AGSC

Geology of the Ballard 1:100 000 Sheet area (3039), Western Australia

M.S. Rattenbury

Record 1999/46

AGSO
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION
DEPARTMENT OF INDUSTRY, SCIENCE & RESOURCES

AGSO RECORD 1999/46

Geology of the Ballard 1:100 000 Sheet area (3039), Western Australia

M.S.RATTENBURY

Formerly of Minerals Division, Australian Geological Survey Organisation, GPO Box 378, Canberra, ACT 2601

Present address: Institute of Geological & Nuclear Sciences, PO Box 30 368, Lower Hutt, New Zealand

CANBERRA 1999

Department of Industry, Science & Resources

Minister for Industry, Science & Resources: Senator the Hon. Nick Minchin
Parliamentary Secretary: The Hon. Warren Entsch, MP
Secretary: Russell Higgins

Australian Geological Survey Organisation

Chief Executive Officer: Neil Williams

ISSN 1039–0073
ISBN 0 642 39809 7

Bibliographic reference: Rattenbury. M.S., 1999. Geology of the Ballard 1:100 000 Sheet area (3039), Western Australia. Australian Geological Survey Organisation, Record 1999/46.

Contents

C3

Abstract

The Ballard 1:100 000 Sheet area encompasses Archaean mafic-ultramafic intrusive and volcanic rock, interflow sedimentary rock, gneiss and granite, minor Proterozoic mafic dykes, and widespread Cainozoic sand, laterite, alluvium, colluvium, and lake deposits. The mafic-ultramafic upper greenschist to amphibolite facies rocks can be subdivided into three informal stratigraphic formations: a lowermost basalt-gabbro unit, an olivine cumulate peridotite unit, and an overlying basalt-komatiite unit. The stratigraphic relationship between the lowermost basalt and peridotite is not clear because of inferred faulting. These units can be correlated regionally with units within other Kalgoorlie Terrane domains, and form the basal part of the Eastern Goldfields mafic-ultramafic succession. To the east, the Ballard Shear tectonically juxtaposes quartzofeldspathic gneiss, with interlayered amphibolite and rare horizons containing metapelitic mineral assemblages, against the mafic-ultramafic metavolcanics and intrusives to the west. Monzogranite occurs widely in the central and eastern parts of the sheet area. The monzogranite has an intrusive contact with the gneiss to the west, and is foliated within a zone up to 4 km east of the contact. Strongly lineated granite occurs at the base of the mafic-ultramafic succession in the northwest corner of the map sheet area.

Four discrete deformation phases have been identified. D_1 thrust-related ramping and duplexing of the ultramafic cumulates with basalt occurs in the central-west of the sheet, within the hinge area of the D_2 Kurrajong Anticline. Small-scale D_1 isoclinal folds occur in many areas, and the dominant D_2 foliation locally crenulates an earlier foliation. The D_2 Kurrajong Anticline can be mapped throughout the northern half of the greenstone belt. Minor associated folding is characteristically upright, close to tight with gently south plunging fold axes. A penetrative axial planar foliation (D_2) is developed throughout the mafic-ultramafic succession and in the underlying deformed granite. The last two deformation phases involve movement of the Ballard Shear with earlier (D_3) relatively ductile sinistral (?) strike-slip followed by relatively brittle D_4 dextral strike-slip.

Mines within the sheet area have produced approximately 451 kg of gold. The larger gold mines at Forest Belle and Golden Vale are part of the Copperfield granite aureole, which had major production on the adjacent Mount Mason sheet area. Most mines and workings occur in the lowermost basalt-gabbro unit, generally occurring in sheared rock types but not concentrated in any particular structure, apart from a small number along the Ballard Shear.

Introduction

The Ballard 1:100 000 sheet area (3039, BALLARD) is located within the Menzies 1:250 000 sheet (SH/51-05), between latitude 29° 00' S and 29° 30' S, and longitude 120° 30' E and 121° 00' E (Fig. 1). BALLARD is in the central-west of the Eastern Goldfields Province of the Yilgarn Craton, approximately 150 km north-northwest of Kalgoorlie. The area has no established dwellings apart from the normally unoccupied Forty Five Mile Well and Kurrajong outcamps of Riverina station in the west, and the Last Chance outcamp of Sturt Meadows station in the northeast. Temporary buildings have been erected at the Golden Vale mine site. Access to BALLARD (Figs. 1, 2) is on unsealed roads from Menzies, Riverina, and Leonora. The western part of BALLARD has numerous tracks and some extensive exploration grids enabling ready access to most of the mafic-ultramafic metavolcanic rocks. Central and eastern areas are not easily accessible except by a limited number of dirt tracks and fence lines, which are commonly overgrown. The area is predominantly lightly wooded with a 4-8 m canopy of *Acacia* (mulga).

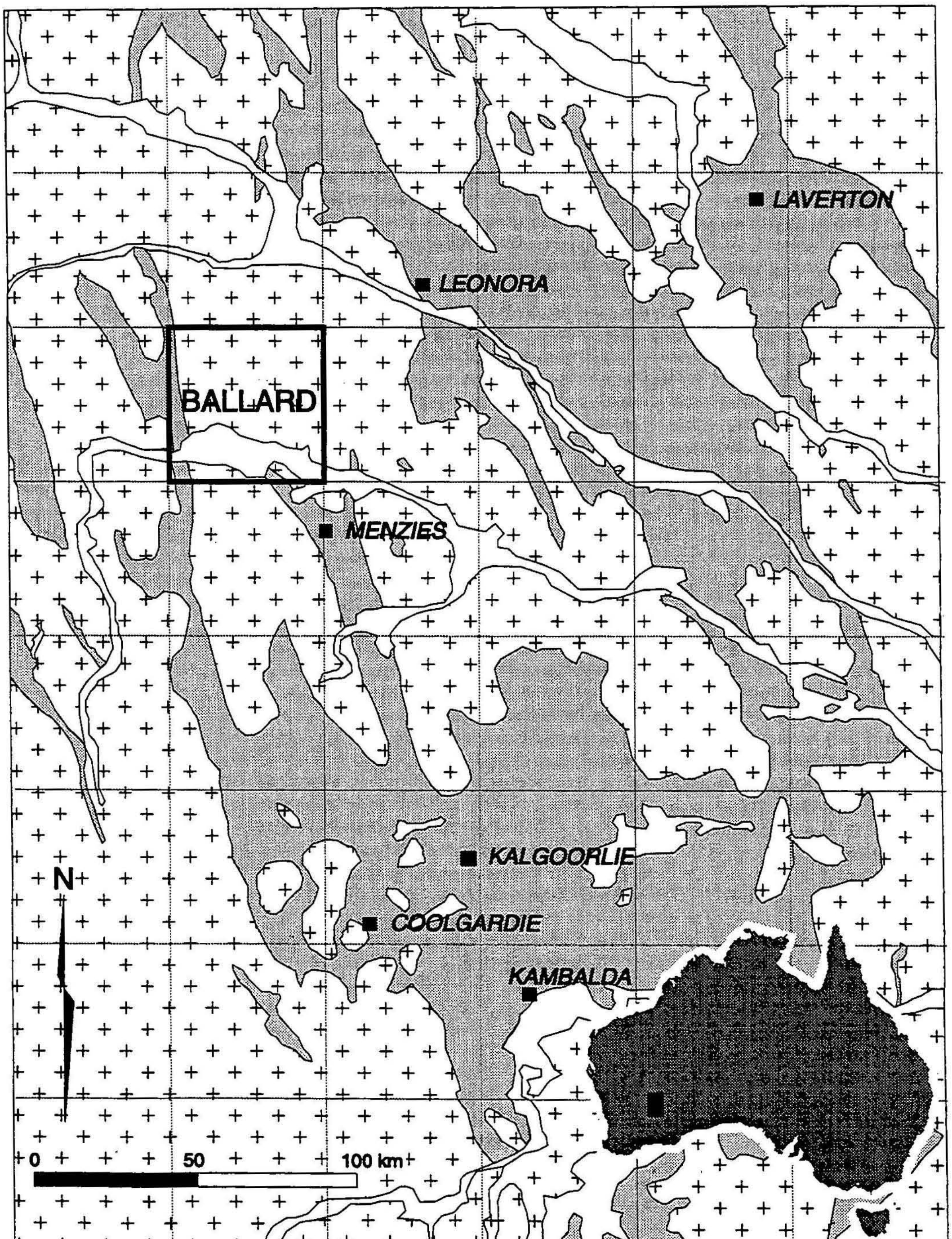


Figure 1. Location of BALLARD in the Eastern Goldfields, showing the metavolcanic and sedimentary rocks (shaded) and the gneissic and granite rocks (crosses).

Lake Ballard, an evaporitic playa which usually remains dry throughout the year, covers much of the southern part of BALLARD. Elsewhere, the land surface ranges in elevation from 360-465 m ASL. A low range trends north-south across the western part of BALLARD, and a gentle topographic high trends east-west across the northern part of the sheet. Drainage is ephemeral and mostly directed towards Lake Ballard.

There is little published previous work on BALLARD. Woodward (1902) visited the Mount Ida Mining Centre, identified a major anticlinal structure, and examined the relationships of the major lodes to the contact between the mafic metavolcanics and the felsic granite/gneiss. Gibson (1907) described the geology and ore deposits of the Mount Ida Mining Centre, notably the Forest Belle gabbro and the production history of various mines in the area. Tomich (1956) reported on the geology of a portion of the Mt Ida District, and produced a geological map at a scale of 1:792. Young & Tipper (1964), during a magnetic and radiometric survey of the Menzies 1:250,000 Sheet area, produced a solid-geology interpretation of BALLARD. They delineated the prominent magnetic east-west dykes, but their interpretation was hampered by a lack of ground control. Kriewaldt (1970) mapped the area during systematic mapping of the Menzies 1:250 000 Sheet area. The explanatory notes for the Menzies Sheet area provide general comments on geology, and a number of samples and thin sections are held in the Geological Survey of Western Australia collections. Hill & Gole (1991) published detailed descriptions and interpretation of the layered komatiites in an area northeast of Forty Five Mile Well, as well as a 1:80 000-scale geological map compiled from exploration company mapping. Unpublished company reports on tenements throughout the mafic-ultramafic metavolcanic belt are held in the Western Australia Department of Mines, but are of variable quality in terms of geological and geophysical mapping, description, and interpretation.

Fieldwork by AGSO was undertaken between June-August 1990, primarily by foot traverses across the mafic-ultramafic metavolcanics and intrusives, and by vehicle traverses across the more accessible granitic terrain. Colour 1:25 000-scale aerial photographs flown in April 1990 were used across the western half of BALLARD. The eastern half of the area was mapped using 1984 1:50 000 black-and-white aerial photographs. Data were compiled on to photo-scale basemaps supplied by AUSLIG. Photo control is relatively good because of a fairly even spread of identifiable roads, tracks, fences, wells, creek beds, and lakeshore segments. Location, sample, geochemical, and structural data reside in the corporate AGSO OZROX database.

Acknowledgments

Reviews by Arthur Hickman (GSWA) and Alastair Stewart (AGSO) improved the manuscript. Alastair Stewart and Geoff Bladon produced the report.

Archaean geology

The basement geology of BALLARD (Figs. 2, 3) comprises, in order of abundance, late Archaean granite, mafic-ultramafic metavolcanics and intrusives, gneiss, and minor metasedimentary rocks, with very minor Proterozoic mafic dykes. Outcrops of these basement rocks are largely restricted to the west and northeast. Depth of weathering is generally tens of metres, except near Bottle Creek where it extends to several hundred metres. Elsewhere, a veneer of Cainozoic sand, alluvium, laterite, evaporitic playa deposits, and colluvium up to tens of metres thick covers basement.

In a regional context, the western part of BALLARD incorporates part of the Mount Ida greenstone belt, which marks the historical division between the Southern Cross and Eastern Goldfields Provinces. The rock types characteristic of the Southern Cross Province, such as extensive banded iron formation and quartzose sedimentary rocks, occur 5 km west of BALLARD, whereas rock types typical of the Eastern Goldfields Province are exemplified by the mafic-ultramafic metavolcanics and intrusives of the western part of BALLARD. A craton-scale magnetic lineament, the Mount Ida Lineament, trends north-south through this region extending south for hundreds of kilometres. The Mount Ida Lineament through BALLARD separates the high magnetic susceptibility ultramafic metavolcanics from the low magnetic susceptibility gneiss and granite. The contact between the metavolcanics/intrusives and the gneiss is a major shear zone, the Ballard Shear, which trends north across BALLARD. All Archaean mafic igneous rocks and sedimentary rocks have been metamorphosed to greenschist-amphibolite facies, but primary sedimentary and igneous textures are commonly preserved, and so for clarity the prefix 'meta' has been omitted. The mafic and ultramafic volcanics crop out in the west and south (AMG 887348).

Metamorphosed ultramafic rocks

Talc-carbonate rock (Auc)

Talc-carbonate rock crops out on both limbs of the Kurrajong Anticline in the centre of the greenstone belt.

Komatiite (Auk)

Medium to pale green, fine-grained komatiite is characterised by distinctive platy olivine spinifex texture (Fig. 4). These rocks occur in several horizons between layers of basalt in the centre and southern half of the greenstone belt between Madhatter mine and the northwestern shore of Lake Ballard, south of Snake Hill, and on the western limit of outcrop near the map boundary with RIVERINA. Komatiite commonly occurs with high-Mg basalt. Preservation of the spinifex texture indicates low strain in this rock type. The rock consists of tremolite (after olivine) in a fine-grained matrix of tremolite-chlorite-plagioclase-opaques. In the hinge region of the Kurrajong Anticline, komatiite has been deformed and altered to green fine-grained amphibole-chlorite schist.

Peridotite (Aup)

Cumulate-textured peridotite, typically with a surficial ferruginous silica capping, occurs in the centre and south of the Sheet area, including the hinge region and eastern limb of the Kurrajong Anticline. Igneous textures are commonly

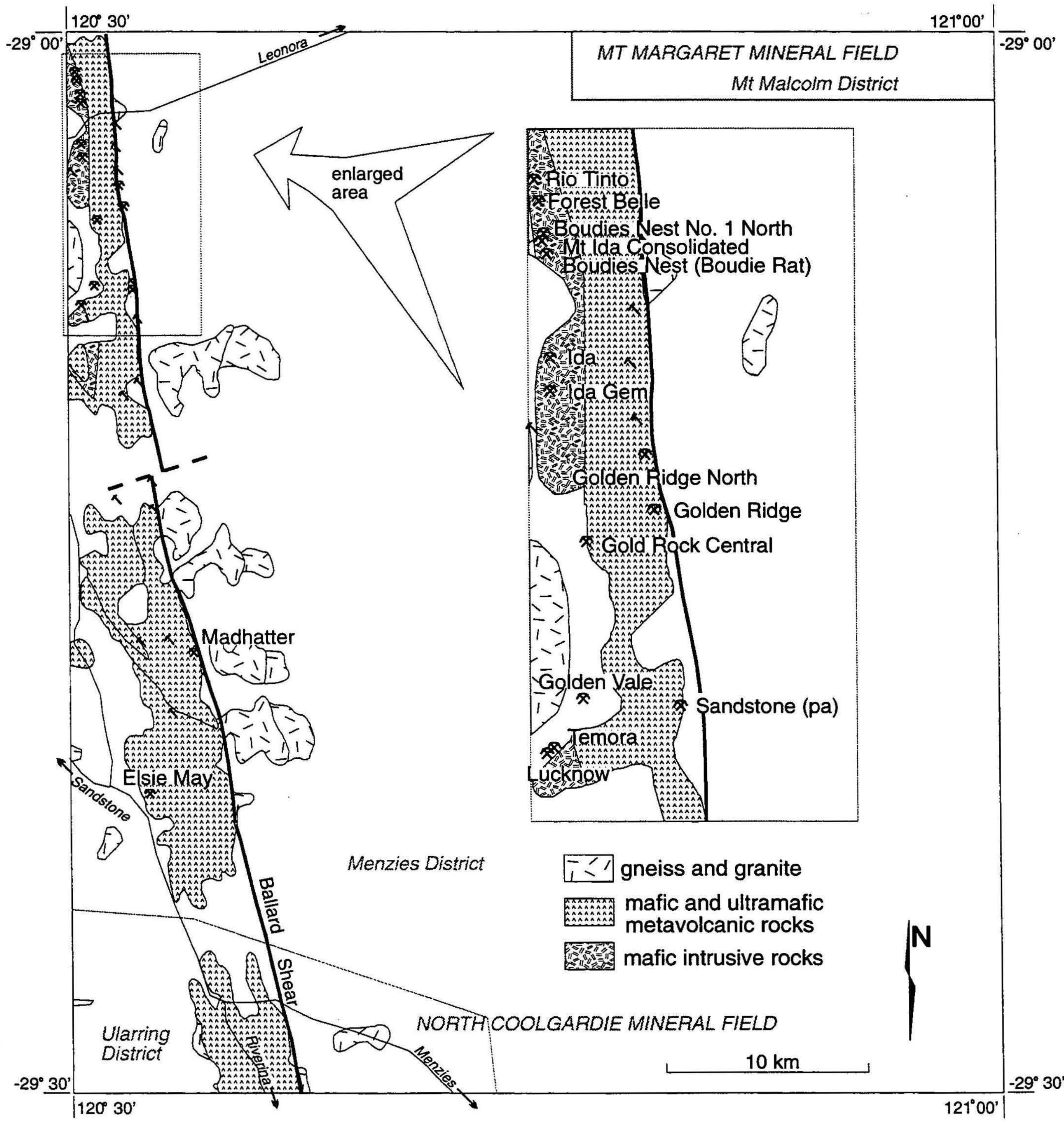


Figure 2. Mines, prospects, mining districts and centres, and roads on BALLARD.

well preserved. The surface rocks display completely serpentinised olivine crystals, as interlocking (adcumulate), transitional (mesocumulate), through to serpentinised olivine separated by fine-grained serpentine-tremolite-magnetite matrix (orthocumulate). Core samples from nickel exploration drilling show relatively unaltered olivine-augite adcumulates, mesocumulates, and orthocumulates (Hill & Gole 1991). Olivine-clinopyroxene-plagioclase harrisite occurs as a thin layer within the cumulate sequence. Hill & Gole (1991) interpret the sequence as an example of olivine accumulation and fractionation in place in a ponded lava lake, capped by gabbro and flow top breccia.

Tremolite schist (Aur)

Tremolite schist forms lenses up to 300 m thick and 5 km long in the north of the greenstone belt.

Serpentinite (Aus)

Serpentinite crops out throughout the greenstone belt, particularly in the centre between Lake Ballard and Fifty One Mile Well.

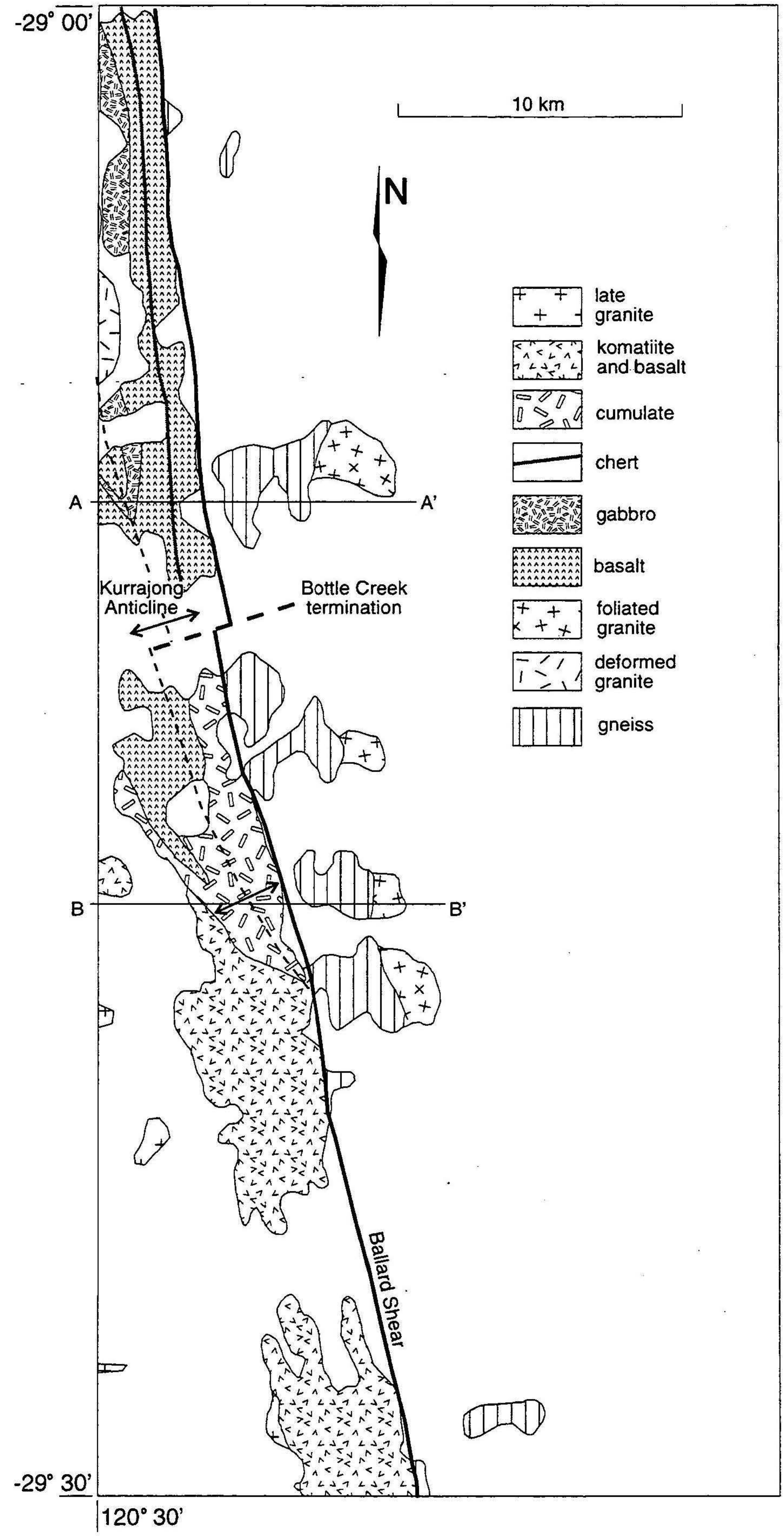


Figure 3. Generalised geology of the mafic-ultramafic and sedimentary basement rocks and major structures in western BALLARD.

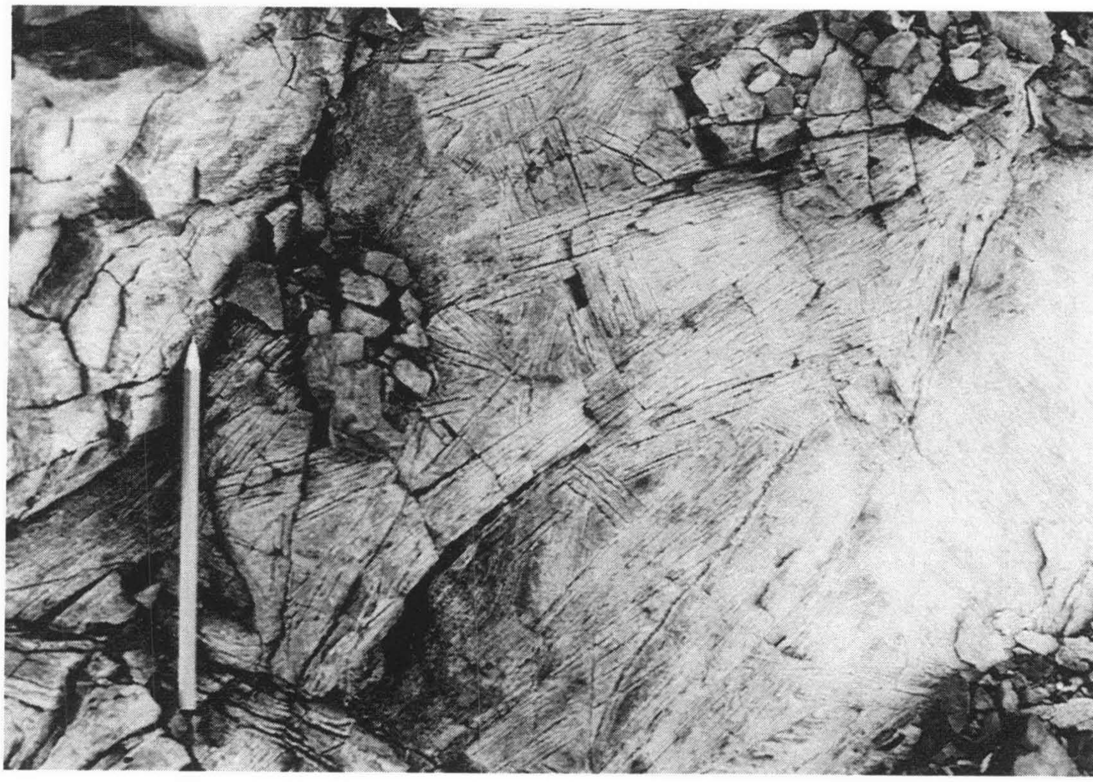


Figure 4. Spinifex-textured komatiite (AMG 657459), pencil 14cm long.

Talc-chlorite schist (Aut)

Small amounts of pale grey strongly foliated talc-chlorite schist form interlayers a few metres thick and of limited lateral extent in basalt in the north of the greenstone belt.

Low-grade metamorphic rocks

Amphibolite (Ala)

Dark green, relatively indurated amphibolite occurs adjacent to granite and interlayered with komatiite in the southwest, and adjacent to basalt in the northwest. Amphibolitic metavolcanics also occur regionally in the north of the mafic-ultramafic volcanic belt, but for stratigraphic clarity the original host rock type has been mapped. Amphibolite also occurs within the banded gneiss (Ang) but in layers too thin to map. The amphibolite is characterised by fine-grained <0.5 mm prismatic hornblende and plagioclase, with subordinate magnetite, epidote, and sphene.

Metamorphosed mafic igneous rocks

Metabasalt (Abb) and amygdaloidal basalt (Aby)

Dark green-grey fine-grained basalt is the most extensive volcanic rock type, occurring throughout the greenstone belt and dominating the northern half. Pervasive foliation, and in some areas pervasive lineation, have obliterated most primary structures. Flow banding, vesicles, and pillows occur in several areas (Fig. 5), especially on the islands in Lake Ballard near Snake Hill. Pillows are usually flattened into the foliation plane, and vesicles have aspect ratios typically 3:1 to 5:1. Vesicle concentrations at the upper surface of individual pillows, together with pillow drape structures, have been used to determine facing, but generally yield contradictory or ambiguous results because of the effects of deformation.

Clinopyroxene occurs in weakly deformed basalt as interlocking short ragged radiating crystals with plagioclase. Plagioclase commonly occurs as heavily saussuritised phenocrysts. Phenocrysts of actinolite (after pyroxene) are common, but aphyric basalt dominates. Larger actinolite blades up to 4 mm long and plagioclase crystals occur in a matrix of actinolite-plagioclase-epidote-sphene-leucoxene. Aligned amphibole and chlorite define the foliation.

Garnet porphyroblasts up to 1 cm diameter occur in a thin foliated basalt unit near Oberwyl Hill (AMG 582838). The garnets occur in a chlorite (after amphibole)-plagioclase-quartz-biotite groundmass. Green chlorite defines the rock foliation with minor biotite forming semicontinuous bands. The garnets are subhedral with inclusion-rich cores and inclusion-poor rims. The inclusions are elongate quartz and magnetite occurring in trains which describe a curved foliation within the outer rim of the garnet crystals. The foliation orientation in the inclusion-rich cores is commonly either truncated by or sharply rotated in transition to the garnet rim foliation orientation. The foliation trajectory defined by the inclusions continues out of the garnet crystals without significant deflection into the foliation defined by actinolite/chlorite blades in the matrix.

Medium to coarse-grained dolerite occurs widely as thin layers within the basalt. Thin beds of fine-grained sandstone occur between some basalt flows.

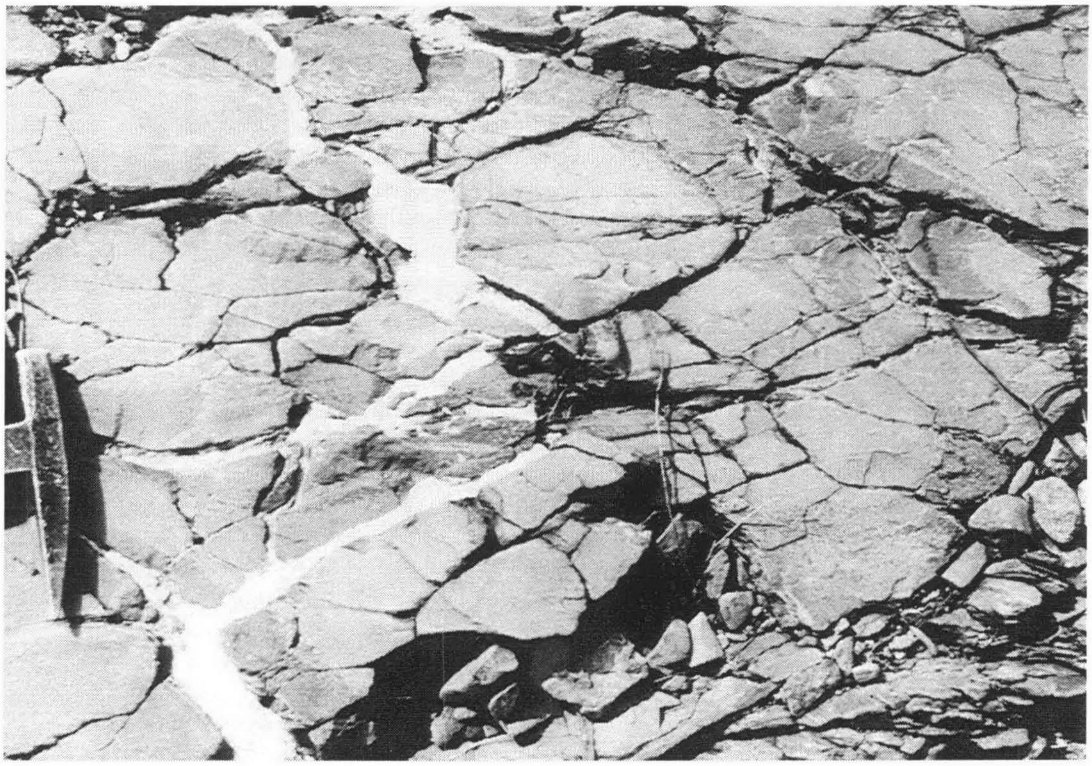


Figure 5. Basaltic pillow lava structures, with vesicle concentrations and pillow drapes indicating east facing (to right). Hammerhead for scale (AMG 653470).

High-magnesium basalt with spinifex texture (Abm)

Grey-green, chloritic, fine to medium-grained high-Mg basalt crops out in the southern half of the metavolcanic belt, interlayered with basalt (Abb) and komatiite (Auk). The basalt is typically well foliated with a silvery lustre along cleavage planes. Subparallel clusters of bladed actinolite up to 20 cm long are common, and have replaced spinifex-textured pyroxene. Plagioclase occurs as interstitial 0.2-mm grains. Tremolite, epidote, and quartz occur in some rocks. Chlorite after amphibole is prevalent where foliation is strong. Pyroxene spinifex texture is characteristic of relatively high-magnesium basalt.

Mafic volcanic rocks ± sedimentary rocks (Abv)

Mafic volcanic rocks ± sedimentary rocks form a single outcrop 1.5 km east of Spotted Dog Hill.

Dolerite (Aod) and porphyritic dolerite (Aodp)

Dark green and white, medium to coarse-grained dolerite occurs in close association with basalt throughout the southern half of the greenstone belt, generally in stratiform sheets emplaced as either flows or sills. The dolerite is typically massive, although occasional internal banding is present. The dolerite has a reddish-brown blocky weathering appearance, and is typically less foliated or lineated than surrounding basalt. Some internal sheet differentiation to more leucocratic, plagioclase-rich variants has occurred within some units. Prismatic actinolite (or hornblende in higher-grade rocks) phenocrysts 0.5 -10 mm, and plagioclase <0.4 mm occur in a matrix of fine grained 0.02-0.1-mm plagioclase. Plagioclase is commonly saussuritised to epidote and quartz. Pyroxene is usually completely replaced by the amphibole. Rare porphyritic dolerite (Aodp), for example, at Spotted Dog Hill, is characterised by large euhedral to anhedral glomeroporphyritic calcic plagioclase crystals (up to 3 cm diameter) in a matrix of 1-3 mm actinolite and 0.01-0.04 mm plagioclase. Amphibole occurs as ragged 2-mm blades, which define the foliation together with the flattened aspect of the plagioclase phenocrysts.

Gabbro (Aog, Aogp)

Coarse to very coarse-grained gabbro occurs sporadically throughout the metavolcanic belt north of Lake Ballard. The gabbro outcrops are blocky and weather red-brown. The gabbro generally occurs as sills within sequences of basalt, dolerite, or peridotite. Amphibole-plagioclase gabbro predominates, with grainsizes ranging up to very coarse (5 mm). Foliation is generally weak or absent. Two-pyroxene gabbro occurs in association with peridotite, and comprises bladed 5 mm clinopyroxene and equant <0.5 mm orthopyroxene with prominent plagioclase laths up to 8 mm long. The Forest Belle sill in the northwest contains plagioclase phenocrysts up to 5 cm diameter. Poikilitic enclosure of calcic plagioclase up to 3 cm diameter by hornblende (after pyroxene) oikocrysts up to 15 cm long occurs in some areas around Forest Belle Mine (Fig. 6). This gabbro is locally strongly foliated and lineated defined by 0.5-2 mm amphibole blades with plagioclase <0.4 mm and epidote <0.2 mm in a fine-grained matrix of recrystallised plagioclase.

Figure 6. Orthocumulate gabbro from near Forest Belle (AMG 568867). Poikilitic euhedral anorthite crystals are commonly enclosed in oikocrysts of former pyroxene (now amphibole). Coin ($2) 1 cm diameter.

Chemical metasedimentary rocks

Chert (Ac)

Reddish-brown to black and white, very fine-grained highly siliceous rock occurs along a topographically prominent ridge in the north of the sheet area. The rock type typically is brecciated with extensive hematite alteration, but has locally well banded quartz, jasper, and silica-iron oxide. The breccia clasts range in size up to 10 cm and contain fine-grained 0.1-mm equant quartz grains. The clasts are generally unfoliated, and the quartz grains show no undulose extinction. The breccia matrix contains 0.1-mm quartz and very fine-grained hematite. The rock type is on strike with siltstone around the Kurrajong Anticline hinge, which suggests that the rock is sedimentary, that is, chert. Exploration drilling beneath the surface ridges of chert, however, indicates the rock is in places poorly siliceous and finely foliated at depth.

Clastic metasedimentary rocks

Siltstone (Ash)

Fine to very fine-grained siliceous siltstone occurs in layers several metres thick between mafic-ultramafic volcanic flows, which can be traced over several kilometres. In the northwest and near Fifty One Mile Well, it forms units up to several hundred metres thick. The siltstone is usually laminated, and composed of very fine-grained quartz, feldspar, and mica.

Sandstone (Ass)

Medium to fine-grained well-bedded silicic sandstone occurs as thin beds between mafic and ultramafic volcanic flow units. The sandstone shows some graded bedding, basal scour structures, and truncated cross-bedding, which enable younging directions to be determined. Grains of quartz, plagioclase, and some rock fragments occur in a poorly sorted matrix of quartz, muscovite, and sericitised feldspar. These rocks commonly have a foliation defined by mica and feldspar alignment.

Pale grey to white, fine to very fine-grained, highly silicic quartzite occurs in a horizon about 1 m thick in the north of the mafic-ultramafic volcanic belt, at AMG 585820. The quartzite is poorly bedded and occurs between mafic volcanic flows. It is composed of fine-grained quartz with larger grains of sericitised feldspar, very fine-grained muscovite, and clinozoisite.

Quartz-feldspar muscovite schist also occurs sporadically in thin layers, characterised by <2-mm grains of sericitised feldspar in a fine-grained matrix of quartz, feldspar, apatite, and muscovite.

Gneiss

Gneiss (Ang)

Segregated quartzofeldspathic gneiss forms a 3-5 km-wide north-trending strip immediately east of the mafic-ultramafic volcanics (Figs. 7-10). The gneiss is composed largely of quartz-feldspar-biotite, with thin continuous interlayered hornblende-rich amphibolite bands up to 5 m thick. The mineral composition of the gneiss varies markedly. Away from areas of mylonitic overprint, the gneiss is composed of quartz, microcline, oligoclase,

Figure 7. Mylonitic shear band cutting gneiss foliation suggesting sinistral ductile movement (AMG 654757). Pencil 12 cm long.

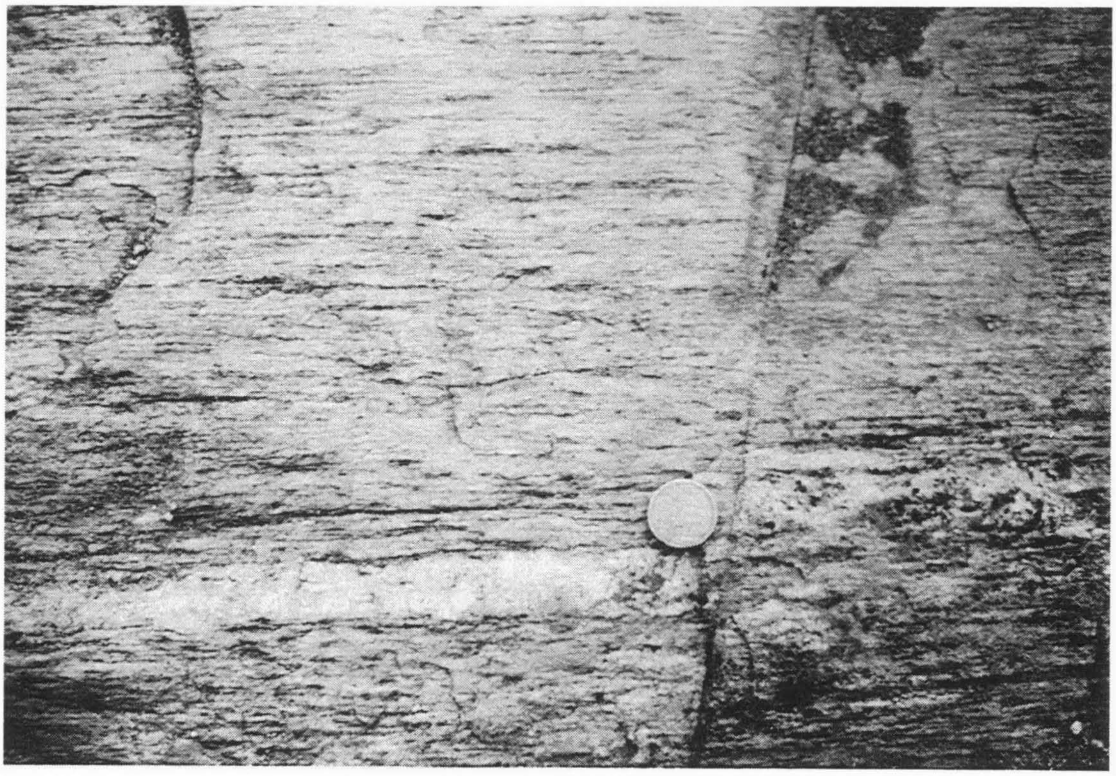


Figure 8. Strongly foliated (mylonitic) gneiss, displaced by a D_4 east-trending fracture (AMG 647573). Coin 1 cm diameter.

biotite, and muscovite. Segregation bands between 0.5-5 cm thick of feldspar and quartz alternate with more biotite-rich, generally finer-grained bands. Quartz commonly occurs as unstrained or slightly strained 1-2 mm grains in ribbons. Finer-grained quartz occurs with feldspar. Microcline grains are typically 0.2-2 mm, equidimensional to subrectangular and show rare zoning. Larger microcline

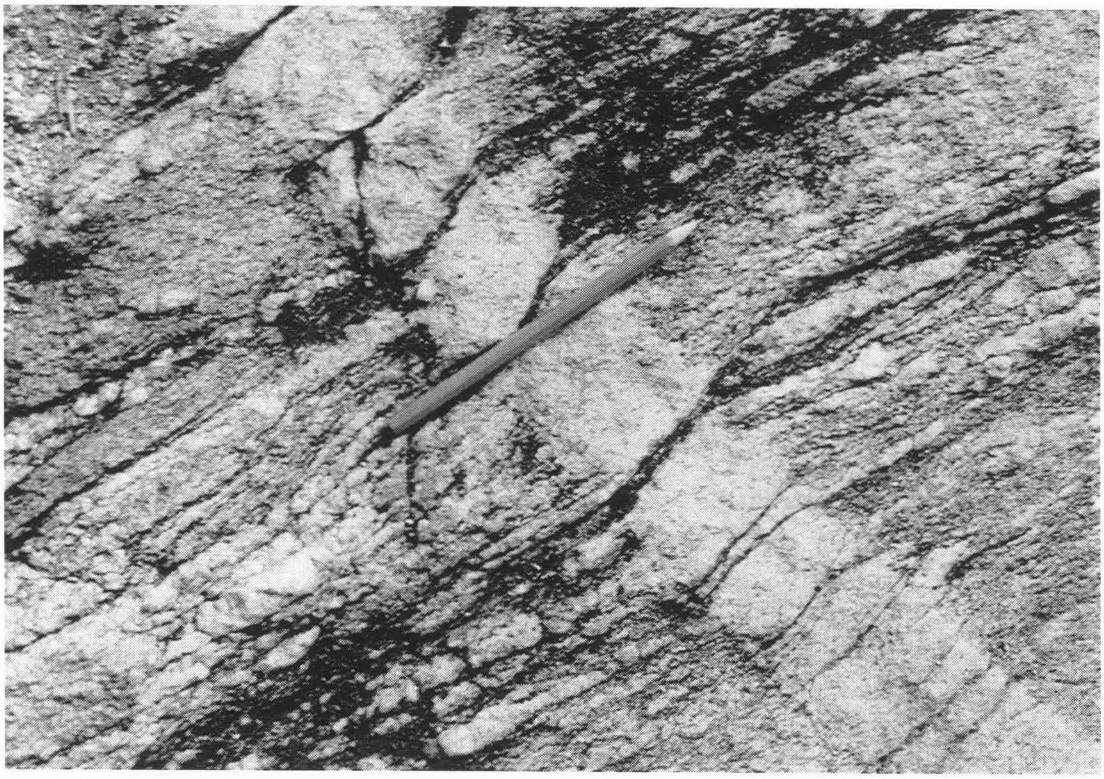


Figure 9. Aplite dyke cutting foliated and segregated gneiss (AMG 735373). Pencil 12 cm long.

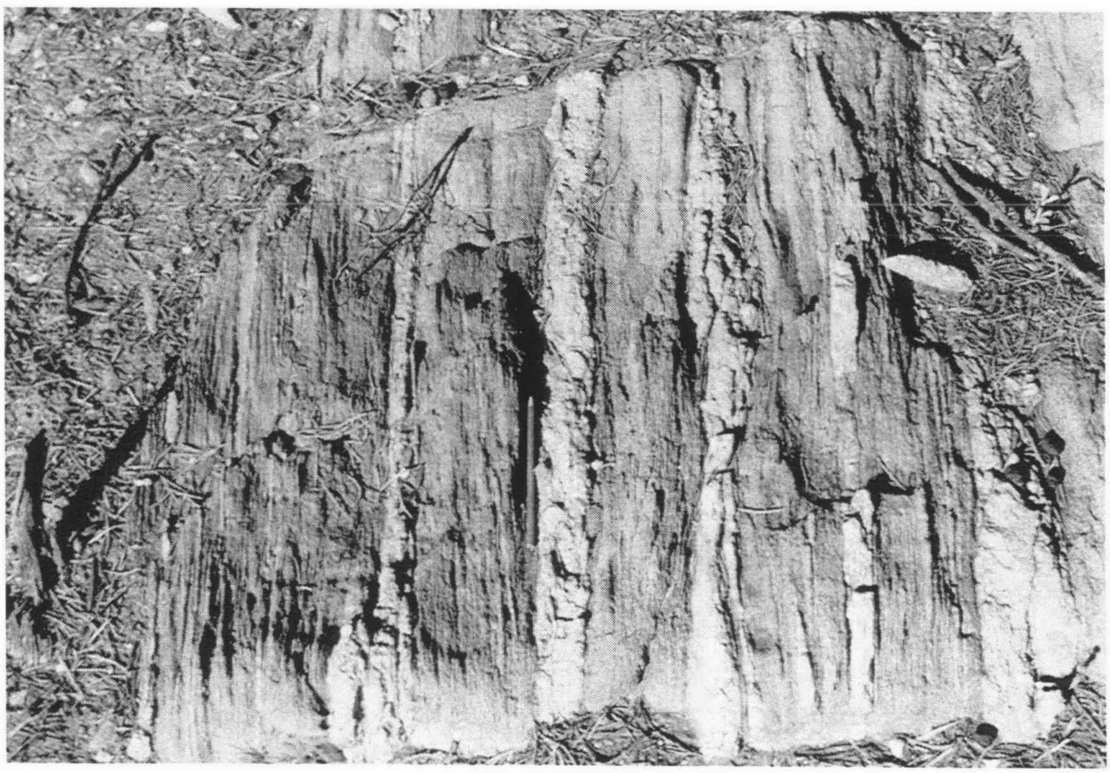


Figure 10. Strongly foliated and coarsely segregated gneiss (AMG 665487). Pencil 12 cm long.

grains commonly have adjacent equidimensional 100-400 μ subgrains occurring in monomineralic bands up to 2 mm wide parallel to foliation. The subgrains typically develop from dynamic recrystallisation of microcline during high ductile strain of the gneiss. Microcline porphyroclasts in some gneiss samples show bending and kinking of twin planes, indicative of moderately high temperature and strain.

One gneiss sample in the south (AMG 691344) comprises the metapelitic assemblage garnet-biotite-staurolite-K-feldspar-quartz. The garnet grains are equant, 0.1 mm diameter and appear to grow across foliation. The garnets are not obviously zoned, and have limited and randomly oriented inclusions of quartz and feldspar. Grain margins are sharp, and internal fracturing has not resulted in significant retrogression. Biotite is typically red-brown, forming thin 1 mm-long blades in semi-continuous monomineralic layers parallel to foliation. Pale yellow-brown staurolite forms subhedral grains up to 0.4 mm within garnet and biotite-rich layers. The assemblage suggests these rocks reached mid-amphibolite facies. Rutile needles in quartz are also indicative of high temperatures.

Cross-cutting quartz-muscovite shear bands (Fig. 7) suggest mylonitic ductile high strain occurred after peak metamorphism and early foliation development.

Granite (Agm, Agn)

Granite is the most common outcropping basement rock type, and probably underlies most of the Cainozoic cover (Fig. 3). Muscovite-biotite monzogranite occurs widely in the northeast and southwest. The monzogranite is massive, lacks xenoliths, and is typically coarse-grained and equigranular; in places it is porphyritic with centimetre-sized K-feldspar phenocrysts. The granite consists of 1-5 mm quartz, microcline and oligoclase, with accessory magnetite and apatite. Microcline grains are commonly perthitic, but generally contain less than 10% albite. Brown and green biotite occur in small fine-grained clots, commonly altered to chlorite and occurring with muscovite, apatite and magnetite. Flow-aligned K-feldspar megacrysts up to 5 cm long occur with 3-10 mm quartz-plagioclase-biotite in the southwest. Aplite dykes, coarse-grained quartz-feldspar sweats, and quartz veins occur sporadically without any apparent preferred orientation.

Foliated monzogranite (Agn) occurs in a north-trending strip several kilometres wide east of the gneiss near Kurrajong Outcamp. The rock is generally weathered, containing 2-8 mm equigranular quartz-plagioclase-K-feldspar with brown biotite defining a variably developed foliation. The monzogranite is not transitional into the gneiss (Ang) to the west as the contact has been narrowed to within several metres, but it may be transitional into the unfoliated monzogranite (Agm) to the east.

Lineated and foliated monzogranite in the northwest (AMG 570790 and 575885) has a stretching lineation defined by submillimetre thick ribbons of quartz, microcline, and biotite. Individual ribbons extend for several centimetres. In some places the lineation is very strong, and a foliation surface cannot be seen, imparting a pencil-like structure to the rock. These rocks contain subhedral-anhedral plagioclase <0.5-3 mm, commonly sericitised, with fine-grained 0.07-0.3 mm equant unstrained quartz. Microcline is generally fine-grained <0.1 mm, subrectangular, and has some curved or kinked twin planes. The microcline generally occurs as subgrains in bands adjacent to bands of plagioclase-quartz and quartz ribbons. Small <1 mm blades of brown biotite occur parallel to foliation, with rare muscovite and magnetite.

Granite in the centre and southeast was not examined.

Lithostratigraphy of Mount Ida greenstone belt

The mafic-ultramafic volcanics of the Mount Ida greenstone belt typically formed as relatively thin subhorizontal volcanic flows of considerable lateral extent, as demonstrated by the numerous thin interlayered sedimentary rocks. These flows were extensively intruded by dolerite and gabbro sills and dykes. The various volcanic flows and interlayered sedimentary rocks can be placed into local stratigraphic sequences, but these sequences generally lack lateral continuity and do not warrant formal stratigraphic status (Fig. 11).

The mafic volcanics in the northern half of BALLARD (Figs. 3, 11) form a layered sequence about 3 km thick, centred around Oberwyl Hill (AMG 582838). The sequence is dominated by tholeiitic basalt, with some dolerite, gabbro, chert, and sedimentary rock. The lowermost unit is a poorly exposed and weathered basalt occurring in the hinge of a major anticline (AMG 575725) cored by deformed granite (Fig. 11). Intrusive into the basalt is the distinctive porphyritic gabbro sill at Forest Belle (see below). Stratigraphically above the gabbro sill is amphibolitic basalt with a few thin bands (1-10 m) of quartzite, felsic schist, and chert. Vesicular basalt with occasional pillows occurs within the massive basalt.

A distinctive chert unit forms a virtually continuous ridge and photo lineament for 22 km in the northwest of BALLARD (Figs. 3, 11), and ranges in thickness from less than 1 m to 30 m. The chert shows some well defined red-brown and white sedimentary banding in places, but more commonly is massive. Many sections of the chert are brecciated, with angular fragments of chert cemented by black hematite-silica cement or fine-grained silica. The chert cannot be traced along strike across Bottle Creek, but a similar unit occurs on MOUNT MASON at approximately the same stratigraphic level.

The host rock of the Forest Belle gold mine (Fig. 11) is a 300 m to 2 km-thick sill of distinctive porphyritic anorthite gabbro, which may be laterally transitional into locally porphyritic dolerite 10 km south. The gabbro has large amphibole crystals (some exceeding 10 cm) with poikilitic enclosure of coarse (up to 5 cm) euhedral crystals of anorthite (AGM 570870). The porphyritic dolerite is characterised by euhedral to ovoid feldspar phenocrysts in a fine to medium-grained mafic matrix. The sill is probably laterally transitional between non-porphyritic gabbro and the porphyritic dolerite at Spotted Dog Hill.

The stratigraphic sequence described above cannot be extrapolated south across Bottle Creek (AMG 600670), implying the existence of a structural break (Fig. 11).

South of Bottle Creek, the lowermost stratigraphic unit is weathered and poorly exposed basalt up to 2 km thick, which may be equivalent to the basalt around Oberwyl Hill. This basalt is overlain by a sequence of layered cumulate ultramafic rocks. These include orthocumulate, mesocumulate, and harrisite, which occur in the hinge area of the Kurrajong Anticline (Figs 3, 11). Spinifex-textured komatiite and high-Mg basalt interlayered with tholeiitic basalt form an overlying stratigraphic sequence with a thickness of at least 6 km (Fig. 11). The sequence is well exposed around the Lake Ballard shoreline near Snake Hill, and includes interlayered dolerite sills and numerous thin sedimentary rock layers. The sedimentary layers are generally less than 10 m thick, silicic, and some have well preserved scouring, grading, and cross-bedding. Some layers can be traced over many kilometres despite their thinness and the presence of surrounding mafic and ultramafic volcanics.

Regional stratigraphic framework

The mafic-ultramafic volcanic stratigraphy of BALLARD has a number of common elements with stratigraphic successions in other areas in the Eastern Goldfields

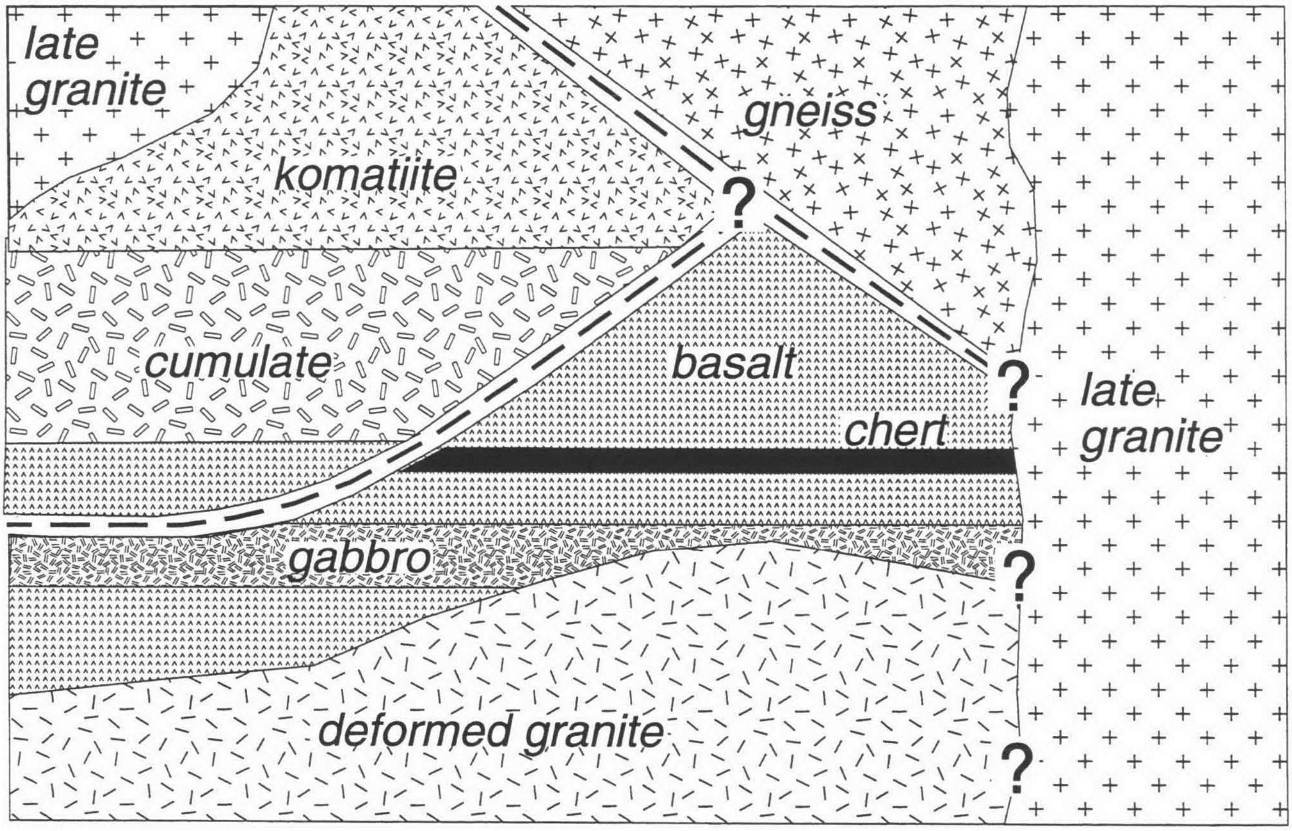


Figure 11. Schematic BALLARD stratigraphy. Faulted contacts shown with heavy dashed line.

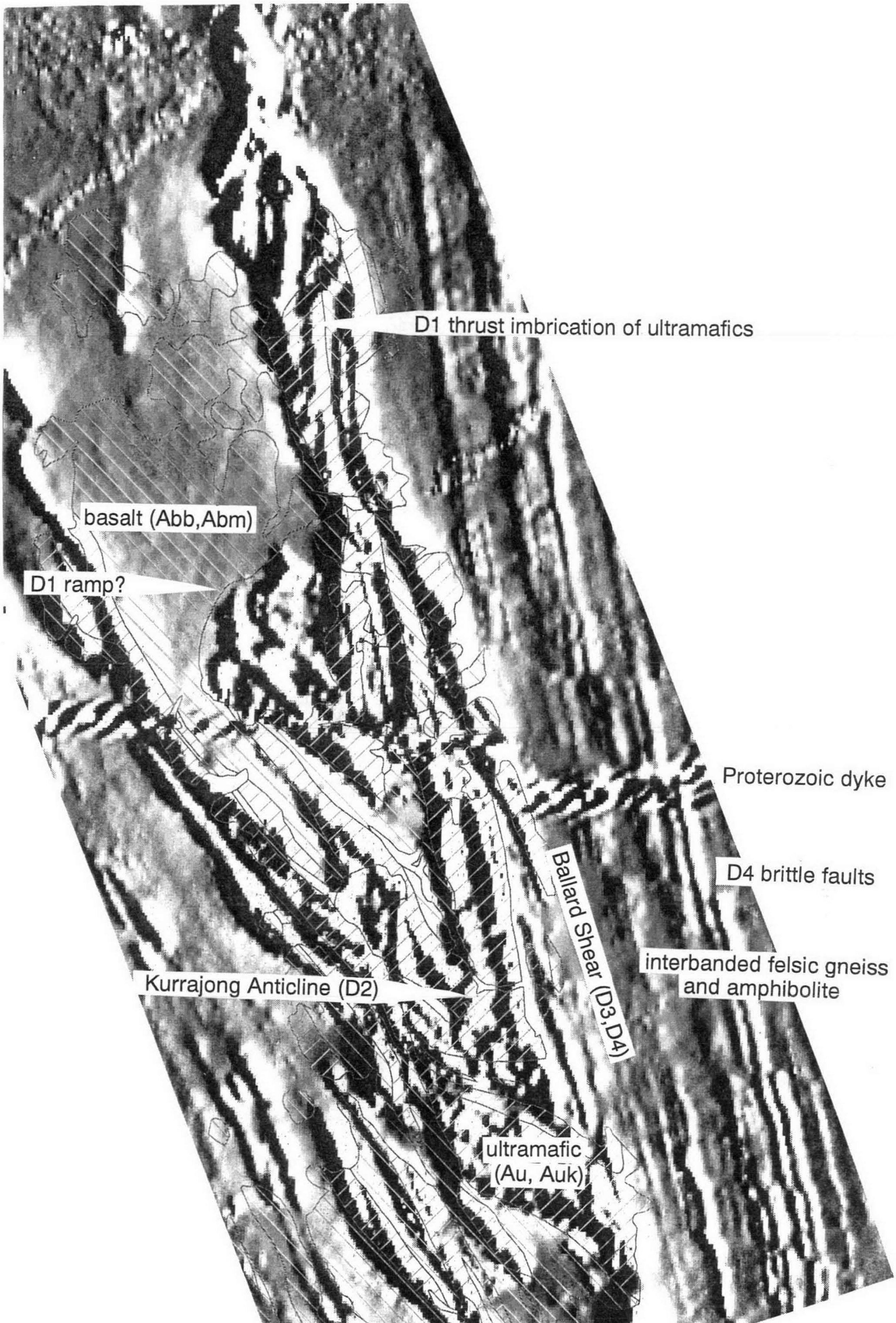
Province. The cumulate ultramafic rocks in the Kurrajong Anticline hinge have been correlated with the Walter Williams Formation (Hill & Gole 1991). The type area of the Walter Williams Formation is near Ora Banda, about 100 km southeast of the Kurrajong Anticline ultramafic rocks (Witt 1990). The cumulate ultramafic rocks therefore could be a key regional stratigraphic marker unit. Swager et al. (1990) have extended stratigraphic correlations across several domains within the Kalgoorlie Terrane of the southern sector of the Eastern Goldfields. The high-Mg basalt lying stratigraphically above the cumulate ultramafic rocks can also be correlated across the Kalgoorlie Terrane. The basalt sequence around Oberwyl Hill, however, is difficult to correlate, given the unit's uncertain stratigraphic position (Fig. 11). Within the Kalgoorlie Terrane, basalt units with minor dolerite and/or gabbro sills occur above and below the ultramafic marker units. The BALLARD stratigraphic succession is relatively low in the Kalgoorlie Terrane stratigraphic scheme, and lacks the upper units such as the felsic volcano-sedimentary Black Flag Group.

Structure

Four discrete deformation events have been identified in BALLARD. Two structural elements dominate the present geometry (Figs. 3, 12, 13); the D_2 Kurrajong Anticline, and the D_3/D_4 Ballard Shear, but there is evidence for early subhorizontal D_1 deformation also.

D_1 thrusting and tight folding

The geometry of the basaltic and cumulate ultramafic rocks within the hinge area of the D_2 Kurrajong Anticline (AMG 620580) suggests early low-angle D_1 thrust deformation (Fig. 12). Restoration of the fold to a pre-D_2 geometry (Fig. 14) shows a number of lateral stratigraphic discontinuities, the most conspicuous of which is the termination of cumulate ultramafic rocks against the chert and basalt across Bottle Creek. The cause of the termination is pre-D_3 since the Ballard Shear (D_3) is not greatly displaced across Bottle Creek. Other evidence for D_1 thrusting within the Kurrajong Anticline hinge area (Fig. 12), such as the termination of ultramafic units against a basaltic ramp-like structure (AMG 595595) and gently oblique internal imbrication of the mafic-ultramafic metavolcanics (AMG 610630), suggests that the Bottle Creek termination structure is probably pre-D_2. Further evidence for early pre-D_2 deformation includes a macroscopic very tight to isoclinal, asymmetric D_1 fold defined by interlayered basaltic and komatiitic volcanics (AMG 640470). The fold is transected by the D_2 axial plane foliation. The entire mafic-ultramafic volcanic sequence is strongly foliated, but only rarely can more than one fabric be observed, probably because the later dominant (S_2) fabric has obliterated earlier fabrics. The northern part of the mafic metavolcanic sequence and the granite to the west have a prominent south-plunging lineation (Fig. 15). The contact between these mafic metavolcanics and the lineated granite is strongly sheared, and this foliation is folded around the Kurrajong Anticline. Rare crenulation by D_2 minor fold axial plane cleavage suggests that the foliation and lineation formed during early penetrative ductile deformation. The early foliation weakens to the south and does not appear to follow the strata around the Kurrajong Anticline.


D1 thrust imbrication of ultramafics
basalt (Abb,Abm)
D1 ramp?
Proterozoic dyke
Ballard Shear (D3,D4)
D4 brittle faults
interbanded felsic gneiss
and amphibolite
Kurrajong Anticline (D2)
ultramafic
(Au, Auk)

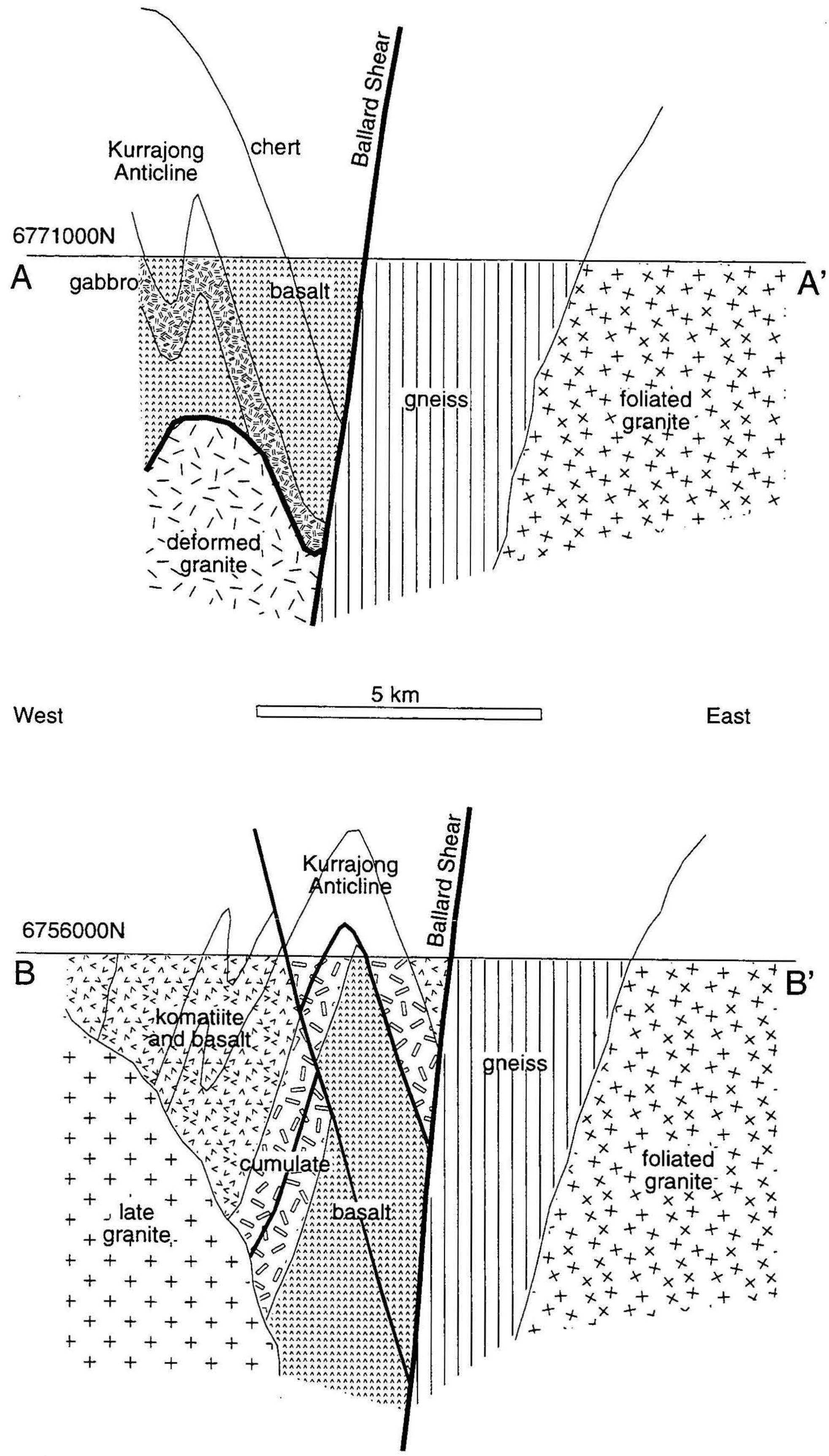


Figure 12 (facing page). Detailed aeromagnetics of the Kurrajong Anticline hinge region. East-west gradient enhanced image from open-file digital data held by the Western Australia Department of Mines.

Figure 13 (above). Cross-sections across the Mount Ida metavolcanic belt. Section lines shown in Figure 3.

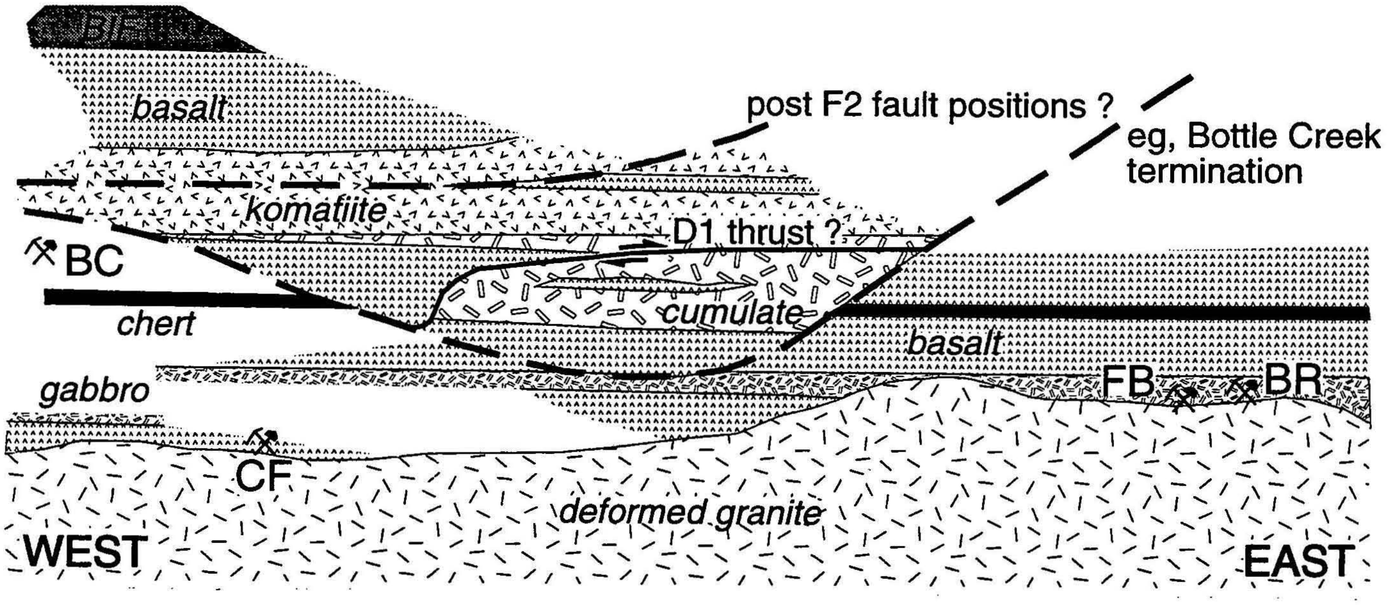


Figure 14. Restored section across the Kurrajong Anticline. Approximate stratigraphic positions of Forest Belle (FB), Boudie Rat (BR), Copperfield (CF), and Bottle Creek (BC) mines are shown.

Kurrajong Anticline (D_2)

The Kurrajong Anticline is a large upright tight D_2 fold with a steep axial plane foliation (Figs. 13, 16). The axial plane of the fold can be traced over 20 km (AMG 570730 to 650530), and the regional fold axis plunges approximately 30° to 165°. Fold facing has been determined from the igneous cumulate layering (Hill & Gole 1991); the numerous thin sedimentary layers yield contradictory younging directions attributed to intrafolial (D_1) folding. To the north (down profile), the anticlinal structure is complicated by smaller wavelength folds (Fig. 13), and strongly lineated granite occurs in the core of the anticline. This granite has a weak foliation (S_1), which is folded around the Kurrajong Anticline.

Ballard Shear (D_3-D_4)

The Ballard Shear is a major D_3 strike-slip ductile shear zone which juxtaposes mafic-ultramafic volcanics against quartzofeldspathic gneiss, and truncates the eastern limb of the Kurrajong Anticline (Figs. 3, 12, 13). The shear zone is characterised by enhanced foliation and intensity of planarity within the gneiss towards the contact with the mafic-ultramafic metavolcanics (Figs. 7-10), accompanied by reduction in grainsize typical of mylonitic deformation. The gneiss/mylonite foliation typically dips very steeply west, with a well developed subhorizontal to gently south-plunging stretching lineation defined by quartz and mica (Figs. 15-16). Composite planar fabrics indicate considerable simple shear, although few asymmetric microstructural criteria have been found (e.g., Fig. 7). The curvature and attenuation of the eastern limb of the Kurrajong Anticline, and the slight anticlockwise rotation of the Kurrajong Anticline axial trace into the Ballard Shear (Fig. 12), suggest sinistral movement of the shear zone. The original spatial and age relationships between the gneiss and the mafic-ultramafic volcanics remain uncertain. There is no direct evidence for significant dip-slip movement across the Ballard Shear. Steeply dipping mineral lineations are not apparent within the shear zone, although steeply plunging mineral lineations occur in less deformed gneiss farther west indicating that penetrative D_3 ductile strike-slip might have obliterated any earlier fabric in the shear zone. Contrasts in metamorphic grade between the gneiss and the metavolcanics cannot easily be constrained because of a lack of reliable geobarometric mineral assemblages. Thus the pre-D_3 relationship between the gneiss and the mafic-ultramafic volcanics remains conjectural. The amount of strike-slip displacement is also uncertain. Mafic-ultramafic metavolcanics do not crop out on the east side of the Ballard Shear within BALLARD. The Lawlers-Agnew mafic-ultramafic sequence 100 km to the north occurs to the east of the Waroonga Shear, a possible extension of the Ballard Shear. The Ballard Shear is probably the northward extrapolation of the Zuleika Shear (Swager et al. 1990), and the nearest mafic-ultramafic metavolcanic sequence occurring east of the Zuleika Shear is near Ora Banda, 70 km to the southeast. While both the Lawlers-Agnew and Ora Banda mafic-ultramafic volcanics have very similar rock types and stratigraphy to the mafic-ultramafic volcanics of BALLARD, a pure strike-slip separation of 50-100 km along the Ballard Shear is unlikely, given the relatively mild mylonitisation fabric within the shear zone. A small component of oblique-slip, or a significant pre-D_3 dip-slip movement along the Ballard Shear could drastically reduce the strike-slip component required, given the shallow fold plunge in the Lawlers-Agnew and Ora Banda mafic-ultramafic metavolcanics.

Small-displacement brittle faults adjacent to the Ballard Shear sinistrally offset magnetically defined banding within the gneiss (Figs. 8, 13). These faults are interpreted to be reidel shears that formed during late D_4 dextral movement on the Ballard Shear.

Timing of granite emplacement and deformation

Foliated granite plutons east of the Ballard Shear are probably intrusive into the gneiss (Figs. 3, 13), and this is supported by numerous aplitic dykes (Fig. 9) near the contact (AMG 735375). The relationship of the foliated granite to the more abundant unfoliated granite which dominates the eastern part of BALLARD is not clear, although their similar mineral composition suggests that the foliated granite is part of the same pluton with varying degrees of foliation development superimposed. Unfoliated granite intrudes and hornfelses mafic-ultramafic volcanics

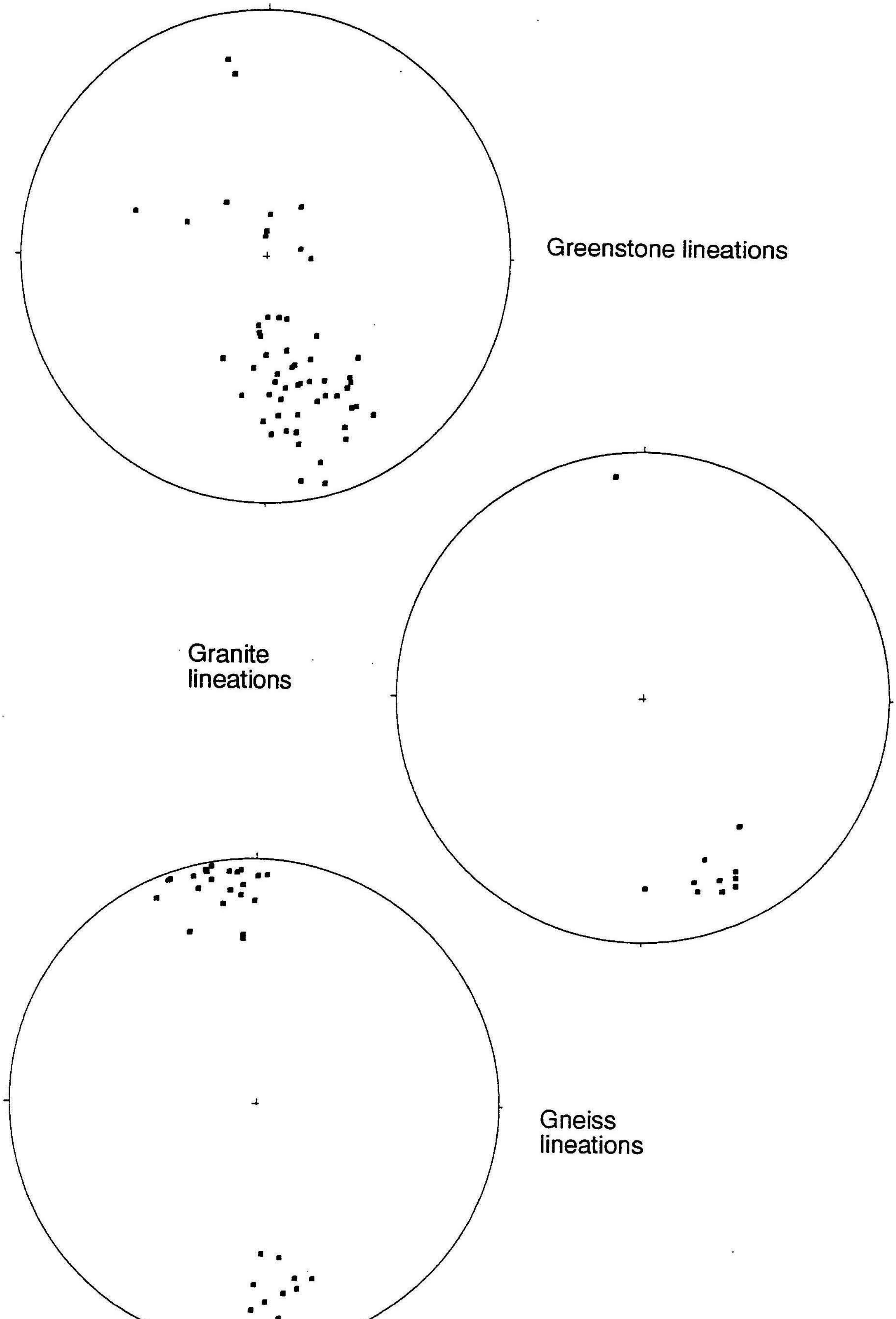


Figure 15. Stretching lineations from metavolcanic, granite, and gneissic rocks. Stereonets are equal area, lower hemisphere projections. Note the overall subhorizontal to shallow south plunge of the D_1 stretching lineations is similar to the southward plunge of the D_2 Kurrajong Anticline.

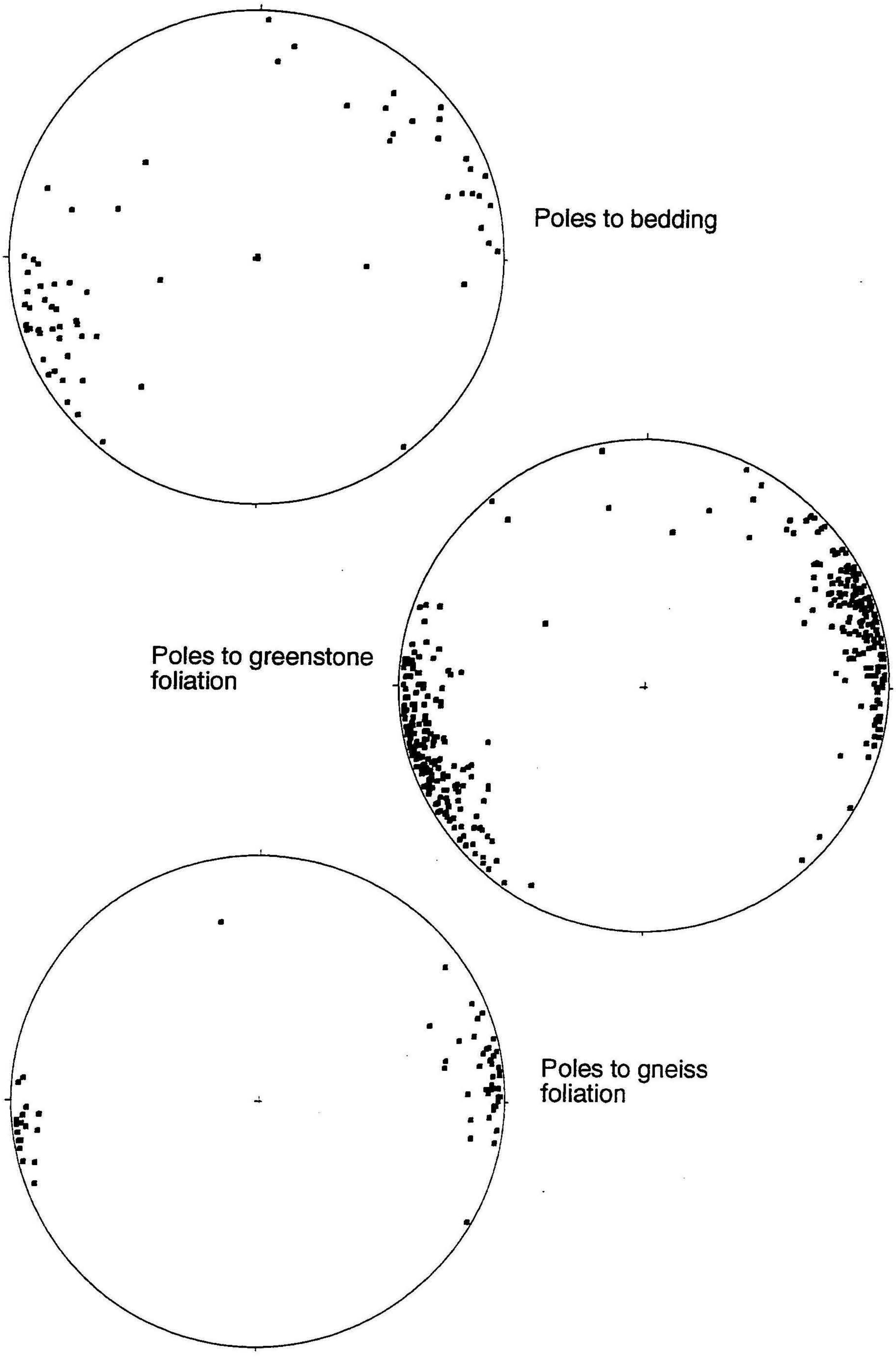


Figure 16. Poles to primary layering and foliation from metavolcanic and gneissic rocks. Stereonets are equal area, lower hemisphere projections.

in the southwest (AMG 640385).

In the northwest, strongly lineated and foliated granite in the core of the Kurrajong Anticline (Figs. 3, 13; AMG 570790) crosses the mafic volcanic layers, indicating a pre-syn-D_2 intrusive age.

Dyke intrusion

Two periods of mafic dyke intrusion have been identified; pre-tectonic and post-tectonic. The pre-tectonic dykes are coeval with emplacement of various mafic sills and volcanic flows, and in some instances can be followed into sills. These dykes are penetratively foliated. Numerous post-tectonic, east-trending dolerite and porphyritic basalt dykes have intruded all other basement rocks and structures. The dykes in many places intruded along pre-existing east-west brittle fractures, showing complex bifurcations and offsets. A major reversely polarised magnetic anomaly trending east-west across the centre of BALLARD is due to a very thin (less than several metres) and discontinuous porphyritic basalt dyke. Undeformed dykes of this orientation have been dated as mid-Proterozoic elsewhere in the Eastern Goldfields (Hallberg 1987).

Regional structural framework

BALLARD has many structural features in common with other areas of the Eastern Goldfields. D_1 thrust imbrication has been recognised in the Kambalda region, where major duplexing has been inferred (Swager & Griffin 1990), and in the Leonora region, where gently dipping penetrative foliation has been identified (Williams et al. 1989). Thrusting is probably widespread in the Eastern Goldfields, but poor outcrop and subsequent deformation hinders its recognition in other areas. The D_2 Kurrajong Anticline is part of regional east-west shortening which resulted in numerous upright open-tight folds (Swager et al. 1990). Similarly, the Ballard Shear is one of many north-striking D_3 strike-slip shear zones. The Ballard Shear can be linked with the Waroonga Shear to the north and the Zuleika Shear to the south, making the combined shear zone one of the more continuous in the Eastern Goldfields Province. The Koolyanobbing Shear about 100 km west in the Southern Cross Province is a probable contemporary structure of similar craton-scale dimensions (Libby et al. 1991). The D_4 reactivation of the Ballard Shear is similar to late dextral and relatively brittle deformation in other shear zones within the Eastern Goldfields (Mueller et al. 1988).

Geochemistry

Twenty-two samples from a broad spectrum of rock types from BALLARD have been analysed by the whole-rock XRF method for major and trace elements. The samples were collected from granite (5 analyses), gneiss (2), basalt (1), dolerite (2), gabbro (3), high-Mg basalt (3), komatiite (2), olivine cumulate (2), amphibolite (1), and a Proterozoic dyke (1).

The granite samples have very similar chemical compositions (Figs. 17-19). One exception (90967099.9) may have some amphibolite contamination, but it also has a similar composition to lineated granite analysed from near Perrinvale 50 km to the west (90967049.1, unpublished ROCKCHEM data). Major element concentrations are typical of granites from the Eastern Goldfields (Archibald et al. 1981). The granites are slightly more potassic with lower CaO, Na_2O and MgO than averaged data from Bettenay (1977). Trace element spidergrams (Fig. 19) show two to three orders of Pb, Rb, U, Ba, and Th enrichment

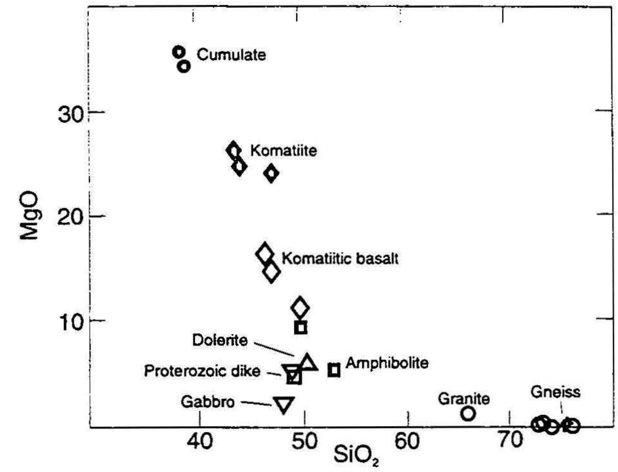


Figure 17. MgO vs SiO_2 for 22 analysed rocks from BALLARD.

relative to primordial mantle, and relatively little enrichment of Sr, Nd, P, Zr, Ti, and Y. The gneiss samples fall within Eastern Goldfields Province-defined granite fields, but have a flatter trace-element concentration range and are less enriched than the granite, particularly in U.

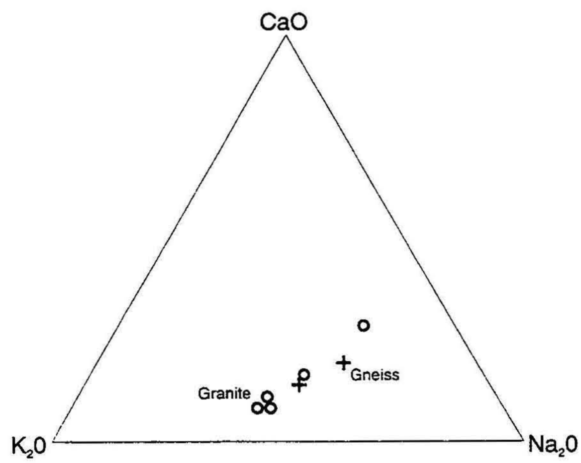


Figure 18. CaO vs K_2O vs Na_2O for seven granite and gneiss samples from BALLARD.

The cumulate-textured rocks have very low SiO_2 (<40%) with more than 34% MgO, typical of peridotites (Fig. 18). The komatiites are more variable; some are clearly ultramafic with less than 45% SiO_2, and MgO around 25%. High-Mg basalts are characterised by 11-17% MgO with SiO_2 contents between 45-50%. The mafic-ultramafic volcanics have one to two orders of trace-element enrichment relative to primordial mantle (Fig. 20), with relatively large Cr and Ni concentrations. The cumulates, komatiites, and high-Mg basalts are particularly enriched in U, and several samples show Sr and Ba depletion. Ti/Zr ratios for the komatiites and high-Mg basalts are slightly below chondritic values. These differ from similar rocks analysed near Kambalda (Redman & Keays 1985) which may reflect variably depleted source mantle regions. The Proterozoic dyke consistently shows two to three orders of trace-element enrichment relative to primordial mantle (Fig. 20).

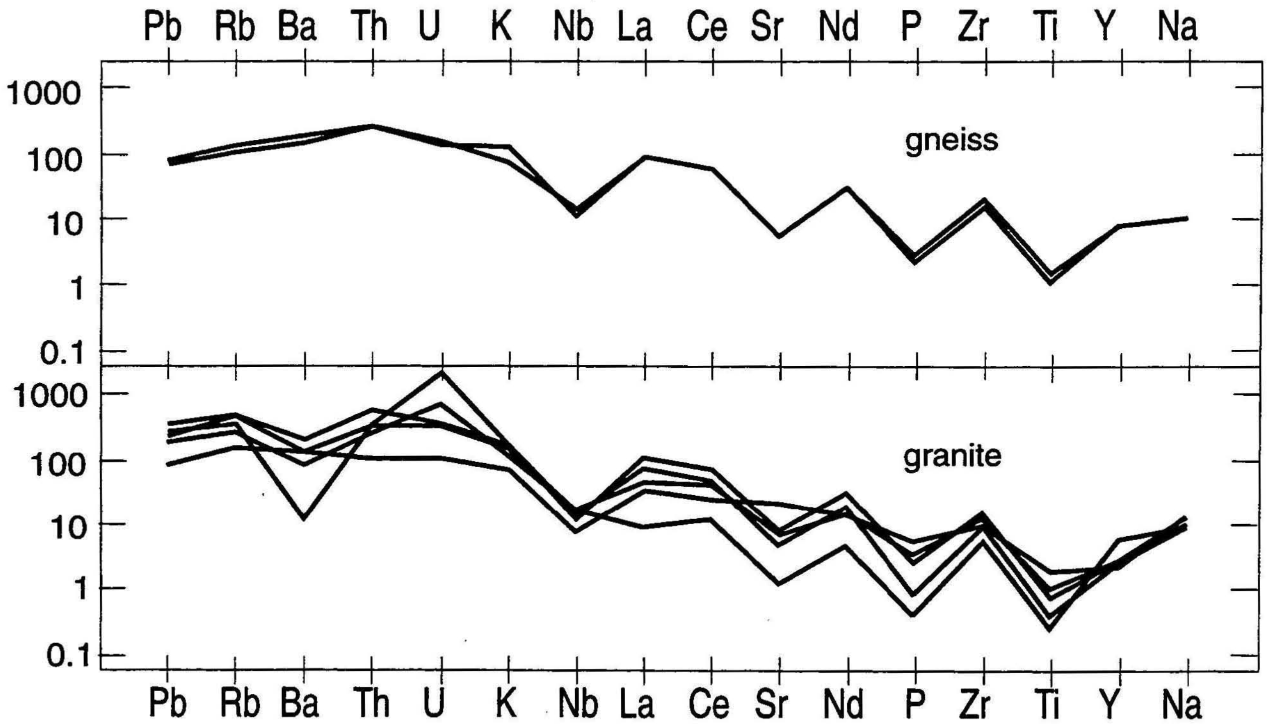


Figure 19. Trace element spidergrams for seven granite and gneiss samples from BALLARD (primordial mantle normalised).

Proterozoic geology

Mafic dykes (Pdy)

Numerous east-trending dolerite dykes less than 1 m wide intrude the mafic-ultramafic volcanics, granite, and gneiss. The dykes are undeformed, intrude across deformed mafic and ultramafic volcanics, and are probably Proterozoic in age. A prominent reversely polarised magnetic anomaly occurring along an east-west trend across the centre of the map (AMG 610590 and 650580) appears to be due to a very thin porphyritic basalt dyke which was not found in situ, but surface float narrowed its position to within several metres.

Cainozoic geology

Sand plain with red or yellow dunes (Czs) and clay-silt-sand colluvium (Cza) are the most extensive deposits, and overlie granite. Colluvial gravel (Czc), laterite (Czl), and lateritic gravel (Czf) are most abundant in the west of the sheet area on the flanks of the mafic-ultramafic ridge, and rarely attain a thickness greater than 4 m; granitic colluvial gravel is also abundant in the northeast. Coarse quartz-feldspar sand (Czg) occurs over granite in the centre of the area. Stabilised dunes of quartz and gypsum (Czd) and clay flats with dune sand (Czb) surround and form islands in the normally dry evaporitic playa (Czp) of Lake Ballard. Sandy colluvium with limonitic pisoliths (Czcl) overlies granite in the northwest. Widely scattered patches and breakaways of silcrete (Czz, Czzg) overlie kaolinised granite. Quartz-rich talus (Czq) forms an apron around a large quartz vein in the northwest. Ephemeral watercourses have associated alluvial channel deposits (Qa). Claypans (Qac) have formed among the quartz and gypsum dunes in the southwest.

Economic Geology

Mining in BALLARD has yielded relatively little gold, in spite of exploration of most of the mafic-ultramafic volcanic sequence. Forest Belle/Boudie Rat (201 kg Au at an average grade of 18 g/t), Ida (136 kg at 36 g/t), Golden Ridge (36 kg at 36 g/t), and Golden Vale (41 kg at 17 g/t) mines have been the largest historical producers (Table 1).

The Forest Belle, Boudie Rat, and Ida mines occur in strongly sheared Forest Belle gabbro within 200 m of the Copperfield granite. The Golden Ridge mines occur within metabasalt and dolerite. These mines, as well as Madhatter, occur in subparallel subsidiary shears to the Ballard Shear, which crops out 150-200 m to the east. The Golden Vale mines are hosted in sheared dolerite and basalt. Numerous small workings occur throughout the northern half of the mafic-ultramafic volcanic sequence (Fig. 2), and are hosted within most rock types in the area. Many workings occur within relatively sheared rock types, adjacent to the Copperfield granite, and along minor shears near the Ballard Shear zone.

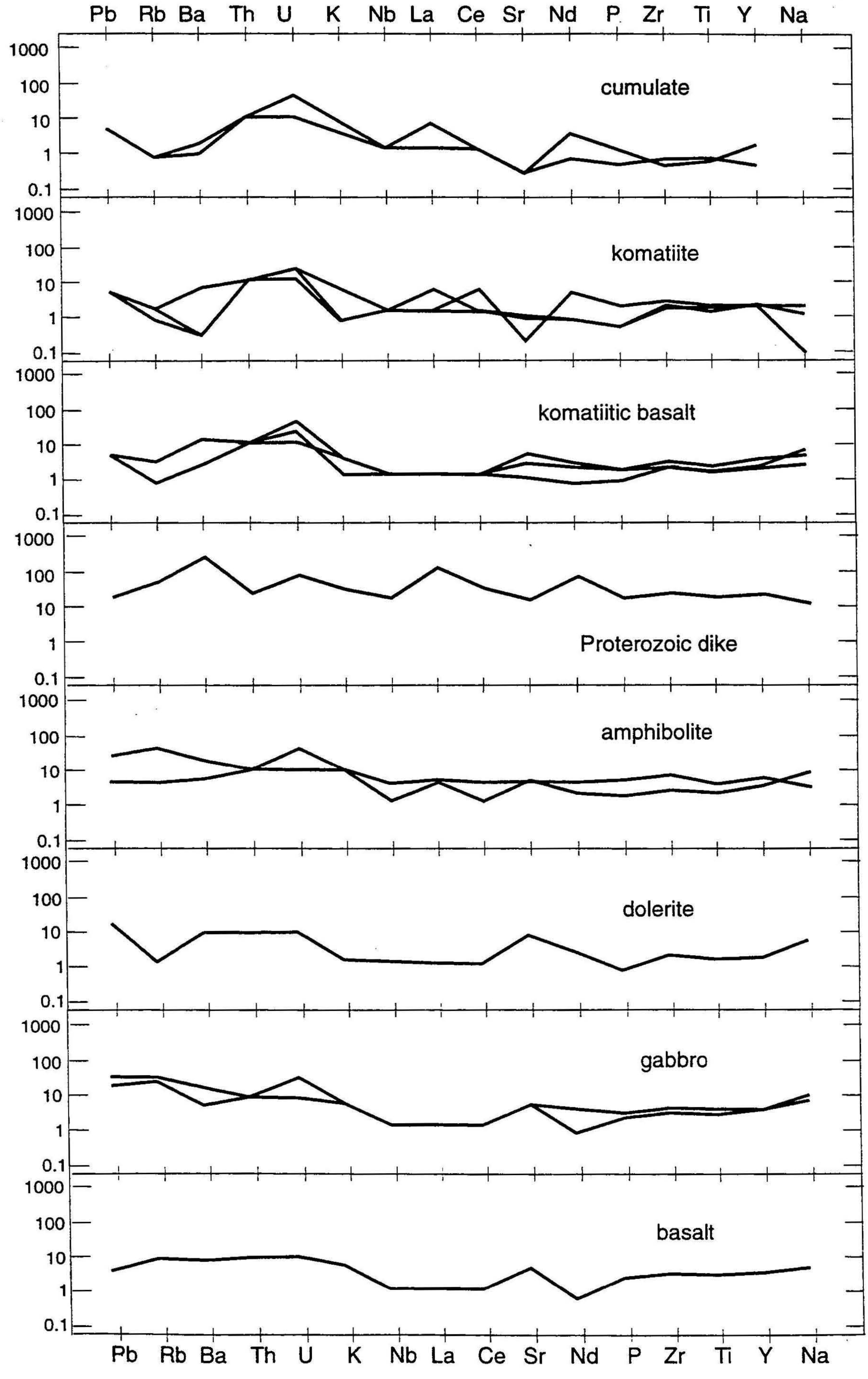


Figure 20. Trace-element spidergrams for olivine cumulate, komatiite, high-Mg basalt, basalt, gabbro, dolerite, amphibolite, and a Proterozoic dyke from BALLARD (primordial mantle normalised).

Table 1. Gold production statistics, BALLARD

Name	*Ore (t)*	*Gold (kg)*	*Grade (g/t)*	*Ore (t)*	*Gold (kg)*	*Grade (g/t)*
Rio Tinto/Mystery	3879.3	94.39	24.3			
Forest Belle/Forest Belle North/Wild Rose	3246.8	79.67	24.5			
Boudies Nest No. 1 North/Bungarra	2951.9	14.69	5.0			
Mt Ida Consolidated	484.7	3.98	8.2			
Boudie Rat/Boudie/Boudie G.M.	159.0	1.04	6.6			
Boudies Nest/Davy Die	338.6	6.80	20.1	11060.2	200.57	18.1
Ida	1468.2	39.24	26.7			
The Ida	1382.8	62.07	44.9			
Mount Ida West	404.4	19.03	47.1			
Ida Gem	514.6	15.37	29.9	3770.0	135.71	36.0
Golden Ridge North	367.8	7.66	20.8			
Golden Ridge	1462.1	28.17	19.3	1829.9	35.84	19.6
Golden Vale	69.3	4.04	58.2			
Sandstone	785.4	19.25	24.5			
Temora	1430.9	12.58	8.8			
Lucknow	140.2	5.32	37.9	2425.9	41.19	17.0
Madhatter	121.0	3.69	30.5			
Elsie May	1693.1	34.24	20.2			
Total	22282.9	451.22	20.2			

References

Archibald, N.J., Bettenay, L.F., Bickle, M.J., & Groves, D.I., 1981. Evolution of Archaean crust in the Eastern Goldfields Province of the Yilgarn Block. In Glover, J.E., Groves, D.I. (editors) Archaean Geology. Geological Society of Australia Special Publication 7: 491-504.

Bettenay, L.F., 1977. Regional geology and petrogenesis of Archaean granitoids in the southeastern Yilgarn Block, Western Australia. Unpublished PhD thesis, University of Western Australia.

Gibson, C.G., 1907. The geology and mineral resources of Lawlers, Sir Samuel, and Darlot (East Murchison Goldfield), Mount Ida (North Coolgardie Goldfield), and a portion of the Mount Margaret Goldfield. Western Australia Geological Survey Bulletin 28.

Hallberg, J.A., 1987. Postcratonization mafic and ultramafic dykes of the Yilgarn Block. Australian Journal of Earth Sciences 34: 135-149.

Hill, R.E.T., & Gole, M.J., 1991. Layered komatiitic rocks at Kurrajong. In Barnes, S.J., & Hill, R.E.T. (editors) Mafic-ultramafic Complexes of Western Australia. Geological Society of Australia (W.A. Division) Excursion Guidebook No. 3: 35-44.

Kriewaldt, M., 1970. Menzies 1:250,000 Geological Series - Explanatory Notes. Bureau of Mineral Resources, Geology and Geophysics, Canberra.

Libby, J., Groves, D.I., & Vearncombe, J.R., 1991. The nature and tectonic significance of the crustal-scale Koolyanobbong shear zone, Yilgarn Craton, Western Australia. Australian Journal of Earth Sciences 38: 229-245.

Mueller, A.G., Harris, L.B., & Lungan, A., 1988. Structural control of greenstone-hosted gold mineralization by transcurrent shearing: A new interpretation of the Kalgoorlie Mining District, Western Australia. Ore Geology Reviews 3: 359-387.

Swager, C.P., & Griffin. T.J., 1990. An early thrust duplex in the Kalgoorlie-Kambalda greenstone belt, Eastern Goldfields Province, Western Australia. Precambrian Research 48: 63-73.

Redman, B.A., & Keays, R.R., 1985. Archaean basic volcanism in the Eastern Goldfields Province, Yilgarn Block, Western Australia. Precambrian Research 30: 113-152.

Swager, C.P., Griffin, T.J., Witt, W.K., Wyche, S., Ahmat, A.L., & Hunter, W.M., 1990. Geology of the Archaean Kalgoorlie Terrane: An explanatory note. Geological Survey of Western Australia Record 1990/.

Tomich, S.A., 1956. Summary report on the geology of portion of the Mt. Ida District, North Coolgardie Goldfield. Western Australia Geological Survey Report for 1953: 18-20.

Williams, P.R., Nisbet, B.W., & Etheridge, M.A., 1989. Shearzones, gold mineralization and structural history in the Leonora district, Eastern Goldfields Province, Western Australia. Australian Journal of Earth Sciences 36: 383-403.

Young, G.A., & Tipper, D.B. 1964. Menzies and Leonora airborne magnetic and radiometric survey W.A. 1964. Bureau of Mineral Resources, Geology and Geophysics Record 1966/15.

Witt, W.K., 1990. Geology of the Bardoc 1:100,000 Sheet, Western Australia. Geological Survey of Western Australia Record 1990/14.

Woodward, H.P., 1902. Western Australia Geological Survey Annual Progress Report for the year 1901: 12-13.