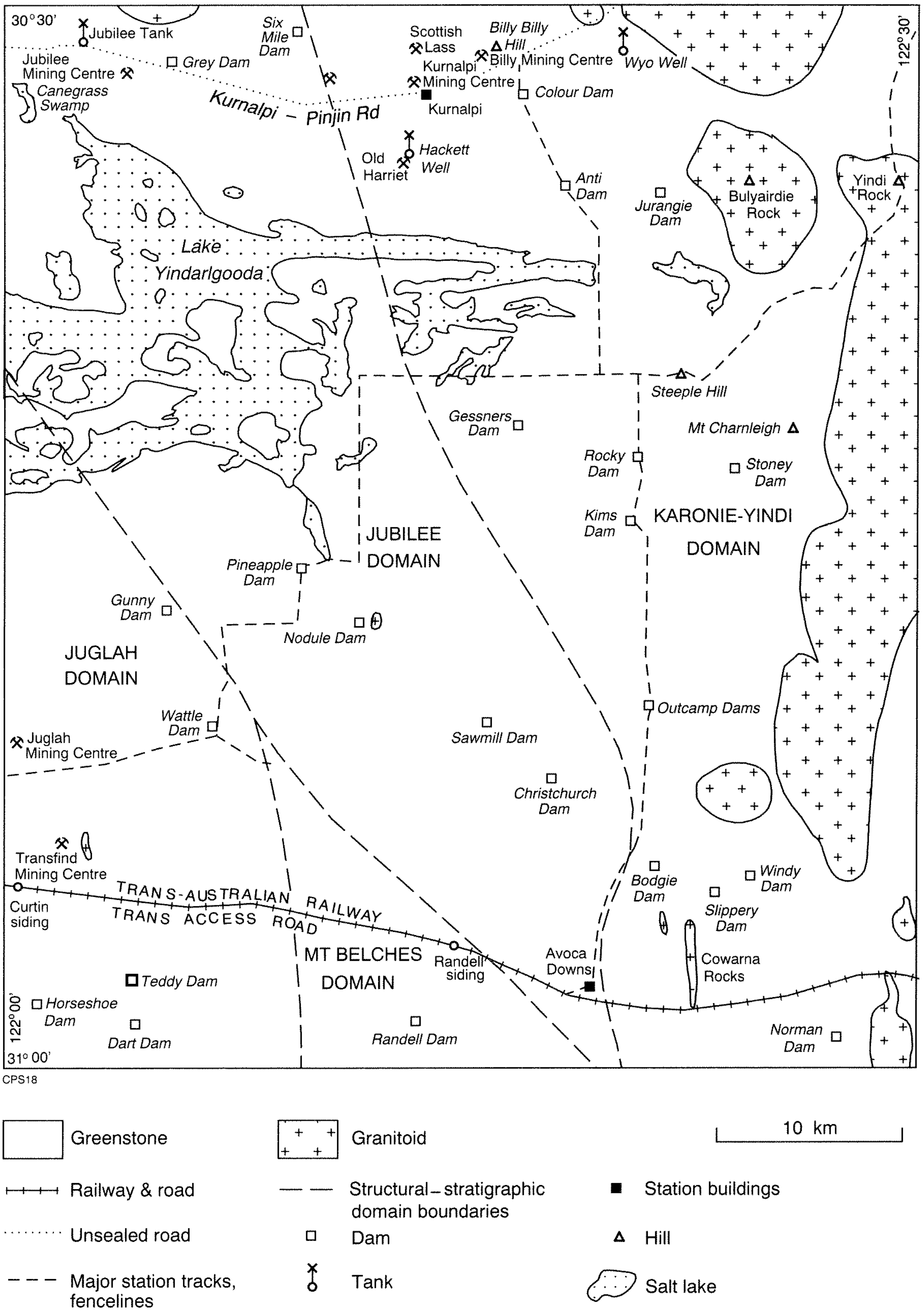

Figure 2. **Location names, major access roads and tracks on KURNALPI. Areas underlain by granitoid and greenstone are indicated, as well as the division of the greenstones into four domains**

Colluvium occurs as reddish brown, ferruginous, sandy clay and fine sand (*Czc*), and fine- to medium-grained quartzo-feldspathic sand (*Czg*) derived from weathering and erosion of granitoid rocks. Scattered small granitoid pebbles occur in *Czg*.

Plains and dunes of yellow sand (*Czs*) occur as sheets of various thicknesses, with scattered small pisolitic pebbles.

Salt lakes (playas) and claypans (*Czts*) contain interbedded clay and sand with evaporite minerals (halite, gypsum), and are surrounded by stabilized dunes of sand, silt, and gypsum (*Cztd*) which were blown from the dried-out playas.

Deep-red clay (*Czr*) forms narrow, linear and east-northeasterly striking depressions. These residual soils directly overlie mafic Proterozoic dykes as can be inferred from scattered gabbroic pebbles, intermittent outcrop and their coincidence with aeromagnetic anomalies.

Quaternary alluvium (*Qa*) in current drainage channels and flood plains consists of clay, silt, sand, and pebbles.

Geological setting

KURNALPI lies within the Eastern Goldfields Province in the Archaean Yilgarn Craton (Gee, 1979; Fig. 1). The Eastern Goldfields Province is characterized by north- to northwest-trending greenstone belts intruded and separated by ovoid to elongate granitoid plutons and/or complexes. Tectonic interpretations have included KURNALPI within the eastern half of the Norseman–Wiluna Belt which was originally interpreted as a rift zone (Gee et al., 1981; Groves and Batt, 1984). Barley et al. (1989) divided the Norseman–Wiluna Belt into a western marginal basin association and an eastern volcanic arc association of which KURNALPI forms part.

An early stratigraphic interpretation (Williams, 1970, 1976), distinguished three cycles of (ultra)mafic to felsic volcanism that are capped by sedimentary sequences and separated by unconformities (Table 1). This overall stratigraphy was deformed by regional folding and faulting. Swager et al. (1990) provisionally distinguished several domains within a regional stratigraphic entity, the Kurnalpi Terrane (Fig. 1). This terrane lies east of the Kalgoorlie Terrane, which has a well-defined regional stratigraphy (c. 2.7 Ga) and deformation history (c. 2.68–2.62 Ga).

The recent mapping suggests division of the region into domains with distinct stratigraphic, lithological and/or structural features bounded by faults or shear zones. These features are described in detail in the section on **Regional geology and structure**. On a regional scale, KURNALPI and adjacent map sheets (ROE, PINJIN, and MULGABBIE) are characterized by interleaved mafic and felsic volcanic–volcaniclastic successions. This interleaving can be observed on various scales, and formed the basis for Williams' (1974) cyclic volcano-sedimentary model for the greenstone stratigraphy. It is possible that primary stratigraphic interleaving is further complicated by structural interleaving as a result of early thrust repetition and/or upright folding. Assessment of the extent of primary and structural interleaving awaits further mapping and follow-up studies including geochronology.

Table 1. Regional stratigraphy proposed for the Eastern Goldfields (Williams, 1970, 1976) showing the cyclic nature of volcano-sedimentary sequences

Cycle	*Sequence*	*Lithology*
3	Kurrawang Group	Epiclastic assemblages, mainly conglomerate, unconformable in part of felsic volcanic and volcaniclastic assemblages: consanguineous felsic intrusive rocks.
	Kalpini Group	Mafic–ultramafic volcanic assemblages and intrusives; concomitant minor interbedded volcaniclastic and epiclastic rocks.
2	Gundockerta Group	Epiclastic assemblages, shallow and deep-water facies; in part conglomeratic, unconformable in part on felsic and minor intermediate volcanic and volcaniclastic assemblages; consanguineous felsic intrusive rocks; minor mafic volcanic rocks.
	Mulgabbie Group	Mafic–ultramafic volcanic assemblages and intrusives; minor felsic to intermediate volcanic rocks; concomitant interbedded volcaniclastic and epiclastic rocks, minor chemical sedimentary rocks; minor felsic intrusive rocks.
1	Gindalbie Group	Felsic to intermediate volcanic assemblages; volcaniclastic, epiclastic and chemical sedimentary assemblages; minor mafic volcanic rocks; consanguineous felsic, intermediate and minor mafic intrusive rocks.
	Morelands Group	Mafic–ultramafic volcanic assemblages and intrusives; concomitant interbedded volcaniclastic and epiclastic rocks, felsic volcanic rocks interleaved towards top of group; minor chemical sedimentary rocks; consanguineous very minor felsic intrusive rocks.

Petrography

Igneous and sedimentary rock nomenclature is used wherever original textures are preserved. However, all rocks are metamorphosed and their original mineralogy is entirely reconstituted. Regional deformation has resulted in widespread modification and obliteration of primary textures. The resulting metamorphic textures are also described because in many cases they are characteristic for particular rock types.

Ultramafic rocks

Komatiite (*Auk*) flow units are characterized by cumulate olivine overlain by spinifex-textured olivine. These textures are preserved even though olivine is replaced by serpentine. The major komatiite unit in the Jubilee area is dominated by cumulate olivine, with spinifex textures becoming more common to the southwest. Lenses of pyroxene spinifex-textured ('stringy beef') high-Mg basalt and minor, fine interflow slate are present. Some interleaving with sedimentary rock and with basalt along the northeastern boundary may be original or tectonic.

The komatiite belt at Jubilee is extensively carbonated with local massive carbonate domains (e.g. east of Jubilee Tank).

Komatiites east of Success Mine are closely interleaved with high-Mg basalt. Olivine spinifex textures are locally well preserved in siliceous cap rocks of small laterite plateaus. Other, volumetrically smaller komatiite flows occur between basalt and felsic volcanic–volcaniclastic sequences east of Billy Billy Hill and Colour Dam, and north of Jurangie Dam.

Strongly foliated zones within komatiite consist of tremolite–chlorite and/or talc–chlorite schist.

Peridotite (*Aup*) consists of 75–90% serpentinized olivine and 10–25% fine-grained interstitial to coarse-grained poikilitic orthopyroxene partly altered to amphibole or chlorite. Ghost textures still outline the 1–4 mm olivine orthocumulate texture within the serpentine groundmass. Peridotite layers underlying komatiite are interpreted as products of ultramafic volcanism rather than intrusive events.

Peridotite in the Pineapple Dam and Six Mile Dam areas, however, occurs as isolated layers/lenses within a basalt sequence, or in several cases is overlain by differentiated gabbro layers. In the Pineapple Dam belt, the top of the pyroxenite–gabbro –leuco-quartz-gabbro sequences locally contains high-Mg basalt (pyroxene spinifex, flow-top breccia) distinctly different from the adjacent basalt–andesitic basalt sequence. Furthermore, northwards where these peridotite–gabbro layers disappear, a major high-Mg basalt (*Abm*) unit occurs at the same stratigraphic level. These observations, and analogies with similar peridotite occurrences elsewhere in the Eastern Goldfields, suggest that the peridotite may be volcanic rather than intrusive in origin (Gole, M., 1990, pers. comm.; Hill et al., 1987).

Peridotite, particularly between Nodule and Pineapple Dams and south of Jubilee Gift Mine, contains small lenses of rodingite, which is Ca-rich and Si-undersaturated rock formed by metasomatism of gabbro or basalt fragments during serpentinization. In advanced stages of alteration rodingite consists of garnet (hydrogrossular), pyroxene (diopside), some fibrous amphibole, and sphene as a minor phase. Hydrogrossular has preferentially replaced plagioclase. In hand specimen, rodingite is cream-coloured and shows perfectly preserved gabbro or fragmental basalt textures. Descriptions of rodingite elsewhere in the Eastern Goldfields are given by Miles (1950).

Fine- to medium-grained tremolite–chlorite schist (*Aur*) occurs in high-strain zones within ultramafic rocks including pyroxenite and high-Mg basalt. Fine-grained talc-chlorite ± carbonate schist (*Aut*) is restricted to deformed ultramafic rocks. Ultramafic schists such as those north of Avoca Downs are deformed lateral equivalents of peridotite.

Carbonated komatiite (*Aukc*) west of Jubilee Tank includes strongly altered rock in which any original textures have been obliterated. Some massive carbonate ridges occur directly north of the Kalgoorlie–Kurnalpi road.

Mafic volcanic and intrusive rocks

Several types of basaltic rocks have been distinguished on textural and/or mineralogical characteristics. In all basalts, however, the original pyroxene and plagioclase have been replaced by amphibole or chlorite and less calcic plagioclase ± alteration products. Small and widely scattered felpspar phenocrysts occur in all basalt types except the high-Mg variety. Epidote alteration is concentrated in small domains and is commonly accompanied by carbonate. More intense carbonate alteration is associated with shear or fault zones. Though certain basalt types may dominate particular domains, they are not necessarily exclusive to any particular domain or area.

Massive fine-grained basalt without further dominant or regionally distinctive characteristics may still have several of the features described below (e.g. *Abp*, *Abd*), but is not further subdivided (*Ab*).

Massive, ophitic-textured basalt (*Abd*) with many slightly coarser grained doleritic layers forms prominent hills around Kurnalpi, and is also present in basalt ridges further east. The doleritic layers or lenses are not necessarily intrusive sills, but rather may indicate thicker flows and/or central parts of flows. Narrow foliated zones form mostly depressions, and are covered by float of the more massive rock.

Variolitic pillowed basalt (*Abv*) occurs around Kurnalpi and is partly interleaved with the massive ophitic-textured basalt (*Abd*). The major belt stretches from south of Hackett Well to north of Scottish Lass Well. The varioles are rounded to slightly ovoid with diameters up to 2 cm, and consist of more plagioclase-rich material that is either coarser or finer grained than the matrix. Well-preserved pillows directly east of the track from Kurnalpi Town Dam to Scottish Lass Well suggest an east-younging sequence.

Amygdaloidal and/or feldspar-phyric basalt and basaltic andesite (*Abi*) are present in the western half of KURNALPI. The main belt lies between Sawmill Dam and Canegrass Swamp. Intermediate compositions are more common north of Lake Yindarlgooda, where felsic volcanic–volcaniclastic rocks are also interleaved with this basalt sequence. In the Pineapple Dam area, however, pervasive carbonate ± epidote/zoisite alteration has resulted in massive pale-green rocks. The andesitic rocks are characterized by networks of fine-grained plagioclase laths with interstitial amphibole or chlorite (after pyroxene), fine-grained quartz (2–3%), and small opaques largely altered to leucoxene ± sphene. Small, altered phenocrysts of plagioclase and pyroxene are present throughout the matrix. Epidote/zoisite ± carbonate are part of the matrix and, with quartz, the main amygdale-filling components.

Feldspar-phyric basalt (*Abp*) is highlighted on KURNALPI wherever it forms distinct layers or lenses. The feldspar phenocrysts, which are extensively altered (sericite, epidote, carbonate), vary from fine- to medium-grained (1–4 mm) regularly distributed crystals, or glomeroporphyritic to medium- to coarse-grained (0.5–2 cm) subhedral crystals. Feldspar-phyric dolerite is commonly spatially associated with *Abp*.

Amphibolite derived from basalt (*Aba*) is characterized by a pervasively developed foliation formed by preferred orientation of hornblende and plagioclase. Despite the regional metamorphic reconstitution of these rocks, their basaltic parentage is in little doubt. Their main occurrence is along the eastern part of KURNALPI characterized by higher metamorphic grades.

High-Mg basalt (*Abm*) is characterized by spinifex-textured amphibole (after pyroxene) and to a minor extent by small varioles. The acicular amphibole varies in length from several millimetres to up to 25 cm locally, and is arranged randomly or in sheaves. A prominent high-Mg basalt belt lies south of Canegrass Swamp, and is laterally transitional to a zone containing peridotite layers/lenses with overlying gabbro, possibly representing ultramafic flows. Other occurrences near Kurnalpi West, between Billy Billy Hill and Colour Dam, and north of Jurangie Dam are associated with komatiite.

Dolerite, pyroxenitic dolerite and gabbro (*Ao*) layers and lenses within basalt sequences can be interpreted as small intrusive sills coeval with volcanism or, alternatively, as thicker and coarser grained flows. They are medium-grained with a 'spotted' texture (dolerite) of 3–5 mm short prismatic amphibole (after pyroxene) in a partially recrystallized matrix of plagioclase, amphibole, skeletal leucoxene after Fe–Ti oxide, and epidote/zoisite. Ophitic textures (gabbro) with prominent plagioclase prisms are present in thicker layers. Porphyritic textures in the pyroxenitic rocks show various amounts of poikilitic amphibole pseudomorphs after pyroxene (up to 1 cm). Although some layering exists in the thicker layers, it is usually difficult to establish a clear differentiation trend.

Feldspar-phyric dolerite and gabbro (*Aop*) are similar to the *Ao* units but contain in addition scattered medium- to coarse-grained feldspar megacrysts.

Pyroxenite and pyroxenitic gabbro layers (*Aox*) are medium grained (3–6 mm) with tremolite/actinolite replacing the original pyroxene. Irregularly distributed plagioclase megacrysts may reach 3 cm in width. Occurrences at northwest Lake Yindarlgooda contain minor interstitial quartz.

Gabbro (*Aog*) layers/lenses are characterized by weakly to strongly developed layering of medium-grained pyroxenite, gabbro–norite, gabbro, quartz–gabbro and/or leucogabbro. This differentiated layering establishes a reliable younging indicator. The best examples are found north of Nodule Dam where the differentiated gabbro sequences overlie serpentinized peridotite and can be interpreted as part of ultramafic flows (Gole, M., 1990, pers. comm.). Southeast of Six Mile Dam leucocratic gabbro with a regular plagioclase–pyroxene banding is separated from underlying peridotite by thin layers of pyroxene-phyric peridotite and pyroxenite.

A thick gabbro complex 2 km east of Wattle Dam contains quartz gabbro with amphibole sheaf textures on its west side, implying a westerly younging sequence. This is in contrast with the apparent regional younging direction, and may also indicate a disrupted intrusive complex rather than a single differentiated body.

In gabbro–norite and some pyroxenites, fine- to medium-grained clinopyroxene is pseudomorphosed by short prismatic amphibole whereas medium- to coarse-grained orthopyroxene is replaced mostly by aggregates of fine acicular amphibole. These megacrysts are commonly poikilitic enclosing mostly plagioclase and minor clinopyroxene pseudomorphs. Locally, coarser plagioclase encloses both pyroxene pseudomorphs. In some localities clinopyroxene is preserved. Plagioclase is usually altered (albite, sericite, epidote/zoisite) and opaques are replaced by leucoxene/sphene.

Intermediate volcanic rocks

Intermediate volcanic rocks (*Aiv*, *Aix*) occur as part of a largely felsic volcanic complex between Transfind and Teddy Dam in the southeast corner of KURNALPI, and within the overall more mafic sequence south of Canegrass Swamp.

Massive andesitic rocks (*Aiv*) are commonly altered, consisting of a fine-grained matrix of feldspar, quartz, biotite, chlorite, epidote, carbonate, and sphene with epidotized or sericitized plagioclase (0.5–5 mm) and small chloritized pyroxene phenocrysts. At Transfind, these intermediate rocks are accompanied by extensive andesitic basalts (*Abi*) with numerous quartz-filled amygdales as well as fine quartz scattered through the feldspar–hornblende matrix. Glomeroporphyritic feldspar is common south of Canegrass Swamp.

East of Horseshoe Dam the andesitic rocks are dominated by coarse fragmental textures (*Aix*) with extensive epidote/zoisite alteration. Irregular feldspar-rich and recrystallized quartz–feldspar-rich domains or fragments are enclosed in an irregular, more amphibole-bearing matrix. Fine-grained sphene is present throughout. Similar, less-altered fragmental layers have been observed locally in the basalt–andesitic basalt sequence south of Jubilee.

It is noteworthy that extensively carbonated basalt and andesitic basalt between Jubilee and Avoca Downs is light coloured in hand specimen suggesting, erroneously, an intermediate rather than mafic composition.

Felsic volcanic and associated rocks

Felsic volcanic and volcaniclastic rocks (*Afv*, *Afs*) show variations in size and ratio of feldspar and quartz phenocrysts in a probable compositional range from rhyolitic to, more commonly, dacitic. Compositional and textural variations on all scales and the well-developed foliation obliterating original volcanic textures prevent a more detailed subdivision. However, volcanic-dominated sequences (*Afv*) are distinguished from clastic-dominated sequences (*Asf*) and very strongly deformed felsic schist sequences of probable volcanic derivation (*Afs*).

Generally, the fine- to very fine-grained quartz–feldspar matrix with regularly distributed white mica and/or biotite and minor epidote/zoisite is recrystallized. Quartz phenocrysts (2–5 mm) are euhedral to rounded and partly resorbed; feldspar phenocrysts are subhedral to totally anhedral, variably recrystallized and at least partly sericitized. Biotite is a common minor phase and occurs as widely scattered flakes throughout the matrix or as small aggregates. Locally, small fragments of slightly different composition (i.e. more mica or chlorite, different phenocrysts) suggest that part of these schistose felsic rocks have originated as crystal and/or lithic tuffs. Such fragmental rocks classified here under volcanic-dominated rocks (*Afv*) may range in composition from acid to intermediate, as for example in the occurrences at northwest Lake Yindarlgooda.

Very fine-grained tuffaceous rock (*Aft*) contains scattered clear, partly resorbed quartz and sericitized feldspar phenocrysts in a finely banded matrix with some lapilli remnants. This rock can be interpreted as a rhyodacitic crystal tuff.

Felsic volcanic rock which cannot be further subdivided (*Af*), generally occurs in extensively weathered areas, and is assumed to include weathered equivalents of *Afv*, *Aft*, *Afs*, *Asf* and possible minor *Aiv* units.

Quartzo-feldspathic schist (*Afs*) is characterized by a pervasive foliation defined by preferred orientations of all matrix minerals (quartz, feldspar, muscovite). This foliation wraps around quartz and feldspar 'augen'. In many places two foliations can be observed in these rocks.

Quartz–aluminosilicate and associated rocks

Several types of quartz–aluminosilicate rock (*Ala*, *Alk*, *Alh*) can be distinguished by the main Al_2SiO_5 polymorph (andalusite or kyanite) and the presence of chloritoid. These rocks occur within felsic volcanic–volcaniclastic sequences, are highly siliceous and have commonly lost original textures, although in several domains pseudomorphs of former phenocrysts can be recognized. Similar rocks have been described from other areas in the Eastern Goldfields (e.g. Miles, 1943; Hallberg, 1987; Purvis, 1984; Martyn and Johnson, 1986; Roth, 1989; Swager, 1991), and are generally considered to be regionally metamorphosed products of early hydrothermal alteration related to felsic volcanism and/or granitoid plutonism. The KURNALPI occurrences all appear within felsic rocks but the same alteration has been observed in komatiite (Purvis, 1984).

The siliceous nature of the rocks and refractory character of aluminosilicate result in some prominent outcropping ridges (e.g. Steeple Hill; east of Colour Dam; between Gessner Dam and Rocky Dam). Except for the andalusite–quartz (*Ala*) 'layers' at Colour Dam, both andalusite and kyanite (*Alk*) are generally present with the latter being the most prominent in the Rocky Dam area. Chloritoid-bearing kyanite–quartz rock and chloritoid–quartz rock (*Alh*) are restricted to the Rocky Dam–Steeple Hill area and the Colour Dam area respectively.

Andalusite occurs as large poikiloblasts enclosing the fine-grained polygonal granoblastic quartz. In hand specimen the andalusite forms quite indistinct brownish aggregates, whereas kyanite forms clear medium-grained prisms and prismatic plates mostly lying within the layering. In thin section kyanite shows a highly skeletal habit enclosing quartz. The matrix consists of (very) fine-grained quartz and white mica, and contains a well-developed quartz–mica layering in some areas. The quartz-rich domains show a clear polygonal–granoblastic texture whereas mica-rich layers show elongate quartz textures controlled by the oriented mica flakes. Minute rutile needles are a ubiquitous minor phase, occurring in irregular concentrations, in trails, and scattered throughout the matrix. Quartz 'eyes', where present, consist of a fine-grained recrystallized aggregate. Tourmaline forms fine- to medium-grained aggregates or prisms.

In the eastern occurrences, medium-grained quartz contains many very fine rutile, mica and even tourmaline inclusions in contrast to the clean finer recrystallized textures elsewhere. These 'dirty' quartz grains may be silicified feldspar crystals.

Chloritoid occurs as fine- to medium-grained unoriented prisms and sheave-like aggregates, and stands out in hand specimen as dark-green crystals.

All porphyroblasts have grown across, and enclosed, both rutile trails and the layering.

Sedimentary rocks

Fine-grained shale/slate, siltstone and minor sandstone (*Ash*) are quartzo-feldspathic to siliceous with variable mica contents and, locally, carbonaceous material. These well-bedded rocks are commonly well foliated and folded on various scales, as for example 2 km south of Anti Dam. Very fine quartz shows shape-preferred orientation controlled partially by the amount of matrix mica (muscovite, biotite) and minute opaques. Feldspar is at least partly sericitized. In grey slates, biotite forms small porphyroblasts enclosing trails that are continuous with the regional foliation. Other porphyroblasts include garnet (e.g. around Bodgie Dam) and andalusite, staurolite and/or cordierite (e.g. southwest of Wyo Well).

The fine-grained slaty to silty rock sequence contains numerous thin layers and lenses of distinctive feldspar-phyric felsic schist (*App*) in a regionally recognizable belt between Norman, Slippery and Bodgie Dams as well as further north onto PINJIN. The same felsic schists occur in adjacent basalt, and very locally can be shown to crosscut bedding, indicating an intrusive origin.

Chert, including grey-white banded chert and silicified grey to black slate (*Ac*) occurs both within slate–siltstone sequences and at the boundary between such sequences and other rock suites. Several prominent beds form good markers. The most persistent chert marker beds continue from east of Dart Dam northwestwards well into the adjacent KANOWNA sheet area (Ahmat, in prep.a), and form the top of a felsic volcanic– volcaniclastic sequence. Drillhole information shows that coarse banded 'cherty' rocks at the surface correspond to grey to black slate below the weathering horizon. However, several of the major *Ac* horizons include probable primary chert units, including finely banded chert. The slates may be pyritic, and at least one prominent gossanous horizon can be followed for 2–3 km northwest of Christmas Gift Dam. Exploration drilling intersected massive pyrite at this horizon. Locally, such 'cherty' layers in mafic volcanics consist of very fine-grained recrystallized quartz and feldspar, and various amounts of very fine amphibole.

Greywacke (*Asg*) forms a distinct unit in the central southern part of KURNALPI. On the adjacent WIDGIEMOOLTHA 1:250 000 sheet the unit is known as the Mount Belches beds. The greywacke contains fine-grained quartz, feldspar and white mica in the matrix and small, partly chloritized biotite porphyroblasts. Layering is defined by variations in grain size and quartz–mica content. Several areas show widely distributed carbonate both in the matrix and as small porphyroblasts. The regional foliation is well developed and defined by quartz, white mica and carbonate shape-preferred orientations. Banded iron-formation layers south of KURNALPI outline the tight regional-scale folding within the unit.

Polymictic conglomerate (*Asp*) with interleaved pebbly sandstone occurs in a belt stretching from Nodule Dam northwestwards well onto KANOWNA and GINDALBIE ('Penny Dam Conglomerate'; Ahmat, in prep.b). Pebbles and boulders, up to 40 cm in diameter, include granitoid, quartz–feldspar porphyry, gabbro, chert, basalt and minor schistose mafic rocks. Pebbles are commonly wedge shaped and faceted suggesting a glacial origin (Myers, J. S., 1990, pers. comm.). The clast- to matrix-supported conglomerate contains the regional upright foliation. Interlayered quartzo-feldspathic sandstone beds with minor conglomerate and siltstone (*Ass*) show small-scale folding.

Quartzo-feldspathic schists (*Asf*) consist of fine- to medium-grained slate, siltstone and sandstone with interlayered quartz- and/or feldspar-phyric layers of felsic volcanic–volcaniclastic derivation. In most weathered areas the regional foliation is the only well-developed structure, but on lake-floor exposures south of Canegrass Swamp many sedimentary features (fragmental mass flow layers, slumps, graded beds, scouring) are preserved.

A distinctive sequence of layered amphibole- and garnet-bearing quartzo-feldspathic schists is interpreted as a sequence of intermediate volcaniclastic rocks (*Asi*). The most prominent outcrops occur at Bodgie Dam, just northeast of Avoca Downs and east of Cowarna Rocks between White Dam and Slippery Dam. They are interlayered with garnetiferous biotitic slate (*Ash*) and quartzo-feldspathic schists (*Asf*). A similar association southeast of Rocky Dam can be interpreted as the northern continuation of the same belt.

The fine-grained matrix consists of ovoid to elongate quartz grains surrounded by variably sericitized feldspar with biotite flakes (1–3%) commonly retrogressed to chlorite. Small feldspar clasts, more extensively sericitized, are scattered through this matrix. Fine irregular opaques, elongate ilmenite and sphene are accessory phases, and thin carbonaceous trails are also present. Carbonate alteration is highly variable; southwest of Windy Dam a massive foliated carbonate layer can be traced over several hundreds of metres.

The amphibole porphyroblasts (0.2–5 mm) have grown across the layering and foliation at various angles though, in general, they tend to lie parallel to the layering. Slightly elongate garnet porphyroblasts are also parallel to layering and vary in size from 1 mm to 1 cm. A distinctive clinopyroxene (diopside) + K-feldspar-bearing layer occurs east of Slippery and White Dams. The poikilitic clinopyroxene is intergrown with (and apparently replaces) amphibole in the matrix, and is also present in small veins.

All porphyroblastic minerals (amphibole, garnet, clinopyroxene, biotite) have grown at a late stage because they have grown across, and enclosed, the well-developed layering.

East of Rocky Dam the intermediate sedimentary and volcaniclastic rocks are conglomeratic (*Asip*), with pebbles and (locally) boulders consisting mainly of amphibole ± biotite–feldspar–quartz rock and feldspar-phyric felsic schist.

Banded iron-formation (*Aci*) is found mainly in the eastern part of KURNALPI with a small occurrence within biotitic greywacke south of Randell Dam. This latter BIF is the northernmost part of quite extensive layers exposed on WIDGIEMOOLTHA. A prominent BIF lies within a lateritized area between Outcamp and Kym Dams. Other, less persistent layers were mapped southeast of Windy Dam and inferred from diamond drillcore and aeromagnetics south of Anti Dam.

Most of the finely banded BIFs contain oxide-facies assemblages consisting of fine-grained polygonal–granoblastic quartz, Fe oxide (magnetite, hematite) and minor biotite. Locally, more-micaceous layers contain both fine-grained matrix and medium-grained, unoriented porphyroblastic biotite. These rocks are transitional to silicate-facies banded iron-formation (*Acis*) characterized by prominent fine- to coarse-grained grunerite crystals and sheaves which grow randomly across the finely banded matrix. Locally, hornblende is present in addition to biotite and grunerite.

Granitoids

Biotite monzogranite (*Agm*) forms large and small plutons in the eastern part of KURNALPI. These granitoids are generally medium-grained, contain equal amounts of plagioclase, K-feldspar and quartz, with biotite (1–3 %) as the only mafic phase. They are commonly K-feldspar porphyritic (up to 2 cm). Several of the small stocks in the Norman Dam area lack these K-feldspar phenocrysts, and instead show slightly larger plagioclase grains in a more even-grained texture. Recrystallization, sericitization and chloritization are widespread, but have not destroyed the overall texture.

Foliation development along contacts with the greenstones ranges from weak to intense. At several localities more leucocratic phases (finer grained; little or no biotite) or pegmatoidal lenses are present. In a small pluton 2 km east of Norman Dam two phases of monzogranite occur. One is variably foliated with porphyritic feldspar and biotite schlieren, and the other is a more common medium-grained variety with some hornblende in addition to biotite (combined 3%). Along contacts with greenstones, the latter contains irregularly interleaved, little-deformed granitoid dykes.

The Cowarna Monzogranite (*Agmc*; named after the type locality at Cowarna Rocks 5 km east of Avoca Downs) is an elongate pluton with some small satellite stocks. This pluton occurs in a structurally complex area with some major faults and folds, and may have been emplaced during development of these structures.

The Yindi Monzogranite (*Agmy*; named after the type locality at Yindi Rock) is fine- to medium-grained and non-porphyritic, and may form a distinct phase at the northern tip of a much larger granitoid complex along the eastern boundary of KURNALPI.

The Bulyairdie Monzogranite (*Agmb*; named after type locality at Bulyairdie Rocks) is characterized by numerous, evenly distributed perthitic K-feldspar megacrysts (1.5–2 cm). It contains hornblende as the mafic phase, and is largely undeformed. A late tectonic emplacement (Witt and Swager, 1989) can be inferred from its massive character, and the disruption and displacement of already folded and cleaved greenstones. The medium-grained groundmass contains plagioclase with few and small epidote and sericite inclusions, recrystallized quartz aggregates after formerly larger grains, minor K-feldspar (5%) and fine- to medium-grade hornblende (2–3%). Epidote, leucoxenated opaques, small euhedral sphene, and short prismatic apatite are accessories.

A similar hornblende-bearing monzogranite (to granodiorite) occurs only locally in the northwestern part of the large biotite monzogranite complex between Yindi Rock and Slippery Dam.

Porphyritic biotite monzogranite to granitoid porphyry (*Agp*) with rapid textural and size transitions is exposed around the Curtin gold prospect. This granitoid body with adjacent dykes and satellite stocks can be interpreted as a shallow-level intrusive, possibly coeval with the felsic volcanic sequences south of the railway line. The porphyritic granite with a biotitic fine- to medium-grained matrix contains widely scattered coarse K-feldspar and less coarse plagioclase phenocrysts, as well as distinct recrystallized quartz aggregates. Over short distances these textures are transitional to porphyry textures containing a very fine-grained biotitic to chloritic matrix with sericitized plagioclase. Quartz phenocrysts and chlorite (after biotite and hornblende) aggregates are less common.

A similar highly porphyritic granitoid with adjacent dykes crosscutting the greenstones is exposed 1.5 km northwest of Wyo Well.

Granitoid rock, not further subdivided (*Ag*), forms highly weathered or very small outcrops 2 km north of Grey Dam.

Porphyry dykes and sills

Felsic porphyry (*Apq*) sills and dykes consist of a very fine-grained quartzo-feldspathic matrix with widely scattered fine- to medium-grained quartz and/or feldspar phenocrysts.

Granitoid porphyry (*Apg*) is dominated by plagioclase phenocrysts with subordinate quartz and, locally, biotite crystals. The very fine-grained matrix contains variable amounts of K-feldspar (3–12 %) suggesting an overall granodioritic composition. Plagioclase phenocrysts (up to 2 cm) are partly euhedral, with oscillatory growth zones, and are at least partially sericitized. Quartz phenocrysts (up to 1 cm) are commonly inclusion-free and mostly recrystallized. Rare medium-grained biotite is generally chloritized or sericitized. The larger porphyries are commonly little deformed, in contrast with the feldspar-phyric schists (*App*).

Small, little-deformed sills and dykes of clearly granodioritic composition occur locally within the eastern belts of metasedimentary and basaltic rocks. These contain only 3–5% K-feldspar in the matrix and hornblende ± biotite as the mafic phases (3–7%). Sphene, rutile, minor Fe-oxide, and zircon are accessories.

Distinctive, strongly foliated, plagioclase-phyric biotitic felsic schist (*App*) occurs as numerous narrow sills or dykes (0.1 to 4 m) in amphibolitic basalt (*Aba*), felsic volcaniclastic (*Asf*) and grey slate–siltstone (*Ash*) sequences in the eastern part of KURNALPI. The schist bands are mostly better exposed than their host rocks. The majority are parallel to the layering of the host rock, and only rarely have crosscutting relationships been observed. Well-exposed lake-floor outcrops of the same association on PINJIN clearly demonstrate the crosscutting nature of the felsic sills (Swager, in prep.). These porphyritic felsic schists invariably contain the regional foliation.

The most characteristic feature in hand specimen, apart from the well-developed foliation, is the presence of numerous plagioclase phenocrysts (1–10 mm). The phenocrysts still show compositional zoning, and are at least partly euhedral despite local irregular terminations. Quartz phenocrysts are few and widely scattered. Fine-grained biotite forms small aggregates, and occurs scattered throughout the matrix. The overall composition of the schists probably lies in the granodiorite field.

A dyke of hornblende lamprophyre (*Apl*) occurs 500 m northwest of Jubilee Tank. Subhedral fine- to medium-grained (0.5–10 mm) hornblende prisms are characteristic phenocrysts in a fine-grained quartzo-feldspathic matrix. Fragmental textures involving similar or slightly more mafic material are present throughout.

Proterozoic mafic dykes

Two major east-northeasterly striking Proterozoic mafic to ultramafic dykes (*Pdy*) outcrop intermittently in the southern half of KURNALPI. They are known informally as the Celebration (*Pdyc*) and Randalls (*Pdyr*) Dykes in the north and south respectively. The dykes are approximately at right angles to the main structural trend of the greenstones. In contrast with the Archaean rocks, the dykes are undeformed and not metamorphosed. Where the dykes do not outcrop, they can be traced on aerial photos by distinctive deep-red soils (*Czr*).

Outcrop is dominated by fine- to medium-grained olivine gabbro, quartz gabbro and minor pyroxenite with a fine-grained plagioclase (15%) network. Biotite and Fe–Ti oxides are accessories.

Some detailed descriptions of both the Celebration and Randalls Dykes north of Avoca Downs and at Cowarna Rocks are given by Purvis and Moeskops (1981). The main dyke, Celebration, is up to 1 km wide, appears to be zoned and is intruded by very fine-grained magnesian basaltic dykes which may contain considerable Ni–Cu sulfides. These magnesian basaltic dykes are also present in Randalls Dyke at Cowarna Rocks.

Regional aeromagnetic maps (Anfiloff and Milligan, 1989) show northeast-striking negative magnetic lineaments of regional extent with no apparent expression on the ground. One such lineament of great regional extent passes approximately along Randell Siding and Mount Charnleigh. A parallel, but less intense lineament in the southeast corner of KURNALPI is not shown on the map.

Regional geology and structure

Several structural–stratigraphic domains can be distinguished on the basis of lithological–stratigraphic characteristics and different structural trends. These domains (Juglah, Jubilee, Mount Belches, Karonie–Yindi) are separated by poorly exposed fault and shear zones inferred largely from oblique structural trends, stratigraphic cut-outs, and incompatible facing directions (Fig. 3). The four domains can be recognized on a regional scale beyond the KURNALPI sheet area, and the differences between the Williams (1976) interpretation and the regional structure presented in this section are pronounced. However, further detailed data are required to confirm the proposed geometry.

The Juglah Domain in southwest KURNALPI lies on the eastern limb of the upright, regional Bulong Anticline (Hickman, 1986; Ahmat, in prep.a). It contains a felsic to intermediate volcanic sequence overlain by a mafic volcanic sequence with ultramafic schist lenses in the south. N. McNaughton (quoted by Barley and Groves, 1988) reported a U–Pb single zircon age of 2720 Ma for the felsic volcanics. At Transfind, the felsic to intermediate sequence is intruded by highly porphyritic monzogranite (granitoid porphyry) with textures suggesting high-level emplacement. These porphyritic granitoids appear to be separate from (or subvolcanic equivalents of) the Juglah Monzogranite exposed on KANOWNA (Ahmat, in prep.a).

The top of the 'felsic unit' is marked by clastic rocks with thin grey to black slates and/or grey-white banded cherts at the contact with the overlying 'mafic unit'. These cherts and silicified slates form good marker beds that can be traced northwards onto KANOWNA (Ahmat, in prep.a) and southwards into the Mount Monger area (Hickman, 1986). Although the slates are strongly foliated with, locally, two foliations (one early, another later and axially planar to the Bulong Anticline), there is no evidence for a pervasive shear fabric. This observation, and the small-scale interleaving (e.g. west of Gunny Dam) may suggest a stratigraphic rather than a tectonic contact between the felsic and mafic units. The contact formed a natural locus for minor movements during subsequent deformation.

The mafic unit can be traced southwards around the anticline to Mount Monger (Williams 1971; Hickman, 1986) and onto KANOWNA (Ahmat, in prep.a). At Mount Monger the mafic unit consists of high-Mg basalt characterized by pyroxene-spinifex textures on various scales and several major ultramafic–mafic lenses, interpreted as intrusive sills by Williams (1971) and Hickman (1986). On KANOWNA, Ahmat (in prep.a) describes the presence of komatiite units which constitute at least part of the ultramafic Bulong Complex. In general, the mafic unit when traced from Mount Monger eastwards and northwards onto KURNALPI becomes thinner (until it dies out northeast of Rocky Dam on KANOWNA), contains progressively fewer ultramafic rocks (none present north of Gunny Dam) and shows a change in basalt composition from high Mg (pyroxene spinifex) to more tholeiitic (feldspar-phyric). These lateral changes may be explained as primary volcanic features suggesting a gradation from the central to the marginal parts of a basin (Ahmat, in prep.a), or alternatively as interleaving of the products of different magmas with different eruption centres.

The contact of the mafic unit with the highly foliated and folded metasedimentary rocks of the Mount Belches Domain is interpreted as a major regional domain-boundary structure (Hickman, 1986), the Randell Shear (Fig. 3). Banded iron-formation layers outline a regional-scale fold pattern on WIDGIEMOOLTHA (Griffin and Hickman, 1988) which intensifies from open northwest-trending folds to isoclinal, attenuated north-trending folds towards the Randell Shear. This structural pattern implies intensifying regional shortening within the Mount Belches Domain towards the shear zone. The Randell Shear is not exposed on KURNALPI, and may lie beneath early syntectonic coarse clastic rocks (see section on Jubilee Domain); farther northwards the domain boundary appears to be an unconformity.

The rather monotonous greywacke sequence has many characteristics of a turbidite sequence (Dunbar and

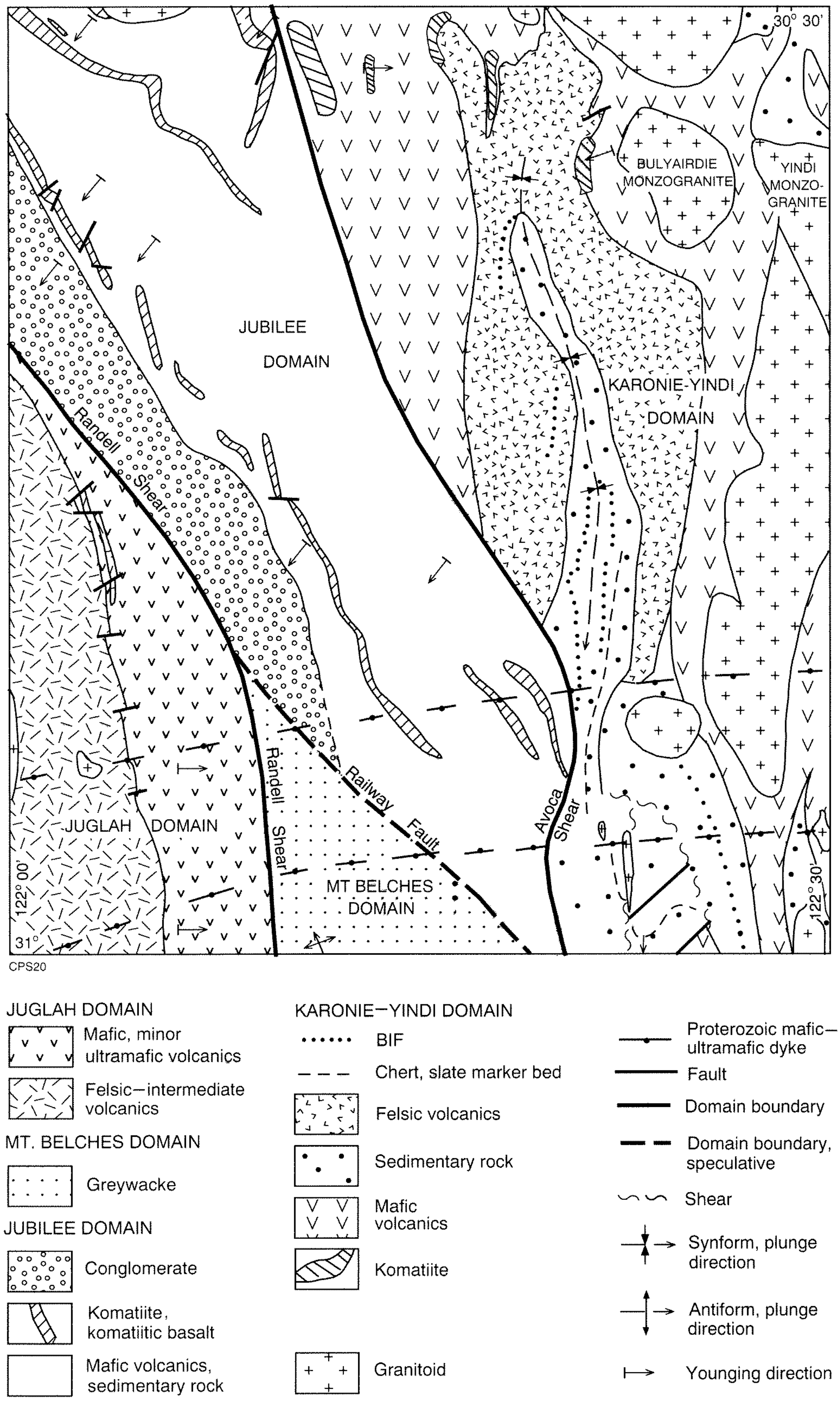

Figure 3. Structural–stratigraphic domains and major structural elements on KURNALPI

McCall, 1971) and has no clear equivalent within other domains. The banded iron-formation layers represent periods of diminished or no supply of clastic material into a relatively deep basin. Sedimentary way-up evidence from WIDGIEMOOLTHA suggests overall younging to the north.

Regional mapping has shown that the greywackes of the Mount Belches Domain occupy a large area on WIDGIEMOOLTHA whereas the Juglah Domain dies out between the Randell and Mount Monger shear zones (Griffin and Hickman, 1988). The northwards continuation of the Mount Belches Domain is not clear. In Figure 3, the domain is interpreted as wedging out in a triangular zone between the Randell Shear and another inferred boundary structure, the Railway Fault. However, an alternative interpretation may be that the greywackes are laterally equivalent to the coarse clastic rocks in the Jubilee Domain, with rapid facies changes rather than the Railway Fault occurring in the unexposed area.

The Jubilee Domain is bounded to the southwest by the Randell Shear and Railway Fault, and to the east by the Avoca Shear. The domain contains a complex sequence of ultramafic–mafic rocks and interleaved sedimentary rocks with several distinct ultramafic units. This sequence is overlain by a prominent polymictic conglomerate of possible glacial origin. The entire succession can be traced northwards onto MULGABBIE (Morris, in prep.) and GINDALBIE (Ahmat, in prep.b), but to the south it is cut out against the Avoca Shear.

Way-up criteria consistently indicate younging to the southwest. Although interleaving of mafic–ultramafic and sedimentary rocks occurs on various scales, no conclusive evidence for large-scale structural repetition has yet been found.

The mafic–ultramafic belts show lateral variations in thickness and/or geochemical character. A well-exposed belt between Nodule Dam and Canegrass Swamp appears to wedge out along strike in both directions. In the Nodule Dam area amygdaloidal feldspar-phyric basalt contains several serpentinite layers and lenses. Several but not all of these are overlain by differentiated gabbro. At a few localities the top of these serpentinite–gabbro layers contains minor high-Mg basalt or brecciated to hyaloclastic basalt suggesting a volcanic rather than intrusive origin (Gole, M.J. 1990, pers. comm.). This suggestion is supported by the observation that north of Lake Yindarlgooda these serpentinite–gabbro layers give way laterally to high-Mg basalt.

In the same area, felsic and intermediate volcanic layers are interleaved with the main basaltic component. This suggests several types of coeval extrusive magmatism within this Nodule Dam–Canegrass Swamp belt.

Several other ultramafic layers occur to the northeast of, and stratigraphically below, the Nodule Dam–Canegrass Swamp belt. These include two distinct lenses several kilometres north of Avoca Downs. Two other prominent ultramafic belts occur in northwest KURNALPI (Fig. 3). The Jubilee ultramafic belt consists of komatiite dominated by serpentinized peridotite and minor dunite. This belt can be traced east and southeast by its aeromagnetic signature. A second prominent ultramafic belt to the north is exposed mainly on MULGABBIE (Morris, in prep.) and appears to be cut out against a granitoid contact. It is possible that this peridotitic unit continues on the east side of the granitoid as the north-trending belt southeast of Six Mile Dam (Fig. 3). Farther eastwards another komatiite unit with considerable high-Mg basalt is exposed.

The complex deformation in the Jubilee–Grey Dam–Six Mile Dam area may be partially caused by a granitoid pluton of which only the southern tip is exposed on KURNALPI. Percussion drilling also suggests the presence of granitoid southwest of Six Mile Dam. If the consistent southwest younging direction of the ultramafic units is correct, then the sequence in the Jubilee Domain is disrupted only by the granitoid intrusion. The Avoca Shear is interpreted to separate the komatiites from the east-younging basalts at Kurnalpi, which are part of the adjacent Karonie–Yindi Domain (Fig. 3). The shear or fault zone is deduced from stratigraphic and structural discontinuities, but its trace farther north is less well defined. Alternatively, the Six Mile Dam ultramafic rocks may young to the east, and thus lie on the east limb of a regional sheared-out anticline. The Kurnalpi basaltic belt may then overlie the komatiites, and the Avoca Shear may separate this basaltic belt from the mixed mafic–ultramafic–felsic suite at Billy Billy Hill.

Major lithological boundaries in the Jubilee area are quite strongly foliated and are zones of higher strain. These bedding-parallel foliations are overprinted by approximately vertical northerly trending foliations.

The Nodule Dam–Canegrass Swamp belt is overlain by a clastic unit, dominated by polymictic conglomerate, which can be traced northwards onto KANOWNA and GINDALBIE, but appears to die out to the south. Wedge-shaped, faceted pebbles suggest a possible glacial origin (Myers, J. S., 1989, pers. comm.; Ahmat, in prep.a).

The structural setting of this coarse clastic unit may be controlled by structural relationships between the Juglah and Jubilee Domains. To the north and west, the conglomerate overlies the mafic unit of the Juglah Domain. On KANOWNA (Ahmat, in prep.a) this mafic unit dies out in the Rocky Dam area, and in the complex, faulted, north-plunging hinge region of the Bulong Anticline the conglomerate appears to overlie the felsic unit of the Juglah Domain without any obvious shearing along the contact. Therefore, the polymictic conglomerate appears to overlie both the Juglah and Jubilee Domains. These geometrical relationships suggest that the conglomerate is an early syntectonic deposit, overlying the major fault which juxtaposes the Juglah and Jubilee Domains. Regional shortening then resulted in coaxial folding of the conglomerate and underlying greenstones, and in the development of the Randell shear along the contact with the Juglah Domain greenstones. An upright cleavage can be mapped throughout the clastic unit, and Ahmat (in prep.a) documented upright folding and mapped thin basaltic/doleritic lenses within the conglomerate.

The Karonie–Yindi Domain, which occupies eastern KURNALPI, is dominated by a regional syncline. This domain may continue both southwards onto WIDGIEMOOLTHA and northwards onto PINJIN, MULGABBIE and EDJUDINA. The Avoca Shear separates the Karonie–Yindi Domain from the Jubilee Domain to the west. The main lithologic–stratigraphic characteristic of the domain is the regional-scale lensoid interleaving of mafic units and felsic volcanic–epiclastic sedimentary units; e.g. north of Yindi Rock and west of Norman Dam. Further mapping is required to distinguish between stratigraphic and structural interleaving.

The regional syncline (Steeple Hill Syncline of Williams, 1970) is in detail a complex structure inferred from a fold hinge outlined by banded iron-formations. The regional stratigraphy comprises mafic volcanics overlain by felsic volcanics which underlie fine-grained slates with local banded iron-formation. Minor ultramafic flows and gabbro sills are locally prominent along the mafic–felsic volcanic contact. Reliable way-up indicators are rarely seen in this well-foliated sequence, and the younging direction is inferred mainly from differentiation trends in ultramafic rocks. The felsic volcanics, with extensive metamorphosed alteration assemblages of quartz–aluminosilicate–chloritoid, form a major volcanic centre in the central part of KURNALPI. To the south, however, these volcanics become much thinner and eventually disappear on both limbs of the syncline. Complex stratigraphic relationships, including the presence of synvolcanic faults, can be expected in a felsic volcanic centre.

Strike-slip faulting has probably affected the syncline, particularly east of Kym Dam where the folded slate–BIF sequence appears in fault contact with the north-trending intermediate/mafic sediment and slate sequence at Bodgie Dam.

The broadly synclinal hinge zone in northern KURNALPI (including a smaller scale antiformal structure east of Colour Dam) may be partly disrupted by granitoid intrusions. The syncline is a major structure that can be traced onto MULGABBIE (Morris, in prep.).

A complex geometry is observed in the Cowarna Rocks area, where disrupted folds and granitoid intrusions occur east of the Avoca Shear. The Cowarna Rocks structure is an overall south-plunging (25–50°) asymmetric S fold with its core intruded by granitoid. A possible interpretation, shown on Figure 4, implies wedging out of the basalt unit south of the railway line. The fold asymmetry is compatible with left-lateral movement along the Avoca Shear.

A characteristic feature of the well-foliated metabasalts and metasedimentary rocks in this area, and along strike northwards, is plagioclase-phyric felsic schists derived from porphyry sills and (low-angle) dykes.

In summary, the three mafic to felsic volcanic domains show quite different detailed stratigraphic–lithological features. These features are consistent over areas much larger than the KURNALPI sheet area. Therefore, an alternative interpretation of a syncline between the Juglah and Jubilee Domains with coarse sediments in the fold core would require substantial lateral variations at depth for which there is no evidence on the surface. The Juglah and Karonie–Yindi Domains contain major felsic volcanic complexes, which in the former are overlain by mafic volcanics, and in the latter appear to be the uppermost unit. These domains are separated by the Jubilee Domain without substantial felsics, and by the sedimentary Mount Belches Domain. Interleaving of mafic, ultramafic, and felsic volcanics as well as sedimentary sequences occurs in all three volcanic domains, and may be both primary and/or tectonic in origin.

The major structural elements can be tentatively correlated with the structural history described for the Kalgoorlie Terrane to the west (Swager et al., 1990). The regional upright folds (Steeple Hill Syncline, Bulong Anticline) can be correlated with the F_2 folds formed during the D_2 regional shortening event. The asymmetric Cowarna fold structure can likewise be interpreted as D_2, but may also be related to D_3 sinistral movement along the Avoca Shear with simultaneous monzogranite intrusion. Definitive large-scale D_1 structures have not been found, but are quite possibly present in the Jubilee Domain. In the Jubilee–Grey Dam area bedding-parallel foliations (S_1?) are clearly overprinted by upright (S_2–S_3) foliations. The domain boundary faults can be interpreted as long-lived structures (Swager et al., 1990) separating areas with different volcano-sedimentary histories.

In tectonic terms, the Juglah and Karonie–Yindi Domains may represent volcanic (magmatic) arc associations, the Jubilee Domain an intra-arc basinal association, and the Mount Belches Domain a foreland sedimentary prism. The coarse conglomerates overlying both Juglah and Jubilee Domains are possibly early syntectonic deposits overlying the principal domain boundary fault.

Metamorphism

Binns et al. (1976) in their regional metamorphic study of the Yilgarn Craton distinguished four metamorphic zones on KURNALPI: very low grade (low greenschist facies) in the northwest; low grade (mid-greenschist to amphibolite transition) in the central part of the sheet; medium grade (low amphibolite) in a narrow zone around the Juglah Granite (on KANOWNA; Ahmat, in prep.a), and high grade (mid- to high amphibolite) in the eastern third of the sheet. The high-grade zone is characterized by a 'dynamic-style' metamorphism with more intense deformation and destruction of original textures, whereas in the very low- to medium-grade zones precursor textures are commonly well preserved ('static-style') despite complete mineralogical reconstitution (Binns et al., 1976).

Mineral assemblages found during regional mapping support the general conclusions of Binns et al. (1976). The location of characteristic porphyroblasts and/or mineral assemblages in different host rocks is shown in Figure 5.

Most porphyroblasts have grown across the main foliation and have enclosed trails that are continuous with and parallel to the main external foliation. This suggests

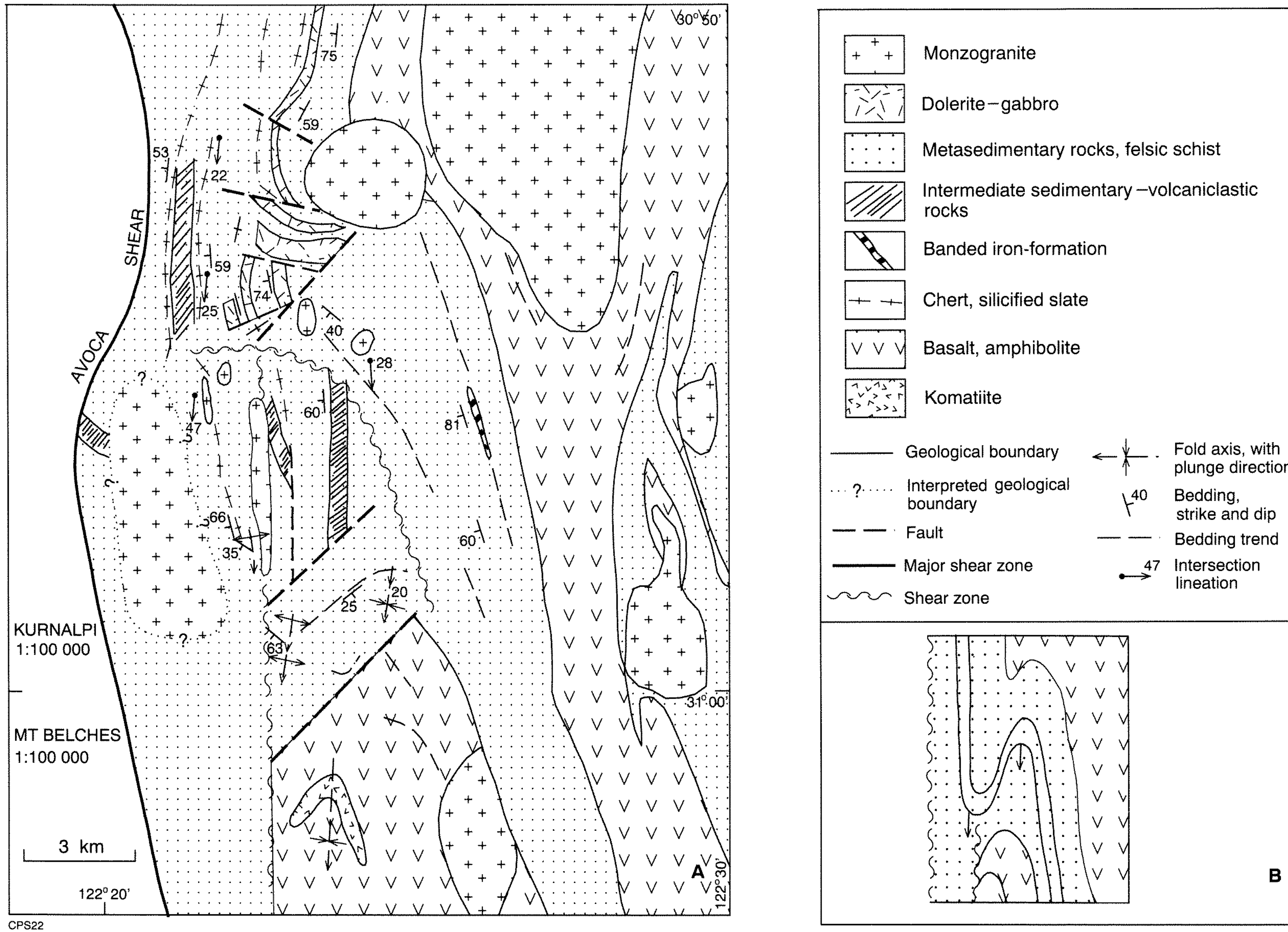

Figure 4. (a) Interpreted geology of the Cowarna Rocks area in the Karonie–Yindi Domain
(b) Schematic illustration of the asymmetric fold structure at Cowarna Rocks. Note that granitoid is not shown. This interpretation implies lateral stratigraphic changes including wedging out of the southwestern basalt unit

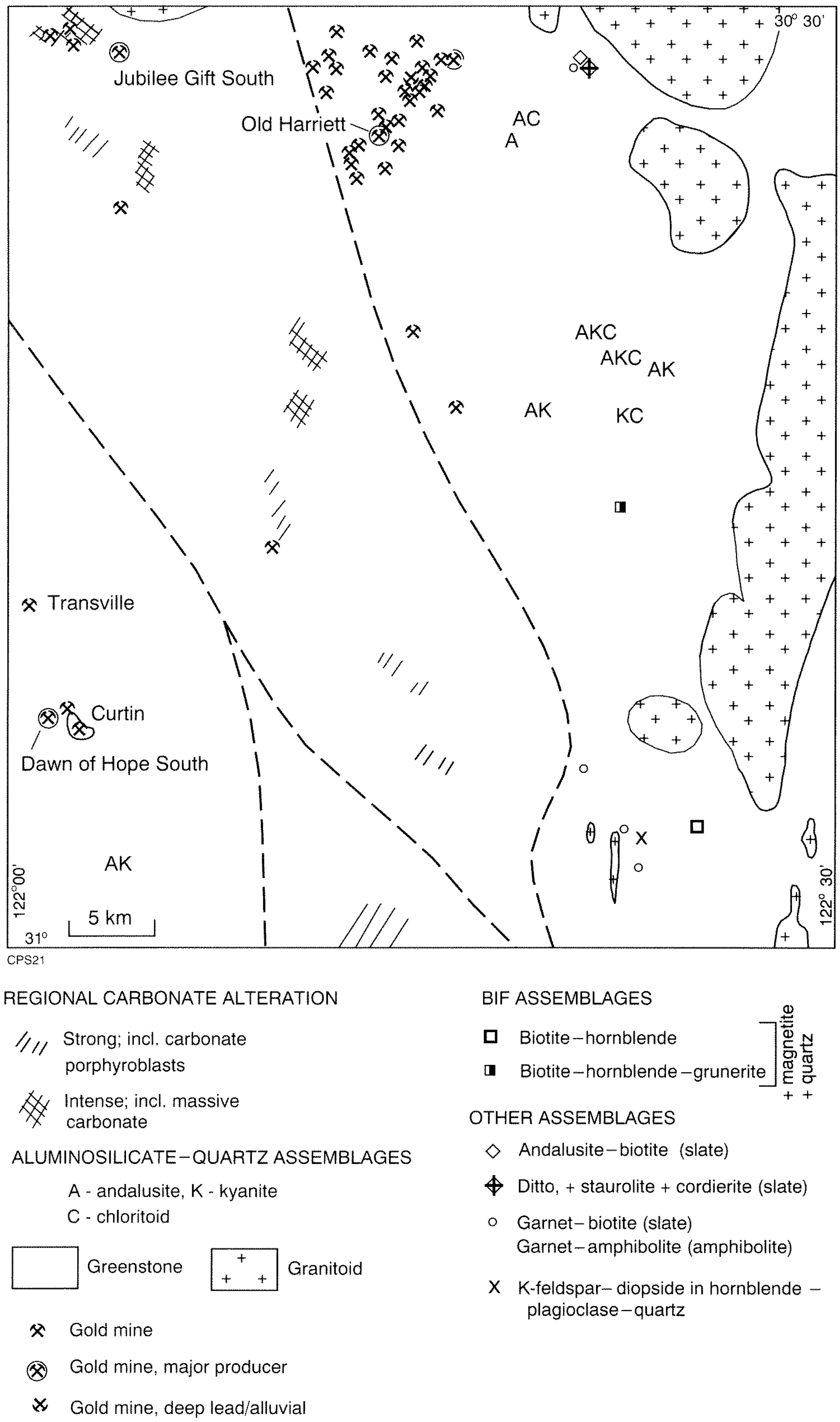

Figure 5. Distribution of distinctive metamorphic assemblages, regional carbonate alteration and main gold mines on KURNALPI

peak metamorphic conditions at a late stage in the regional deformation history. For example, the greywacke belt (*Asg*; Mount Belches Domain) contains small biotite porphyroblasts that have grown across the upright foliation, which is axially planar to the regional folds.

A P–T grid derived for Al-rich shales (Wallmach and Meyer, 1990) has been used to show that the kyanite + andalusite + chloritoid-bearing assemblages in the metamorphosed altered felsic volcanics around Steeple Hill provide only approximate pressure–temperature estimates of 2.5 kb and 350°C.

Assemblages in silicate-bearing banded iron-formation southeast of Windy Dam (quartz–magnetite–biotite–hornblende) and southeast of Rocky Dam (quartz–magnetite– grunerite–hornblende–biotite) suggest medium- to nearly high-grade conditions (Gole, 1981).

Garnet and amphibole porphyroblasts in biotitic quartzo-feldspathic schists, which are part of the intermediate sedimentary/volcaniclastic rock association (*Asi*) near Cowarna Rocks, also indicate amphibolite facies, or medium- to high-grade conditions. This association includes carbonate-bearing areas with distinctive diopside–K-feldspar (–hornblende–plagioclase–biotite–quartz) assemblages characteristic of amphibolite facies conditions in calcareous rocks (Witt, 1991).

Fine-grained slates south of Wyo Well contain andalusite–biotite assemblages with local cordierite–andalusite–staurolite–biotite-bearing layers, indicating once again amphibolite facies (high-grade) conditions.

Regional carbonate alteration has affected, to varying degrees, most rock types on KURNALPI. This alteration appears most intense in a northwest-striking belt between the Jubilee area and Sawmill Dam (Fig. 5). Carbonate may occur as widespread matrix mineral or as porphyroblasts. Locally massive carbonate lenses are present. The timing of original carbonate alteration predates at least the most recent deformation increments because most carbonated rocks show evidence of the regional deformation. On a local scale many narrow shears and/or zones of more intense foliation development contain variable amounts of carbonate.

Economic geology

Three historical gold-mining centres with only modest production figures lie within KURNALPI. These are the Jubilee and Kurnalpi Mining Centres in the Kurnalpi District of the Northeast Coolgardie Mineral Field, and the Transfind Mining Centre in the Bulong District of the East Coolgardie Mineral Field. Production figures of these centres and the major mines are listed in Table 2. A detailed survey of the principal mines is planned.

The Kurnalpi Mining Centre, discovered in 1894, is renowned for its alluvial and deep-lead gold. Several large nuggets of more than 200 ounces (approximately 6.2 kg) have been found (Montgomery, 1906; Jutson, 1914), and at the time of writing (1990) prospectors were working shallow deposits for 'alluvial' gold with some success. Gold production from primary lodes appears to be outweighed by alluvial and dollied gold, as shown by the production statistics for the Kurnalpi King, Pride and Wonder deposits (Table 2). Most of the primary lodes occur as quartz veins along narrow shears within basalt (e.g. Old Harriett) except for the Billy Billy workings which follow a narrow quartz vein at the contact between carbonated mafic and ultramafic rocks and felsic quartz- and feldspar-phyric schist (Jutson, 1914). The Scottish Lass workings follow an intermediate (40°) north-dipping quartz vein in metabasalt with carbonate and pyrite-bearing alteration assemblages.

In the Jubilee Mining Centre, Jubilee Gift is the major producing mine. Two lines of workings exist: a southern line along the contact of sedimentary and strongly foliated and schistose ultramafic rocks, and a line some 20 m across strike to the north and entirely within sedimentary rocks.

At the Transfind Mining Centre the major part of the historical production is from the Transfind (Transville) workings with gold mineralization in and along quartz veins within felsic epiclastic metasediments (*Asf*). The Curtin prospect and older workings to the north show gold mineralization within variably porphyritic biotite monzogranite (*Agp*) in and along north to north-northeast-trending pyritic shear zones with quartz veins. The Juglah workings also follow quartz veins of similar strike in felsic volcanics– volcaniclastics, but recorded production is very low.

Massive sulfide exploration in the 1970s concentrated on base metals in the felsic volcanic complexes between Colour Dam, Gessner Dam, and Christmas Gift Dam. Several reports on exploration (including maps, aeromagnetics) in these areas are available on the WAMEX open-file system at the Department of Minerals and Energy. Numerous gossanous layers and lenses have been identified, commonly associated with chert and/or grey to black slate. Drilling of a prominent bedding-parallel gossanous horizon in the area east and north of Christmas Gift Dam demonstrated the presence of massive pyrite at depth. Only traces of lead, zinc or copper were found. A gossanous zone at the Colour Dam prospect, southeast of the dam, appears to be a fault zone with interleaved and strongly altered felsic volcanic–volcaniclastic and mafic/ultramafic schists containing lenses of sulfide gossan. Gold anomalies along this zone were tested by trial pit in the late 1980s.

The quartz–aluminosilicate rocks within the felsic volcanic complexes are generally interpreted as metamorphosed highly altered rocks, possibly representing advanced argillic alteration. Similar rocks in Canada and Finland are associated with massive pyrite with base-metal sulfide lenses and local Au–Ag–Cu mineralization (e.g. Marquis et al., 1990; Papunen et al., 1989).

Nickel exploration in the Jubilee komatiite belt has not delineated any substantial mineralization. The Acra prospect, about 1 km south of Grey Dam, lies along the northern, or basal, contact of peridotite (*Aup*) with sedimentary rocks (*As*). Gossanous material along the contact assayed up to 1.8% nickel and 0.4% copper.

Table 2. Gold production statistics of mining centres and principal mines on KURNALPI, to 31 December 1988

Mining centre and mine	*Alluvial gold (kg)*	*Dollied gold (kg)*	*Tonnes treated (kg)*	*Gold produced (kg)*	*Total*	*Period*
			Northeast Coolgardie Mineral Field–Kurnalpi district			
Kurnalpi Mining Centre	29.655	122.87		201.093	353.535	
Billy Billy			797.21	23.171	23.171	1903–1905
Scottish Lass (Hampton Hill G.M.s)				11.637	11.637	1898–1901
Kurnalpi King		26.473	9 860.40	9.849	36.322	1912–1913
Kurnalpi Pride		20.603	33.17	11.836	32.439	1915–1921
Kurnalpi Wonder		13.601	8.12	3.98	16.999	1912–1913
Old Harriett			961.80	35.595	35.595	1931–1937
Jubilee Mining Centre	5.214	4.934	3 780.58	63.179	73.327	
Jubilee Gift			1 469.40	33.413	33.413	1899–1903
Mountain Maid/Iron Prince			204.70	6.601	6.601	1898
			East Coolgardie Mineral Field–Bulong district			
Transfind Mining Centre		0.184	1 890.98	37.145	37.329	
Transville			942.30	26.718	26.718	1923–1927

Source: Department of Minerals and Energy, List of Cancelled Gold Mining Leases, 1954; unpublished records.

Diamond drilling intersected several disseminated sulfide zones in the lower 120 m of the peridotite, showing best assay values of 0.53–0.69% nickel over widths up to 21 m (Marston, 1984).

The Cowarna Rocks prospect near Christchurch Dam, 10 km north of Avoca Downs, contains disseminated nickel sulfides in serpentinized peridotite (*Aup*) adjacent to unmetamorphosed Proterozoic magnesian basalt dykes, which are part of the Celebration Dyke (*Pdyc*; Purvis and Moeskops, 1981; Marston, 1984). The best intersection encountered during shallow percussion and diamond drilling averaged 1.1% nickel and 0.63% copper over a width of 3 m at a vertical depth of 46 m (Marston, 1984).

Andalusite and kyanite occur locally in relatively high concentrations in quartz–aluminosilicate rocks (*Ala*, *Alk*), but are always intimately intergrown with quartz and minor amounts of very fine rutile.

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Appendix

Location of names referred to in text

Name	*AMG coordinates* *Easting*	*Northing*
Anti Dam	43365	661620
Avoca Downs	43500	657535
Billy Billy Hill	42900	662315
Bodgie Dam	43830	658045
Bulyairdie Rock	44330	661640
Canegrass Swamp	43125	662050
Christchurch Dam	43480	658570
Christmas Gift Dam	44150	659300
Colour Dam	43125	662095
Cowarna Rocks	44040	657665
Curtin mine	40865	658150
Dart Dam	41115	657190
Gessners Dam	43050	660330
Grey Dam	41310	662260
Gunny Dam	41270	659380
Hackett Well	42540	661795
Horseshoe Dam	40585	657325
Jubilee Tank	40845	662345
Jubilee Gift mine	40915	662280
Juglah mine	40480	658710
Jurangie Dam	43870	661610
Kanowna	36550	661250
Karonie	45800	656650
Kurnalpi	42600	662110
Kurnalpi King mine	42775	662160
Kurnalpi Wonder mine	42735	662265
Minters Gully	42740	662150
Mt Belches	42730	655800
Mt Charnleigh	44565	660340
Mt Monger	39620	656950
Nodule Dam	42280	659305
Norman Dam	44805	657160
Old Harriett mine	42535	661790
Outcamp Dam	43800	658900
Pineapple Dam	41975	659600
Randell Dam	42585	657230
Randell Siding	42800	657640
Rocky Dam	43740	660185
Sawmill Dam	42950	658780
Scottish Lass Well	42585	662300
Six Mile Dam	41815	662480
Slippery Dam	44145	657920
Steeple Hill	43970	660625
Success mine	42125	662180
Teddy Dam	41095	657450
Wattle Dam	41515	658775
White Dam	44130	657385
Windy Dam	44340	657990
Wyo Well	43670	662445
Yindi Rock	45115	661630

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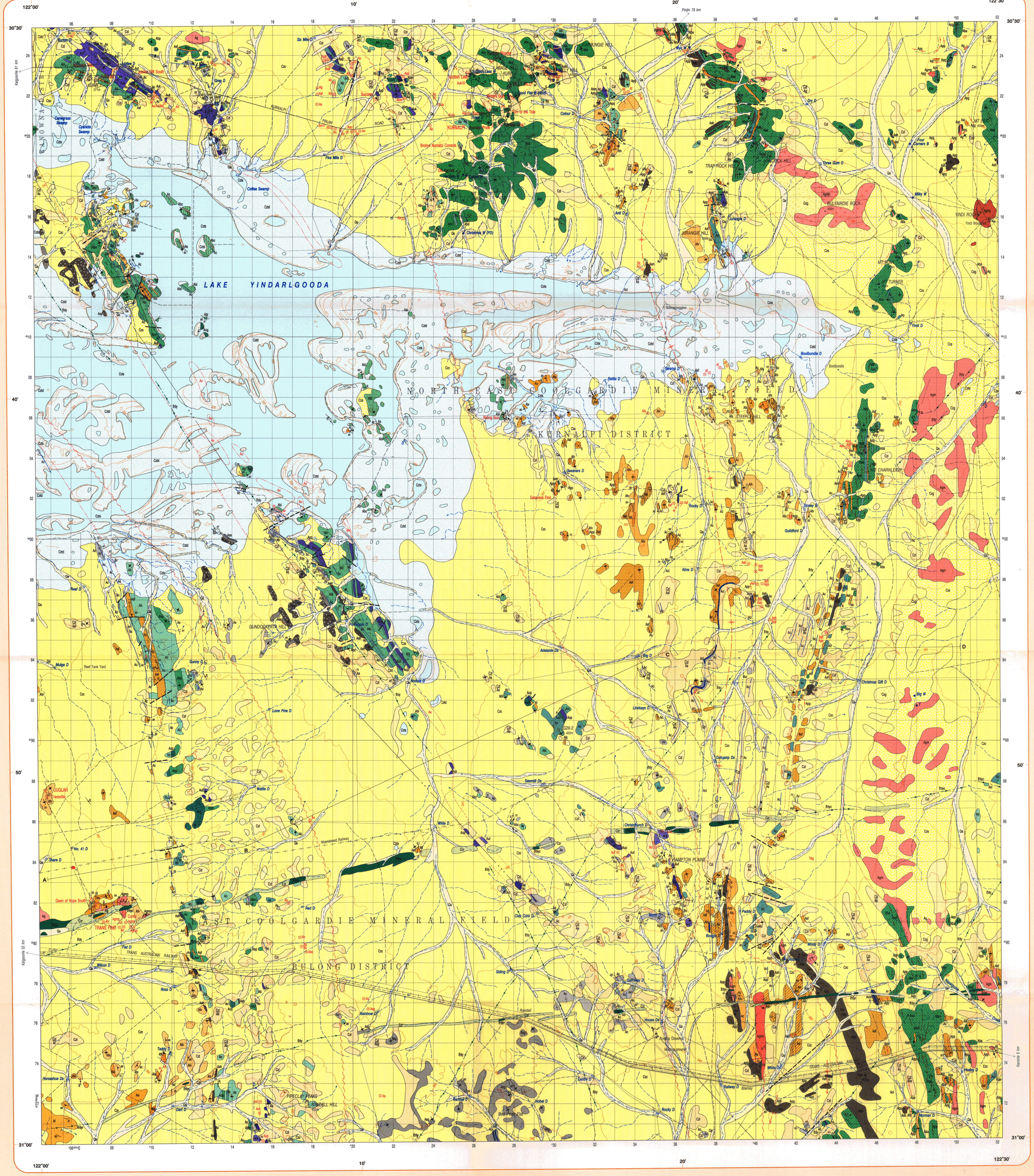
KURNALPI

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET 3336



PHANEROZOIC — CAINOZOIC — QUATERNARY

Qa — Alluvium — clay, silt, sand, and gravel; in stream channels and flood plains

Czts — Evaporite, interbedded with clay, silt, and sand in playas
Cztd — Sand, silt, and gypsum in stabilized dunes adjacent to playas

Czc — Colluvium — gravel and sand as sheetwash and talus; includes laterite fragments
Czg — Quartzo-feldspathic sand over granitoid rock
Czs — Sandplain — yellow sand, with some pisolitic laterite pebbles
Czl — Laterite and reworked products
Czr — Residual, deep red, unconsolidated soil; overlies mafic and ultramafic Proterozoic dykes

PROTEROZOIC

Ꝑdy — Mafic and ultramafic dykes; interpreted from aeromagnetic data where dashed.
Ꝑdyc — Celebration Dyke, Ꝑdyr — Randalls Dyke

ARCHAEAN

Veins and dykes: q — quartz, g — granitoid, p — pegmatite

Ag — Granitoid, undivided
Agm — Monzogranite; common K-feldspar phenocrysts, with biotite and local hornblende
Agmc — COWARNA MONZOGRANITE: K-feldspar phenocrysts
Agmy — YINDI MONZOGRANITE: even-grained
Agmb — BULYAIRDIE MONZOGRANITE: perthitic K-feldspar megacrysts with hornblende
Agmp — Porphyritic biotite monzogranite to monzogranite porphyry

Apq — Felsic porphyry, sill or dyke; small quartz and/or feldspar phenocrysts
Apg — Granitoid porphyry, includes granodiorite porphyry; prominent plagioclase, quartz and/or biotite phenocrysts
Apl — Hornblende lamprophyre
App — Plagioclase-phyric biotite felsic porphyry; numerous euhedral plagioclase and few quartz phenocrysts; strongly foliated; narrow sills and dykes

As — Sedimentary rock, undivided
Ash — Grey slate, siltstone, and minor sandstone; commonly well cleaved; with biotite, and local garnet, andalusite, staurolite, and/or cordierite porphyroblasts
Asg — Greywacke, with minor interbedded siltstone; cross-bedded and graded; biotite bearing; widespread carbonate alteration
Asp — Polymictic conglomerate, with subordinate sandstone; faceted pebbles and boulders of granitoid, felsic porphyry, gabbro, chert, and mafic schist
Ass — Sandstone, with minor conglomerate and siltstone
Asf — Quartzo-feldspathic to micaceous epiclastic slate, siltstone, and sandstone interleaved with feldspar-phyric schist of felsic volcanic and volcaniclastic derivation
Asi — Intermediate sedimentary and volcaniclastic rocks; well banded and foliated; amphibolite-biotite-feldspar-quartz schist, locally garnetiferous; biotite(-garnet) slate and feldspar-phyric felsic schist
Asip — Conglomeratic intermediate sedimentary and volcaniclastic rocks; pebbles predominantly amphibole-feldspar-quartz-garnet rock and feldspar-phyric felsic schist
Ac — Chert, locally grey and white banded; includes silicified grey to black slate; finely layered and locally pyritic; interpreted where dashed (section only)
Aci — Banded iron-formation, oxide facies; quartz-magnetite(-biotite) rock; interpreted from aeromagnetic data where dashed
Acis — Banded iron-formation, silicate facies; includes biotite-grunerite(-hornblende) siliceous slate

Af — Felsic (acid to intermediate) volcanic rock, undivided
Afv — Felsic volcanic and volcaniclastic rock; foliated; porphyritic with prominent feldspar and/or quartz phenocrysts or clasts; includes fragmental rocks and crystal lithic and finely layered tuffs
Aft — Felsic tuffaceous rock; finely banded; foliated; fine- to medium-grained quartz and feldspar phenocrysts
Afs — Quartzo-feldspathic micaceous schist derived from felsic volcanic, subvolcanic, and/or volcaniclastic rock
Ala — Quartz-andalusite rock with local chloritoid-quartz-mica rock within felsic volcanic sequence
Alk — Quartz-kyanite-andalusite rock with local chloritoid; local quartz clasts
Alh — Quartz-choritoid-kyanite rock

Aiv — Intermediate volcanic rock; andesite to basalt with feldspar and hornblende phenocrysts; amygdaloidal; epidote and/or carbonate alteration common; includes feldspar-quartz-chlorite-hornblende schist
Aix — Intermediate volcanic rock, with fragmental and tuffaceous textures; epidote and carbonate alteration

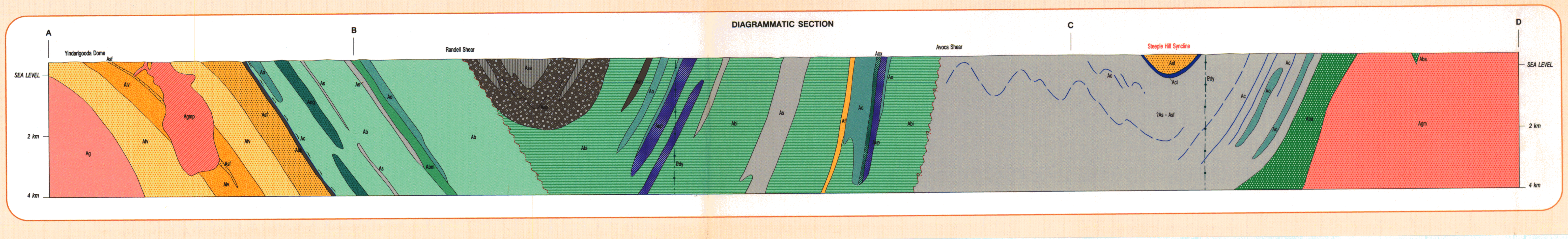
Ao — Mafic intrusive rock, undivided
Aog — Gabbro, with minor pyroxenite and quartz gabbro
Aop — Feldspar-phyric dolerite and gabbro
Aox — Pyroxenite and pyroxenitic gabbro; with scattered euhedral feldspar phenocrysts

Ab — Basalt, undivided; includes feldspar-hornblende or chlorite schist; locally feldspar-phyric
Abd — Basalt and dolerite; massive, ophitic textured
Abv — Basalt with abundant varioles; pillowed
Abp — Basalt, feldspar-phyric
Abi — Basalt to basaltic andesite; amygdaloidal, feldspar-phyric; contains brecciated flow tops and fragmental/tuffaceous layers
Abm — High-Mg basalt with quenched pyroxene (amphibole) texture; includes ocellar-textured basalt
Abc — Basalt, extensively carbonated; includes massive carbonate lenses
Aba — Amphibolite, derived from basalt

Au — Ultramafic rock, undivided
Auk — Komatiite; olivine cumulate zones dominate spinifex-textured zones; includes tremolite-chlorite and talc-chlorite schist
Aukc — Komatiite, extensively carbonated; includes carbonate-talc-chlorite schist and massive carbonate lenses
Aup — Peridotite, serpentinized; locally with rodingite lenses
Aut — Talc-chlorite(-carbonate) schist; minor tremolite-chlorite schist

Metamorphosed at greenschist and lower to middle amphibolite facies

DIAGRAMMATIC SECTION



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PIETRO GUJ
DIRECTOR, GEOLOGICAL SURVEY
OF WESTERN AUSTRALIA

SCALE 1:100 000

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

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

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