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Abstract

BALLIMORE and SANDALWOOD 1:100 000 Sheet areas are in the north of the Eastern Goldfields Province of the Archaean Yilgarn Craton of Western Australia. They include parts of the Mount Fisher, Dingo Range, and Lake Violet greenstone belts. These comprise, in decreasing order of abundance: tholeiitic basalt, shale and siltstone, ultramafic rocks, felsic volcanic rocks, and chert, all metamorphosed to greenschist facies. Large regions of granite and granitic gneiss separate the greenstone belts. A belt of calc-silicate gneiss and iron formation in the northwest of BALLIMORE is called the Bartletts Bore greenstone belt. Mafic dykes which are probably Palaeoproterozoic cut the Archaean rocks.

Palaeoproterozoic sedimentary rocks of the Earaheedy Basin (Nabberu Province) unconformably overlie the Archaean rocks and mafic dykes in the northeast of BALLIMORE. They include sandstone and conglomeratic sandstone of the basal Yelma Formation; iron formation, siltstone, and sandstone of the Frere Formation; limestone, shale, and siltstone of the Windidda Formation; and sandstone and siltstone of the Wandiwarra Formation at the top. Total thickness of the sequence is estimated at 700 m. Conglomeratic sandstone outliers a few metres thick in the east of BALLIMORE are inferred to be unconformable on the Palaeoproterozoic sequence, and are assigned to the Permian Paterson Formation of the Officer Basin.

Interpretation of aeromagnetic, gravity, and γ-ray spectrometric data has provided a solid-geology map of BALLIMORE and SANDALWOOD. These data reveal the boundaries of the greenstone belts, major shear zones both along their margins and cross-cutting them, large oval composite masses of granitic gneiss-migmatite-granite (which make up the major part of SANDALWOOD), a large elongate body of banded gneiss (southwestern BALLIMORE), and discrete granite plutons (mainly in central and northwestern BALLIMORE). Several point-source magnetic anomalies may be caused by small intrusions such as syenite, kimberlite, or carbonatite. Numerous easterly and north-northwesterly-striking major dykes, probably Palaeoproterozoic, are revealed by the magnetic data.

The alignment of the major shear zones and the shapes of the granitic bodies suggest that the Archaean deformation apparent from the aeromagnetic data was mainly sinistral strike-slip shear.

γ-ray spectrometric data mainly show variations in regolith materials derived from the underlying Archaean bedrock. Two broad types of granite are distinguished, corresponding to Low-Ca plus syenitic types and High-Ca plus high-field-strength-element granites, respectively. The γ-ray data also delineate large areas of laterite and silcrete on kaolinised granite concealed beneath aeolian and colluvial sediments less than 0.5 m thick.

Mineral deposits include the Mount Fisher gold deposit in the southeast, which produced 852 kg of gold between 1937 and 1989. The setting of this deposit is unusual for the Eastern Goldfields, in that it is confined to a chert band that extends north and south of the mine for 10 km. Other small abandoned gold mines are located near Mount Fisher, and in the southwest (Lake Violet greenstone belt).

Much of the area's greenstone is under cover and under-explored, so there is potential for future gold discoveries. The potential for economic nickel deposits is low; ultramafic rocks are only a minor component of the greenstones in the area, and where exposed are poor in olivine. Some point-source magnetic anomalies may be caused by kimberlite, suggesting that there is potential for diamonds.

Contents

Introduction

A geological survey of BALLIMORE and SANDALWOOD 1:100 000 Sheet areas, Western Australia (Fig. 1), was carried out by D.H. Blake in 1995, and a geophysical interpretation of the same sheet areas was completed by A.J. Whitaker and A. Sedgmen in 1996. This work was part of the Eastern Goldfields National Geoscience Mapping Accord (NGMA) Project of the Australian Geological Survey Organisation (AGSO) and the Geological Survey of Western Australia (GSWA). A main aim of the project was to aid mineral exploration in the area by producing new geoscientific maps and data-sets based on integrated studies of geology, airborne geophysics (magnetics, γ-ray spectrometrics), gravity, geochemistry, and geochronology.

BALLIMORE is bounded by latitudes 26° 00′ S and 26° 30′ S and SANDALWOOD by latitudes 26° 30′ S and 27° 00′ S; both are bounded by longitudes 121° 00′ E and 121° 30′ E. The two sheet areas form the eastern part of the Wiluna 1:250 000 sheet area, and cover part of the Eastern Goldfields province of the Archaean Yilgarn Craton (Fig. 1). BALLIMORE also includes, in the northeast, part of the Palaeoproterozoic Earaheedy Basin of the Nabberu Province.

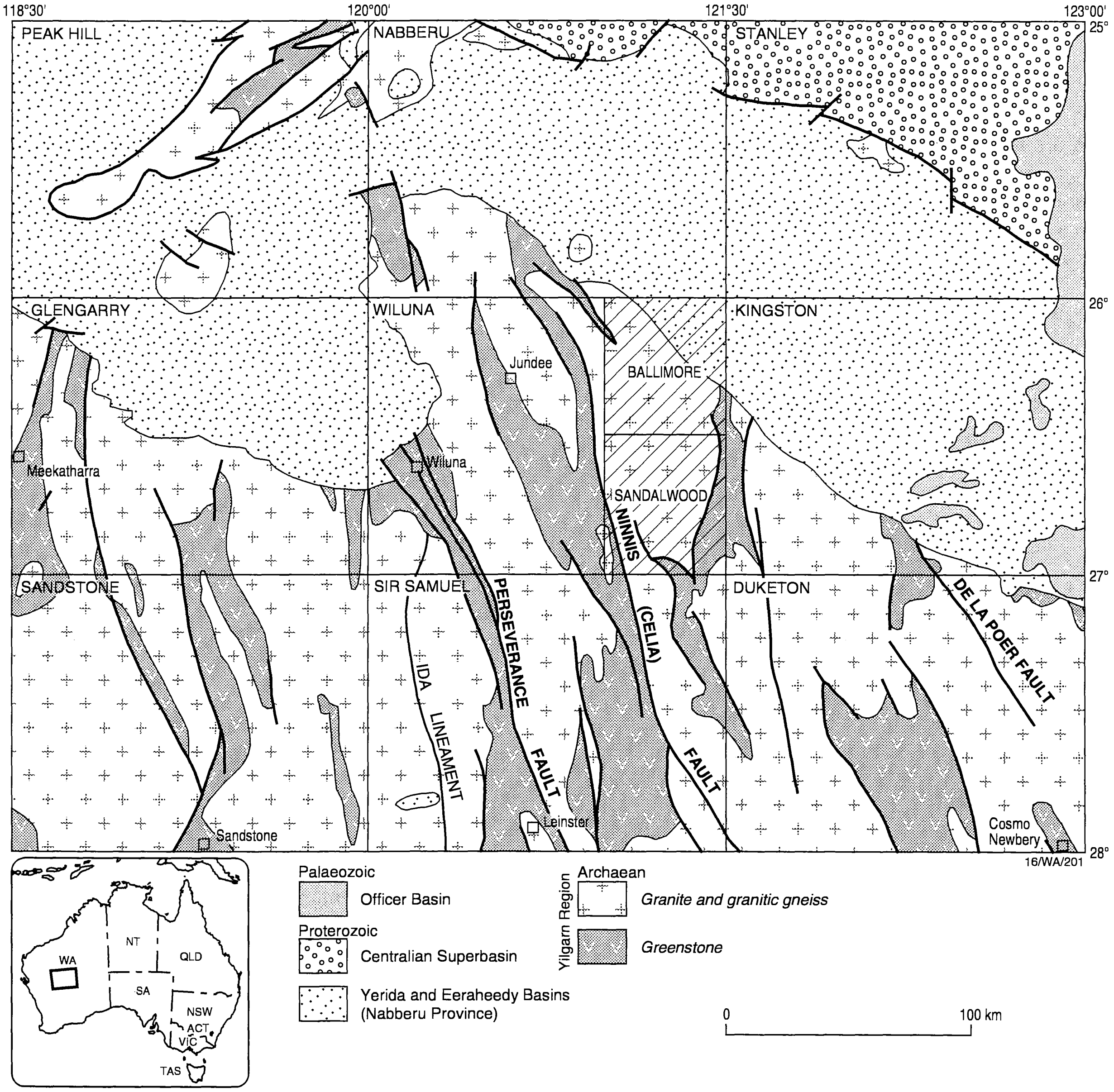

Figure 1. Regional geology of the northern part of the Eastern Goldfields Province and neighbouring areas, Western Australia (after Myers & Hocking 1998). BALLIMORE and SANDALWOOD are hatched.

The highest point in the area is about 600 m above sea level (a.s.l.) in northeast BALLIMORE, and the lowest part is about 495 m a.s.l. in northern SANDALWOOD. Much of the area consists of sand plains with scattered sand dunes and clay pans. There are also salt and clay pans along general drainage depressions. The depressions have barely perceptible slopes, and slope down from breakaways capped by laterite, or from low rounded hills in the south, or from low cuestas and flat-topped ridges in the northeast. Rare tors and rounded boulders of granitic rocks occur in places.

There are no towns or homesteads in the area. The nearest town is Wiluna to the west. The main access to BALLIMORE is the unsealed Wiluna – Granite Peak Road and a connecting road to Lorna Glen homestead to the east. An unsealed road branches eastwards from the Wiluna – Granite Peak Road in LAKE VIOLET and crosses SANDALWOOD from west to east, joining the Mount Fisher-Wanggannoo Road just to the east of this sheet area. Tracks along fence lines provide reasonable access to most parts of the area. Sheep grazing and mineral exploration are the main activities. The abandoned Mount Fisher gold mine is in the southeast of SANDALWOOD, and gold has also been mined in southwest SANDALWOOD.

The climate is semi-arid. The annual rainfall averages about 240 mm, but is very unreliable. Summers are hot, with maximum daily temperatures over 40°C common, and winters are cool to mild.

Geological and geophysical investigations

The geology of the Wiluna 1:250 000 Sheet area was previously investigated by CSIRO (Sofoulis & Mabbutt 1963) and GSWA (Elias & Bunting 1982). The regolith-landforms of the sheet area have been mapped by AGSO (Craig & Churchward 1995); the units mapped are distinctive patterns of recurring landform elements with characteristic regolith associations. They are based on systematic analysis and interpretation of 1:82 000-scale aerial photographs, Landsat Thematic Mapper satellite imagery, field observations, and literature research. AGSO has also issued a variant of this map in different colours to emphasise greenstone, granite, and iron-rich saprolite, and to show the main gold and nickel occurrences (Craig 1997).

The NGMA geological mapping of BALLIMORE and SANDALWOOD in 1995 was carried out using black-and-white aerial photographs at 1:50 000-scale, taken in 1989. Sites visited were located using a Global Positioning System instrument (GPS) in addition to the aerial photographs. Field and photo-interpreted geological data were plotted on to transparent overlays on aerial photographs and then compiled on photoscale topographic bases. The resulting compilation sheets have been digitised and entered into an ARC/INFO geographic information system (GIS). Site locations (GPS readings), structural measurements and chemical analyses are stored in the AGSO OZROX and OZCHEM databases. Details of rock samples collected in 1995 are listed in the Appendix. Magnetic (Fig. 2) and γ-ray spectrometric data were acquired jointly by AGSO and GSWA in 1994 from an airborne geophysical survey carried out in 1990-91 by AERODATA Holdings Ltd. Gravity data were acquired by AGSO and GSWA in 1993-94 via ground-based vehicle traverses infilling the 11-km National Gravity grid (Murray 1997). A. Sedgmen made a preliminary interpretation of the magnetic data for the 1995 geological fieldwork. A.J. Whitaker subsequently completed an interpretation of the geophysical data. Print-on-demand coloured maps of the geology combined with the interpretation of the magnetic data were released by AGSO in 1996 for BALLIMORE and SANDALWOOD at 1:100 000 scale (Blake & Whitaker 1996a, 1996b). The data are also available in digital format.

Geological maps at 1:100 000 scale are available for three adjacent sheets: MILLROSE (Farrell & Wyche 1997) and LAKE VIOLET (Stewart & Bastrakova 1997) to the west, and WANGGANNOO (Lyons et al. 1996) to the south. The geology of the adjacent Nabberu 1:250 000 Sheet to the north is described by Bunting et al. (1982) and that for the Kingston 1:250 000 Sheet to the east by Bunting (1980).

All Australian Map Grid (AMG) references use the AGD 66 spheroid.

Acknowledgments

The authors thank D.C.Champion and T. Mackey for reviewing the manuscript, and Lana Murray for preparing the diagrams.

Outline of geology

SANDALWOOD and most of BALLIMORE lie within the Eastern Goldfields Province of the Yilgarn Craton. This province is an Archaean granite-greenstone terrane consisting of north-northwest-trending greenstone belts generally less than 50 km wide, formed predominantly of supracrustal rocks, and wide belts of granitic rocks up to 100 km wide.

The greenstone belts of the Eastern Goldfields Province consist of mafic and ultramafic volcanics, subordinate felsic and intermediate volcanics, and a variety of volcaniclastic and other sedimentary rocks, including sandstone, siltstone, conglomerate, chert, and iron formation. These rocks are generally moderately to tightly folded about steeply dipping axial planes. Bedding, cleavages, and fold trends are typically parallel or subparallel to the margins of the greenstone belts. Many greenstone belts can be shown to represent keels of synclines or synclinoria; others are anticlinal. They are commonly bounded by faults, some of which have been interpreted as plate boundaries (e.g., Myers 1995), although this view is not accepted by many (e.g., Whitaker 1997). However, few faults appear to have had more than 5 km of either horizontal or vertical displacement. Regional metamorphism within the greenstone belts ranges from lower greenschist to upper amphibolite facies, and commonly increases in grade towards the margins of the belts.

The intervening belts of granitic rocks include various types of granite and quartzofeldspathic gneiss (e.g., Champion & Sheraton 1997). Most of the gneisses probably represent deformed granites, but some may be metamorphosed quartzofeldspathic volcanic and sedimentary rocks. The granites form numerous coalescing plutons with circular to elliptical outlines, as revealed by regional aeromagnetic data; the long axes of elliptical plutons are subparallel to the regional north-northwest structural grain. Some of the granites are locally to pervasively foliated. Foliations in the gneiss and granite are commonly more variable in orientation than those in greenstone belts, especially away from these belts; they have strikes that are typically subparallel to pluton margins and dips that range from flat-lying to vertical.

Geochronological data (e.g., Nelson 1997) indicate that the supracrustal rocks of the greenstone belts are between 2710 and 2670 Ma old, and that the granitic rocks range from 2710 to 2630 Ma, with a peak emplacement age of ~2665 Ma. The overlap in age between greenstone belts and granite plutons is also shown by field evidence; some greenstone belts include conglomerate containing abundant granite clasts up to boulder size, and many belts are seen to be intruded and contact metamorphosed by granite plutons.

Seismic reflection data obtained along a traverse across part of the Eastern Goldfields Province near Kalgoorlie (Goleby et al. 1993), 400 km south of Wiluna, have been interpreted by Drummond et al. (1993) and Swager et al. (1997) to indicate that the greenstone belts are underlain by felsic rocks at relatively shallow depths (6-8 km).

The Archaean rocks host a variety of mineral deposits, the most important economically being those mined for gold and nickel. Most of the mineralisation is within the greenstone belts, where gold and nickel deposits are commonly associated with mafic and ultramafic (komatiitic) volcanics respectively.

Both greenstone and granite belts are cut by swarms of mafic dykes striking in various directions. The swarms, which include both normal and reversely magnetised types, predate sedimentation in the Palaeoproterozoic Nabberu Province to the north. This sedimentation took place at around 1700 Ma (Krapez & Martin 1999), after the Yilgarn Craton had been eroded to a general plain, similar to what it is now. The sediments were deposited on greenschist facies bedrock, indicating that in this part of Western Australia around 6 km of bedrock was probably removed by erosion between about 2600 Ma and 1700 Ma.

BALLIMORE and SANDALWOOD (Figs. 1 & 3) include parts of three major Archaean greenstone belts and extensive areas of Archaean granitic rocks. The three greenstone belts, which are represented by mafic, ultramafic, and felsic volcanic rocks, various sedimentary rocks, and mafic intrusives, are the Lake Violet greenstone belt in the southwest, the Dingo Range greenstone belt in the central south, and the Mount Fisher greenstone belt in the far east. There is also a much smaller poorly defined greenstone belt, here termed the Bartletts Bore greenstone belt, in the northwest. Several small gold shows are present in the greenstone belts in SANDALWOOD, but the only deposit of economic significance is at the abandoned Mount Fisher gold mine near the eastern edge of this sheet area. There are no mines or prospects in BALLIMORE. The Archaean rocks are overlain unconformably in the northeast by flat-lying to gently dipping sedimentary rocks of the Palaeoproterozoic Earaheedy Group. This sedimentary sequence comprises, from the base upwards, sandstone and conglomerate of the Yelma Formation, shale and ironstone of the Frere Formation, limestone, shale, and siltstone of the Windidda Formation, and sandstone and shale of the Wandiwarra Formation. A small outcrop of sandstone and conglomerate in eastern BALLIMORE is assigned to the Permian Paterson Formation. Over most of the area the Archaean rocks are covered by surficial Cainozoic sediments, especially alluvial, colluvial, and aeolian clay, silt, and sand. The aeromagnetic data enable the greenstone belts, granitic rocks, and cross-cutting mafic dykes to be mapped beneath this cover and also, to some extent, beneath the Palaeoproterozoic Earaheedy Basin sequence.

Archaean

Metamorphosed ultramafic rocks

Ultramafic rock (Au; undivided or unassigned)

Distribution: southeastern SANDALWOOD (Mount Fisher greenstone belt).

Lithology: talc schist, caprock silcrete, and serpentinite; also altered metabasalt, bedded chert, and quartz-feldspar porphyry; some possible pillow lavas in Mount Fisher open cut.

Relationships: felsic volcanic rocks (unit Af) exposed along strike to south.

Chlorite schist (Aul; in drill holes only)

Distribution: southwestern SANDALWOOD (Lake Violet greenstone belt).

Lithology: greyish-green fine-grained lineated schist composed of chlorite, amphibole, smectite (possibly montmorillonite), and clay (possibly mixed-layer).

Tremolite-chlorite schist (Aur; in drill holes only)

Distribution: southwestern SANDALWOOD (Lake Violet greenstone belt).

Lithology: greyish-green fine-grained schist composed of actinolite, chlorite, illite or montmorillonite, and possible epidote.

Serpentinite (Aus; in drill holes only)

Distribution: southwestern SANDALWOOD (Lake Violet greenstone belt).

Lithology: mottled greenish-black and cream, medium-grained, equigranular serpentine with a small amount of opaque grains.

Talc schist (Aut; in drill holes only)

Distribution: SANDALWOOD (Mount Fisher and Lake Violet greenstone belts).

Lithology: pale brown to buff or varicoloured maroon and white or greyish white speckled with yellow-brown, fine to medium-grained talc schist with or without minor goethite or hematite. At AMG 056195, moulds after thin prisms several millimetres long cut the schistosity.

Low-grade metamorphic rocks

Amphibolite (Ala)

Distribution: southern BALLIMORE and southern SANDALWOOD (some outcrops in Lake Violet and Dingo range greenstone belts).

Lithology: foliated, massive, and thinly banded medium to fine-grained amphibolite (green hornblende + plagioclase +/- clinopyroxene +/- epidote); cut by aplitic to pegmatitic veins of leucogranite; outcrop at SANDALWOOD AMG 323209 consists of fine-grained 'hornfels' made up of pale brownish amphibole, plagioclase, and megacrystic epidote (in amygdales?).

Relationships: intrudes and/or intruded by granite (units Ag and Agl); appears to intrude metasediments (unit As) in southwestern SANDALWOOD.

Quartz-feldspar schist (Alf; in drill holes only)

Distribution: southwestern SANDALWOOD (Lake Violet greenstone belt).

Lithology: speckled red-brown and white, fine-grained, composed of kaolin, smectite (possibly montmorillonite), and minor quartz. The clay minerals are presumed to be, at least partly, after feldspar.

Schistose clay rock with quartz eyes (Alfq; in drill holes only)

Distribution: southwestern SANDALWOOD (Lake Violet greenstone belt).

Lithology: white, weakly foliated schist to massive rock composed of rounded phenocrysts of quartz to 1 mm size in very fine-grained groundmass of kaolin.

Quartz-chlorite schist (Alqc; in drill holes only)

Distribution: southwestern SANDALWOOD (Lake Violet greenstone belt).

Lithology: brown to khaki, fine to very fine-grained, saccharoidal to schistose rock composed of quartz, chlorite, kaolin, and smectite (possibly montmorillonite).

Quartz-muscovite schist ± feldspar (Alqm)

Distribution: southwestern SANDALWOOD (Lake Violet greenstone belt).

Lithology: grey, fine-grained lineated schist composed of gritty quartz and muscovite. May represent altered felsic volcanics.

Relationships: mafic schist (Abf) nearby.

Gneiss

Banded to agmatitic felsic gneiss (An)

Distribution: small outcrop in southwestern BALLIMORE (AMG 130760).

Lithology: highly weathered quartzofeldspathic gneiss showing compositional banding (meta-arkose?).

Relationships: adjoins foliated leucogranite (Agng) to east and north, and foliated amphibolite (Abam) to south.

Calc-silicate gneiss (Anc)

Distribution: northwestern BALLIMORE (Bartletts Bore greenstone belt); extends northwest into MILLROSE, where it has been mapped as Agnq – granitoid rock and quartzofeldspathic gneiss (Farrell & Wyche 1997).

Lithology: calc-silicate gneiss (green hornblende + diopsidic clinopyroxene + oligoclase ± microcline and minor quartz, titanite, and apatite); banded quartzofeldspathic gneiss (bands up to 20 cm thick); foliated granite and hornblende granodiorite (e.g., at AMG 006028); laminated, medium to fine-grained ironstone/ferruginous quartzite (5 m-thick band at AMG 020050).

Relationships: unit includes undoubted metasediments, which are presumed to be intruded and contact metamorphosed by large granite plutons (indicated by regional aeromagnetic data) to east and west.

Metamorphosed mafic igneous rocks

Fine-grained mafic igneous rocks, undivided (Ab)

Distribution: southeastern SANDALWOOD (Mount Fisher greenstone belt; AMG 500280).

Lithology: lateritised basalt and laminated quartz-free metasediments.

Relationships: cut by granite veinlets.

Amphibolitic metabasalt and metasediments (Aba)

Distribution: southeastern BALLIMORE and eastern SANDALWOOD (Mount Fisher greenstone belt);

Lithology: foliated amphibolitic metabasalt (blue-green amphibole + feldspar, with quartz-filled amygdales) and interlayered mafic metasediments, epidotic quartzite, and cherty ironstone/ferruginous quartzite; also ophitic metadolerite (plagioclase + uralitic amphibole).

Relationships: cut by leucogranite veins (Ag); probably intruded by porphyritic granite (Agmp).

Metabasalt (Abb; in drill holes only)

Distribution: southeastern SANDALWOOD (Mount Fisher greenstone belt) and southwestern SANDALWOOD (Lake Violet greenstone belt).

Lithology: in southeastern SANDALWOOD generally weathered basalt; fine-grained grey schist at AMG 445240. In southwestern SANDALWOOD, greyish green, fine-grained, foliated and lineated metabasalt composed of amphibole and plagioclase.

Mafic schist (Abf)

Distribution: western SANDALWOOD (Lake Violet greenstone belt).

Lithology: heavily weathered lateritic rock with relict foliation.

Metamorphosed felsic extrusive rocks (Af)

Distribution: southeastern and southwestern SANDALWOOD (Mount Fisher and Lake Violet greenstone belts).

Lithology: foliated, massive to thinly banded, white kaolinitic to cherty rocks, some with small quartz eyes (phenocrysts?).

Metasedimentary rocks

Chert (Ac)

Distribution: southeastern SANDALWOOD (Mount Fisher greenstone belt).

Lithology: banded iron-rich chert.

Clastic metasedimentary rocks (As)

Distribution: southeastern BALLIMORE (Mount Fisher greenstone belt), southwestern SANDALWOOD (Lake Violet greenstone belt).

Lithology: meta-arkose, quartzite, cherty ironstone/ferruginous quartzite, and possible metabasalt (highly weathered fine-grained quartz-free rock); bedding generally parallel to subvertical foliation.

Relationships: BALLIMORE – in contact to west with granite (Ag) which is foliated parallel to contact; SANDALWOOD – apparently intruded to east by amphibolite (Abam) and granite (Agl).

Shale (Ash; in drill holes only)

Distribution: southwestern SANDALWOOD (Lake Violet greenstone belt).

Lithology: dark yellow, cream, or pale brown to white, fine to very fine-grained laminated shale with parallel laminae about 1 mm thick, composed of kaolin, quartz, and smectite (possibly montmorillonite).

Granite

Unassigned granite (Ag)

Distribution: southern SANDALWOOD.

Leucogranite and microgranite (Agl)

Distribution: widespread in BALLIMORE and SANDALWOOD.

Lithology: medium to fine-grained leucocratic biotite granite; minor porphyritic granite (tabular phenocrysts 2-3 cm long of poikilitic and perthitic microcline and/or sodic plagioclase); quartz is invariably strained; biotite is commonly chloritised; pegmatitic and aplitic veins are common. In places the granite shows a weak to strong, steeply dipping to flat-lying foliation which may be parallel to the margins of the pluton. Exposed granite is typically highly weathered, and iron-stained to bleached (lateritic weathering profiles), but small tors (e.g., at AMG 195727) and boulders of fresh granite are present in a few places. Gabbro and amphibolite, as well as granite have been intersected in drill holes into unit Agl.

Relationships: intrudes Mount Fisher and Lake Violet greenstone belts; may be intruded by, or contemporaneous with, granite of unit Agmf; overlain by sedimentary rocks of the Palaeoproterozoic Yelma Formation, Earaheedy Group, in northern BALLIMORE (granite underlying the unconformity is weathered). Aeromagnetic data indicate that unit Agl consists of several intersecting plutons, at least some of which postdate unit Agng, and that it is intruded by several concealed magnetic dykes (probably mafic) and small equant normal and reverse-magnetised igneous bodies. Exposed contacts between porphyritic and non-porphyritic phases of unit are sharp, but it is not clear which is the older phase.

Biotite monzogranite (Agm; in drill holes only)

Distribution: southern SANDALWOOD.

Lithology: medium-grained biotite leucogranite.

Fine-grained biotite monzogranite (Agmf)

Distribution: southern BALLIMORE and northern SANDALWOOD, where unit is exposed as smoothly rounded whalebacks.

Lithology: fine-grained monzogranite/quartz syenite consisting of megacrystic and poikilitic microcline, subordinate subhedral plagioclase and anhedral quartz (not strained), and minor subhedral to euhedral green hornblende, very pale clinopyroxene (some needle-like crystals) and titanite; crosscutting aplitic to pegmatitic veinlets.

Relationships: presumed to intrude adjacent medium-grained leucogranite of unit Agl.

Hornblende monzogranite (Agmh; in drill holes only)

Distribution: northern SANDALWOOD.

Lithology: grey, medium to fine-grained hornblende-biotite granite.

Porphyritic monzogranite (Agmp)

Distribution: small pluton forming tors and whalebacks in Prominent Hill area of southeastern BALLIMORE.

Lithology: uniform, densely porphyritic, biotite leucogranite/monzogranite consisting of equant phenocrysts up to 2 cm across of plagioclase and perthitic microcline, clots of reddish brown biotite, and strained quartz. Not foliated.

Relationships: Inferred to intrude leucogranite (Ag) exposed to east and concealed to west and to be intruded by small dolerite body (Ꝑdy) exposed to north.

Foliated leucogranite, gneiss, and massive leucogranite (Agng)

Distribution: western BALLIMORE.

Lithology: foliated leucogranite and granitic gneiss and minor massive leucogranite; even-grained and medium to fine-grained, rarely porphyritic; exposures generally highly weathered, i.e., bleached to iron-stained parts of lateritic weathering profiles; 'fresh' samples examined in thin-section contain hornblende rather than biotite.

Relationships: unclear.

Veins

Quartz (q)

Distribution: southwestern SANDALWOOD, northwestern BALLIMORE.

Relationships: intrudes leucogranite (Agl).

Palaeoproterozoic

Mafic dykes (Ꝑdy)

Distribution: small outcrop north of Prominent Hill, southeastern BALLIMORE.

Lithology: massive even-grained dolerite exposed as small spheroidal boulders and cobbles; not evident on aeromagnetic data.

Relationships: no contacts with adjacent units exposed; inferred to intrude leucogranite of unit Agmp and metabasalt of unit Aba in Mount Fisher greenstone belt; tentatively regarded as Palaeoproterozoic like similar dolerite exposed near Kalgoorlie (Fletcher et al. 1987). Shown on map as 'd'.

Earaheedy Group

Defined by Commander et al. (1977); described by Bunting et al. (1982), Commander et al. (1982), Bunting (1986), and Gee (1986). Consists of deltaic to shallow-marine sedimentary rocks deposited in the Earaheedy Basin of the Nabberu Province at around 1700 Ma (Krapez & Martin 1999).

Crops out extensively in northern BALLIMORE, where the group is flat-lying to gently dipping, or gently folded; not cleaved.

Four formations represented in BALLIMORE: from oldest to youngest, the Yelma, Frere, Windidda, and Wandiwarra Formations.

Yelma Formation (ᴇEy)

Relationships: nonconformable on weathered Archaean granitic rocks (unit Agl); contacts with overlying Frere Formation concealed by Cainozoic cover.

Thickness: >15 m; 30-50 m reported by Elias & Bunting (1982); overlain, presumably conformably, by Frere Formation.

Lithology: basal beds generally of medium to thick-bedded felspathic/lithic quartz sandstone which is medium to coarse-grained, well to poorly sorted, with cross-bedding and gritty laminae common; interbedded conglomeratic sandstone containing granule, pebble, and cobble-size subangular clasts of vein quartz present in places. Overlying beds consist of thinly-bedded, medium to fine-grained sandstone with bedding planes commonly marked by mudstone partings and/or pellets; some linguoid ripple marks. Trough cross-bedding indicates current directions from east-southeast (Elias & Bunting 1982).

Frere Formation (ᴇEf, ᴇEfs)

Relationships: presumed to be conformable on Yelma Formation and overlain conformably/concordantly by Windidda or Wandiwarra Formations, but contacts not exposed.

Thickness: about 1300 m according to Elias & Bunting (1982), but this may be an over-estimate as the formation is flat-lying to gently northeast-dipping, and if it has an average dip of 2° to the northeast, its maximum thickness is only about 500 m.

Lithology:

ᴇEf: iron formation, thinly bedded to laminated shaly siltstone, and minor fine-grained quartz sandstone; forms cuestas up to 50 m high; most cuestas are capped by partly lateritised iron formation.

Iron formation alternates with hematitic shaly siltstone in bands up to 50 m thick. Individual beds are up to 1 m, but mainly less than 300 mm, thick, and typically consist of peloids and ooliths 1-2 mm in diameter, and angular cherty ironstone fragments generally less than 10 mm across enclosed in variably jasperoidal chert containing specular hematite and, in places, magnetite. Oncolitic and stromatolitic textures are locally present. The iron formation was probably deposited in a shallow-marine (lagoonal) environment (Krapez & Martin 1999).

ᴇEfs: recessive band of thinly bedded to laminated shaly siltstone and minor fine-grained sandstone with, locally, a few thin beds of iron formation.

Shaly siltstone: thinly bedded to laminated; has micaceous bedding planes.

Sandstone: quartzose, commonly friable; in places shows linguoid ripples

Windidda Formation (ᴇEd, ᴇEds)

Relationships: concordant between Frere and Wandiwarra Formations

Thickness: probably less than 50 m in BALLIMORE; more than 1000 m to east, in Kingston 1:250 000 Sheet area.

ᴇEd: grey stromatolitic limestone (at AMG 380230) and thinly interbedded shaly siltstone and pink limestone (at AMG 375222).

ᴇEds: variably iron-stained, thinly bedded to laminated shale and siltstone, with very fine-grained muscovite on bedding planes; exposed in laterite-capped breakaways bordering claypans.

Wandiwarra Formation (ᴇEw)

Relationships: appears to be concordant on Windidda Formation.

Thickness: possibly 100 m in BALLIMORE, where neither base nor top is exposed; 500 to 1500 m to north, in Nabberu 1:250 000 sheet area (Bunting et al. 1982).

Lithology: thinly bedded, medium-grained to very fine-grained, pale grey quartz sandstone and iron-stained shaly siltstone; distinguished from Frere Formation by lack of iron formation.

Permian

Paterson Formation (PAf)

Defined as Paterson Range Series by Wells (1959); redefined as Paterson Formation by Wales & Forman (1981). Described by Lowry et al. (1975).

Distribution: two small outcrops in eastern BALLIMORE.

Relationships: inferred to be unconformable on Proterozoic Earaheedy Group (Frere Formation); some silcrete cappings.

Thickness: probably a few metres.

Lithology: flat-lying, highly weathered, arkosic sandstone with some thin claystone layers; sandstone contains scattered sub-rounded to angular pebble to boulder-size clasts of flaggy sandstone, siltstone, and oolitic ferruginous chert, like that in underlying Earaheedy Group, and glassy quartzite of Archaean type; may be fluvial.

Cainozoic

Thirteen Cainozoic units have been mapped (based on airphoto interpretation). Sand plain with dunes (Czs), the most extensive, forms large areas in central BALLIMORE and in the north and south of SANDALWOOD. Gently sloping fans of colluvial gravel and sand (Czc) surround ridges of sedimentary rocks of the Earaheedy Group in the north of BALLIMORE and rises of laterite and laterite gravel (Czl) in the south of SANDALWOOD; both grade laterally into extensive plains of pebbly colluvial loam (Cza). In central SANDALWOOD and southern BALLIMORE, colluvial loam forms large areas around tracts of granitic sand (Czg) which adjoin outcrops of granite; in SANDALWOOD, the colluvium grades downslope into clay and dune sand (Czb), and thence into small playas (Czp). Colluvial lateritic gravel (Czf) mantles laterite rises in the east of SANDALWOOD, and forms small areas in the centre and south of BALLIMORE. Calcrete including minor unmapped outcrops of other Cainozoic units (Czk) is extensive on the southwestern side of the area of Palaeoproterozoic sedimentary rocks in the northeast of BALLIMORE. Smaller areas of calcrete also occur in western BALLIMORE and in an area of clay and dune sand (Czb) associated with the playas (Czp) in central SANDALWOOD. Small patches of silcrete and kaolinised granite (Czzg) cap granite in the south of BALLIMORE. Silcrete derived from ultramafic rock (Czu) forms a ridge in southwestern SANDALWOOD.

Alluvial silt and sand mark active stream channels (Qa) draining low ridges and hills, and are particularly extensive in the northeast of BALLIMORE, where there also claypans (Qac).

Geophysical interpretation

Airborne geophysical data acquired jointly by AGSO and GSWA (Table 1) provide considerable information on the surface and subsurface geology of BALLIMORE and SANDALWOOD. The magnetic data are particularly useful for areas of Archaean bedrock because of the relatively high resolution of the airborne survey and thinness of the surficial cover. The γ-ray spectrometric data acquired with the magnetic data provide information on materials within 0.5 m of the surface (the effective distance of attenuation for γ-rays) and so provide information mainly on regolith materials. Gravity data provide some complementary information for the Archaean, but are too coarse for mapping at 1:100 000 scale.

Table 1. Aeromagnetic and γ-ray spectrometric data acquisition details

Survey specifications	*Instrument details*
Flight-lines orientation – E-W,	Magnetometer sensitivity – 0.04 nT
Flight line control – air photo	Magnetometer readings – ~12 m intervals
Tie-lines – N-S	Spectrometer – 256 channels
Line spacing – 400 m	Spectrometer volume –16.78 l
Ground clearance – 60 m	Spectrometer readings – ~60 m intervals

Geophysical data sets

Specifications of the aeromagnetic and gamma (γ)-ray spectrometric data for the Wiluna 1:250 000 Sheet purchased jointly by AGSO and GSWA from Aerodata Holdings in 1994 are listed in Table 1. Aerodata acquired the data between November 1990 and February 1991.

Interpretation was based mainly on a 1st vertical derivative image (reduced to the pole), with additional information from total magnetic intensity and east-west horizontal derivative images. A composite 3-band image, K - red, U - blue, Th - green, was used for interpreting the spectrometric data. The grid cell size used for these images was 100 m.

New gravity data were obtained by ground-based vehicle traverses using tracks mainly along fence lines to infill the regional 11 km-spaced national coverage to a nominal 4 km spacing over parts of the two 1:100 000 sheet areas. Interpretation of the gravity data was based on contoured Bouguer anomalies with an approximate 1-km grid cell size.

Aeromagnetic and gravity interpretation

The area of sparse Archaean outcrops consists of four main crustal components (geophysical map units) based on the magnetic data (Fig. 2). These are undivided gneiss-migmatite-granite, discrete granite plutons, banded gneiss, and greenstone.

Gneiss-migmatite-granite and discrete granite plutons (Ag_l, Ag_m, Ag_h)

Gneiss-migmatite-granite and discrete granite plutons make up at least 80% of the Archaean rock in the area (Figs. 2, 3). Boundaries between different granites are based on changes in average, and/or variability of, magnetisation. Notations '_l', '_m', and '_h' indicate low, medium, and high average magnetisation, respectively.

By far the largest extent of granitic rock is attributed to gneiss-migmatite-granite, which forms a belt trending north-northwest across the sheet areas. The belt has been subdivided largely on the basis of average magnetisation, which ranges from low to moderate; however, internal boundaries are poorly defined. Compositional layering is rarely apparent, but where present it shows some alignment north to north-northwest. The belt of gneiss-migmatite-granite is bounded to the west by the Lake Violet greenstone belt and the northern extension of the Celia Lineament (Williams, 1974), and to the east by the Mount Fisher greenstone belt (Fig. 3). In SANDALWOOD, the belt includes three rounded to lenticular areas, 15-35 km long by 7-25 km wide, which are inferred to be deformed granite domes. The two larger domes (Fig. 3, localities 1 and 2) are relatively poorly and evenly magnetised, whereas the magnetisation of the smallest dome (Fig. 3, locality 3) is variable and may indicate a composite body. The boundaries of the domes are generally poorly defined, as they correspond to mostly gradational (rarely sharp) changes in average magnetisation. Inferred gneissic banding parallels the margins of the domes in places. The domes are elongated between

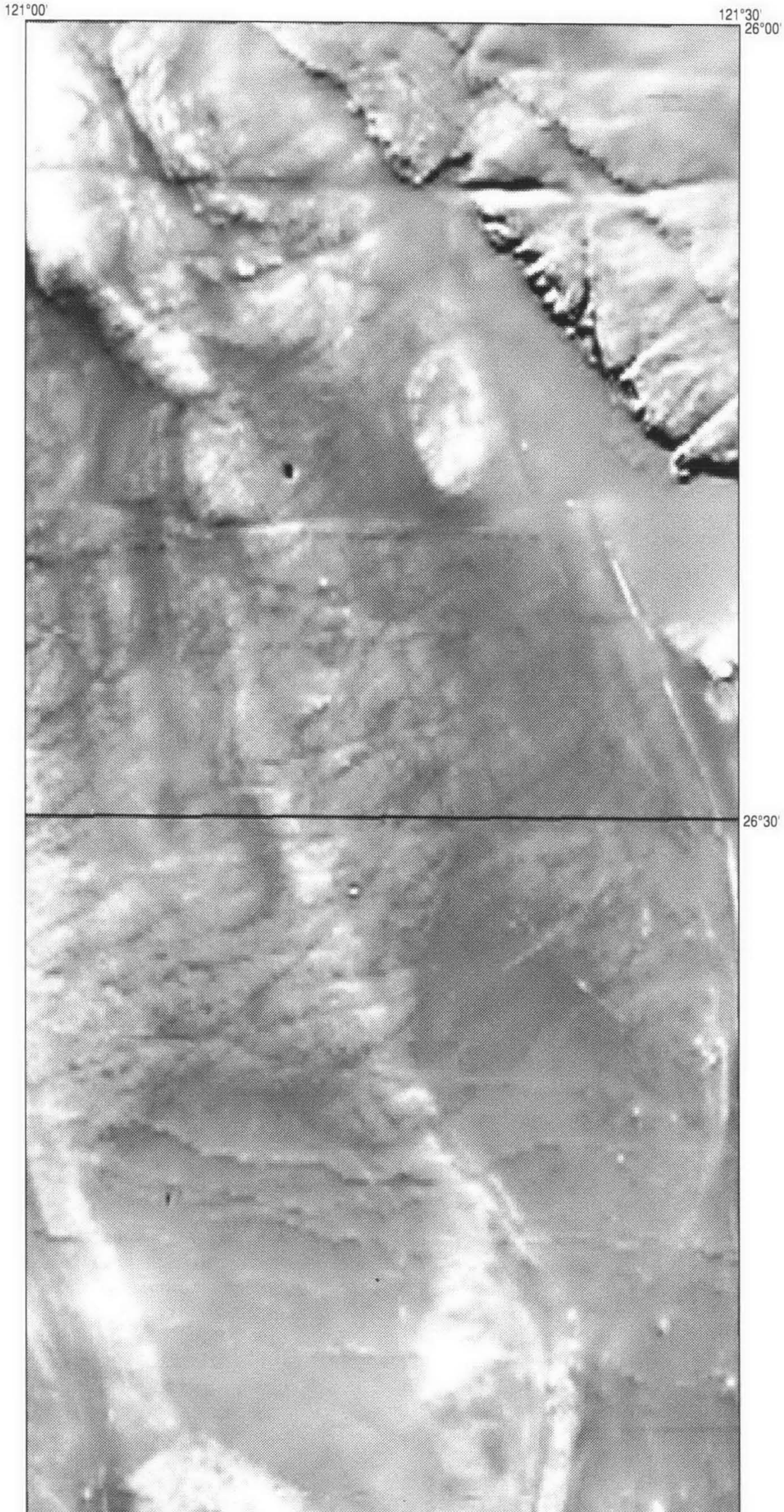

Figure 2. Total magnetic intensity image of BALLIMORE and SANDALWOOD.

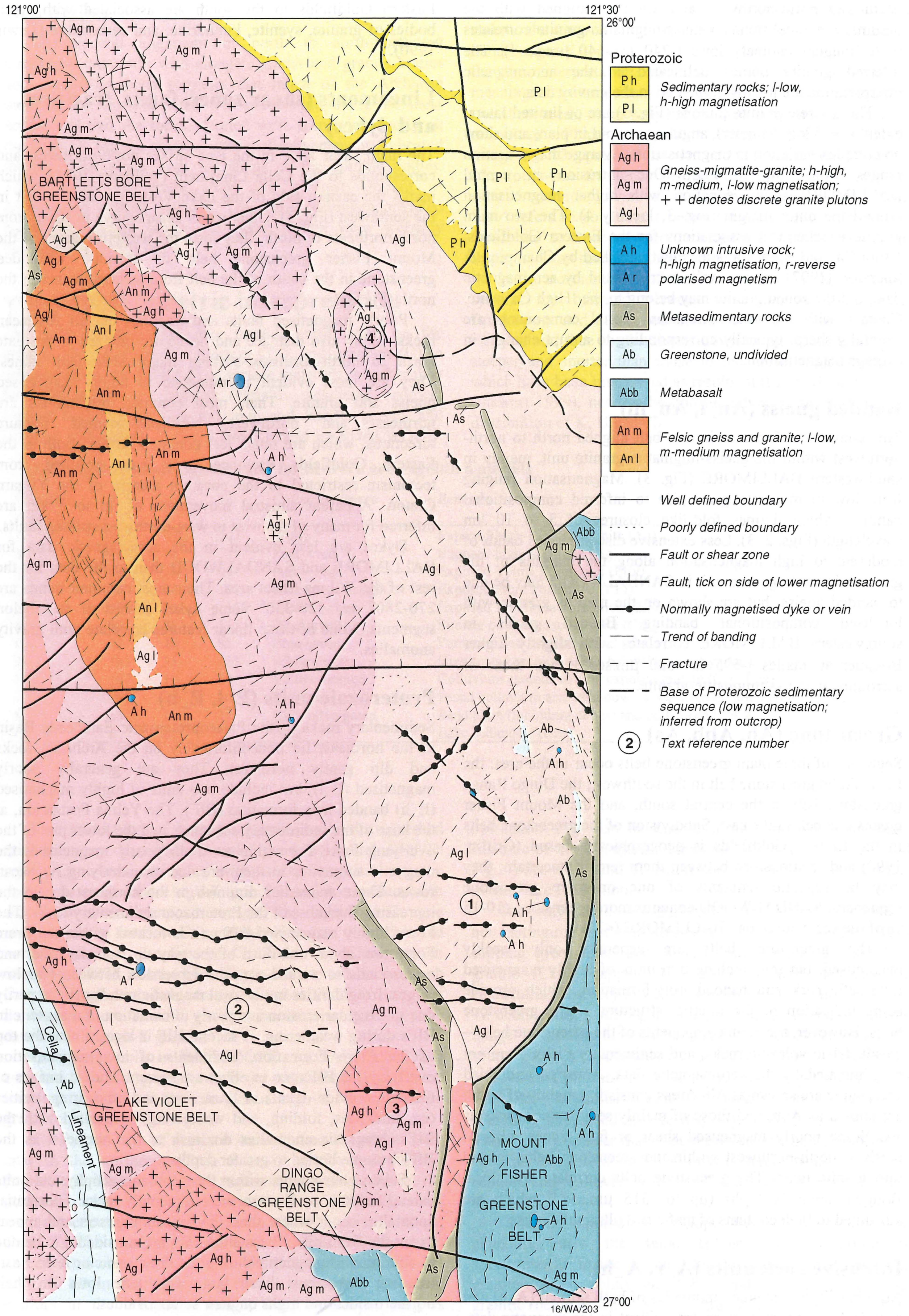

Figure 3. Solid-geology map of BALLIMORE and SANDALWOOD.

north and north-northwest and are thus aligned with the dominant regional trends. Gneiss-migmatite-granite correlates with Bouguer anomaly lows (-740 to -640 μm.sec^{-2}). The inferred granite domes delineated in the aeromagnetic interpretation are not discriminated in the gravity data.

The discrete granite plutons (Fig. 3) are of limited lateral extent (to 25 km diameter), angular to ovoid in plan, and show no complex variation in magnetisation. Average magnetisation ranges from low to high. One intrusion in central BALLIMORE shows zonation with higher magnetisation around the outer margin (Fig. 3, locality 4). The two main granite geochemical associations for the Eastern Goldfields, 'High Ca' and 'Low Ca' suites distinguished by Champion & Sheraton (1997) are not well discriminated by aeromagnetic data, but the zoned granite may belong to the 'High Ca' suite. Contacs with the other Archaean crustal components are generally sharp, typically corresponding to abrupt changes in average magnetisation.

Banded gneiss (An_l, An_m)

This component forms a sinuous belt aligned north to north-northwest within the gneiss-migmatite-granite unit, mainly in southwestern BALLIMORE (Fig. 3). Magnetisation ranging from low to moderate gives rise to inferred compositional banding which defines fold-like closures of 5 to 10 km wavelength (Figs. 2, 3). Less extensive discontinuous bands of moderate to high magnetisation along the margins of the gneiss-migmatite-granite unit in SANDALWOOD may be due to banded gneiss, but are shown on the map as granite with localised compositional banding. Banded gneiss in southwestern BALLIMORE correlates with slightly higher Bouguer anomalies (-595 to -620 μm.sec^{-2}) than those of surrounding gneiss-migmatite-granite.

Greenstone (Ab, Abb, As)

Segments of three main greenstone belts occur in the area: the Lake Violet greenstone belt in the southwest, the Dingo Range greenstone belt in the central south, and the Mount Fisher greenstone belt in the east. Subdivision of the greenstone belts in the Eastern Goldfields is geographically based (Griffin, 1990) and relationships between them remain uncertain; they may be separate remnants of one or more greenstone sequences. SANDALWOOD contains more greenstone (10-15 % of the sheet area) than BALLIMORE (<3%).

The greenstone belts are generally only weakly magnetised, but they include thin units of highly magnetised ultramafic rock and banded iron formation, which provide some indication of the internal structure of the greenstone belts. However, the main components of the greenstone belts – basalt, felsic volcanic rocks, and sedimentary rocks – are not discriminated by the aeromagnetic data. Areas of undivided greenstone are shown as Ab. Areas consisting mainly of basalt are shown as Abb, and those of mainly sedimentary rocks as As. Some poorly magnetised shear or fault zones, aligned north to north-northwest within the greenstone belts, extend into granite units. The greenstone belts correlate with local Bouguer anomaly highs (up to -315 μm.sec^{-2}) which are attributed to high contents of mafic and ultramafic rocks.

Intrusive rock units (A_r, A_h)

Numerous 'point source' anomalies of both normal (A_h) and reverse (A_r) magnetisation are evident in the magnetic data. The anomalies, which are particularly obvious in the granite-gneiss-migmatite unit, are inferred to be due to small igneous intrusions. Similar magnetic anomalies elsewhere in the Eastern Goldfields to the south are associated with small bodies of granite, syenite, kimberlite, and carbonatite (Lewis 1990).

Lineaments (shear zones, faults, fractures, and dykes)

The main shear zone in the area strikes north-northwest and corresponds to the Celia Lineament (Williams 1974), which marks the eastern side of the Lake Violet greenstone belt in the southwest (Fig. 3). Other major shears curve in strike from north-northeast to north; they form the western margin of the Mount Fisher greenstone belt, or separate undivided greenstone in the south of the belt from metasediments in the north (Fig. 3).

Poorly magnetised faults and fractures cut all Archaean rocks. Many also displace and hence are inferred to postdate north to north-northwest-striking major shear/fault zones. They are most evident in moderate to highly magnetised gneiss and granite. Their most common orientations are northeast and northwest. Northeast-oriented fracture directions, which are much less common farther south in the Eastern Goldfields Province, may have resulted from tectonism restricted to the northern margin of the Yilgarn Craton. Apparent sinistral movements of up to 5 km are inferred for many of the west to west-northwest striking faults.

Dykes are less evident in the aeromagnetic data for BALLIMORE and SANDALWOOD than in the data for the rest of the Wiluna Sheet area. Their most common trends are 270-280° and 320-330° Some dykes consist of en-echelon segments. None of these linear features correlate with gravity anomalies.

Proterozoic units (Ꝑ_l, Ꝑ_h)

Sedimentary rocks of the Palaeoproterozoic Earaheedy Basin in the northeast lie nonconformably on the Archaean rocks and dip gently northeast. They are generally poorly magnetised (Ꝑ_l), but include two units of highly magnetised (Ꝑ_h) banded iron formation (BIF). The Yelma Formation, at the base of the sedimentary sequence, and the lower part of the overlying Frere Formation are both poorly magnetised; the magnetic anomalies in them are due to underlying Archaean rocks. These anomalies diminish to the northeast due to the increasing thickness of the Proterozoic sedimentary rocks. The lower highly magnetised BIF unit is located within the Frere Formation about one-third of the way up from its base, and corresponds to a sand-covered depression between two low ridges. Irregularities in the local magnetic trends may be partly due to irregular erosion and partly to oxidation of magnetite in BIFs during weathering. A second BIF is located near the top of the Frere Formation. Sediments of low magnetisation overlying the BIFs are in effect transparent, and so images of the data provide details of lineaments and other irregularities (eg. thickness, folding, and weathering) associated with the BIFs. Magnetic anomalies diminish to the northeast as the BIFs become buried to greater depths.

Several lineaments within the Archaean geophysical units extend beneath the Proterozoic sedimentary rocks. Substantial anomalies occur where these lineaments intersect and appear to cut the BIF units. These anomalies are considered to be due to alteration of magnetite during the Proterozoic or later. East-trending lineaments have large amplitude lows on their northern sides and highs on their southern sides.

The Earaheedy Basin coincides with the lowest Bouguer anomaly in BALLIMORE, but this low is attributed to underlying Archaean granite rocks rather than to thick Proterozoic sediments.

Discussion

The general alignment of north to north-northwest trending shear zones with elongate gneiss and granite bodies and greenstone belts suggests that much of the Archaean deformation was associated with movements along the shear zones, and that the rocks affected were somewhat ductile at the time. A general sinistral sense of movement is indicated for the shear zones from the shape of the granitic bodies. These bodies generally show the greatest amount of deformation at their margins. This early tectonism predated many crosscutting faults and dykes, which were probably developed in brittle crust.

γ-ray spectrometric interpretation

The γ-ray spectrometric data provide information on the amount of potassium (K), thorium (Th), and uranium (U) in approximately the top 0.5 m of surface materials, whether they be fresh bedrock or regolith (variably weathered bedrock, surface cappings such as ferricrete and laterite gravel, and surficial sediments). In BALLIMORE and SANDALWOOD, where there are few exposures of fresh bedrock, the data mainly show variations in regolith materials. A composite 3-band image (K – red, U – blue, Th – green; Fig. 4) was used for the interpretation, as this shows more geologically meaningful features than the single band images. Within the two sheet areas, mean γ-ray spectrometric count rates (cps) are potassium ~70 cps (range 0 to 270cps); uranium ~20 cps (range 0 to 130cps); and thorium ~50 cps (range 0 to 170 cps). The count-rate frequency distributions for each element are skewed towards lower values. In the following discussion, 'low' refers to count rates below the arithmetic mean value, 'moderate' to those between the mean and twice the mean, and 'high' to count rates more than twice the mean value.

In the northern part of the Eastern Goldfields, most lake systems are oriented between west and west-northwest. Breakaways and associated basement outcrops are similarly oriented and face south. Slopes down to the south tend to be steeper and shorter than those to the north. These features, which have been interpreted as results of tilting of fault-blocks (Stewart 1999), need to be considered when interpreting the distribution of K, U and Th.

Table 2. Radiometric count rates for bedrock and regolith materials

Locality (Fig. 4)	*K*	*U*	*Th*	*Colour on image*	*Remarks*
A	236	136	203	White	Exposed high-K-U-Th granite (Ag)
B	150	20	33	Pink – red	Exposed high-K granite (Ag)
C	400	18	43	Pink – red	Exposed Yelma Formation (ⱣEy)
D	46	24	157	Blue-green (bright)	Exposed Frere Formation (ⱣEf)
E	220	20	115	Cream-yellow	Exposed Windidda Formation (ⱣEds)
F	30	25	115	Blue-green	Silcrete on kaolinised granite (Czzg)
G	23	20	85	Blue-green	Ferricrete and lateritic gravel (Czl)
H	181	31	117	White-cream	Granite and granitic debris below breakaway (Ag, Czg)
I	167	10	83	Yellow-orange	Colluvium associated with exposed granite (Czg, Cza)
J	108	2.5	40	Red-pink	Distal colluvium and sand down-slope from granite exposures (Czs)
K	13	11	19	Dark olive green	Sand plain (including dunes) and colluvium (Czs & Czb)
L	0	62	30	Blue	Lake sediments (Czp)

Two broad types of Archaean granite can be distinguished from the γ-ray data (Table 2 and Figs. 4, 5): a high-K-U-Th type (A), which correlates with white to yellow in the composite image, and a high-K type (B), which correlates with red tones in the composite image. The high-K-U-Th type corresponds to the 'low Ca' and syenite suites defined in the northern part of the Eastern Goldfields by Champion & Sheraton (1997), and the high-K type corresponds to the 'high Ca' and 'high high-field-strength-element (HFSE)' suites of the same authors. Granitic gneiss is not discriminated by γ-ray data from the high-K granite.

Greenstone belts in BALLIMORE and SANDALWOOD correlate with blue-green tones in the composite image. These tones are typical of the ferruginous regolith developed on greenstone belts in this region.

The largest area of exposed basal Yelma Formation (400 cps) in the northeast (C in Fig. 4), at the base of the Proterozoic Earaheedy Basin sequence, is red to pink in the composite image, but in this image is not readily distinguished from adjacent exposures of Archaean high-K granite (236 cps; Table 2). The overlying Frere Formation (banded iron, shale, and chert) is characterised by low K, low to moderate U, and high Th (D in Fig. 4), giving rise to green and blue-green colours in the composite image; weak colour striping is parallel to bedding. A shale unit near the top of the Frere formation (ⱣEfs), corresponding to strike-aligned creamy colours in the composite image, has moderate to high K, low U, and moderate Th count rates. Cream bands within the Frere Formation may also be due to shale. The overlying shaly siltstone of the Windidda Formation (ⱣEds; E in Table 2 and Fig. 4) has K, U, and Th count rates similar to those of shale in the Frere Formation.

The γ-ray data for BALLIMORE and SANDALWOOD do not distinguish between ferricrete and lateritic gravel (Czl) capping greenstone, and silcrete and associated kaolinised granite (Czzg) capping breakaways. These materials are characterised by very low K, low to moderate U, and moderate Th count rates, resulting in blue-green areas in the composite image. In the adjoining Sir Samuel 1:250 000 Sheet area to the south, Czzg is associated with slightly higher U count rates relative to Czl, and is not so green on the γ-ray image (A. Whitaker – unpublished data). The areal extent of laterite and silcrete + kaolinised granite (Fig. 5) inferred from the γ-ray data is much greater than that shown on the geological maps, probably because it includes areas covered by thin (<0.5 m) aeolian and colluvial sediments with similar spectrometric signatures.

Colluvial aprons down-slope from bedrock outcrops generally have the same colours in the composite spectrometric image as the source rocks. Thus proximal granite-derived colluvium (Czg) tends to be red (high-K granitic rocks) or white–yellow (high-K-U-Th granite/syenite). The spectrometric characteristics of distal colluvium (Cza) are far more variable, but are also noticeably influenced by the nature of the source materials up-slope. In most instances the composite image shows a continuum in colour down-slope

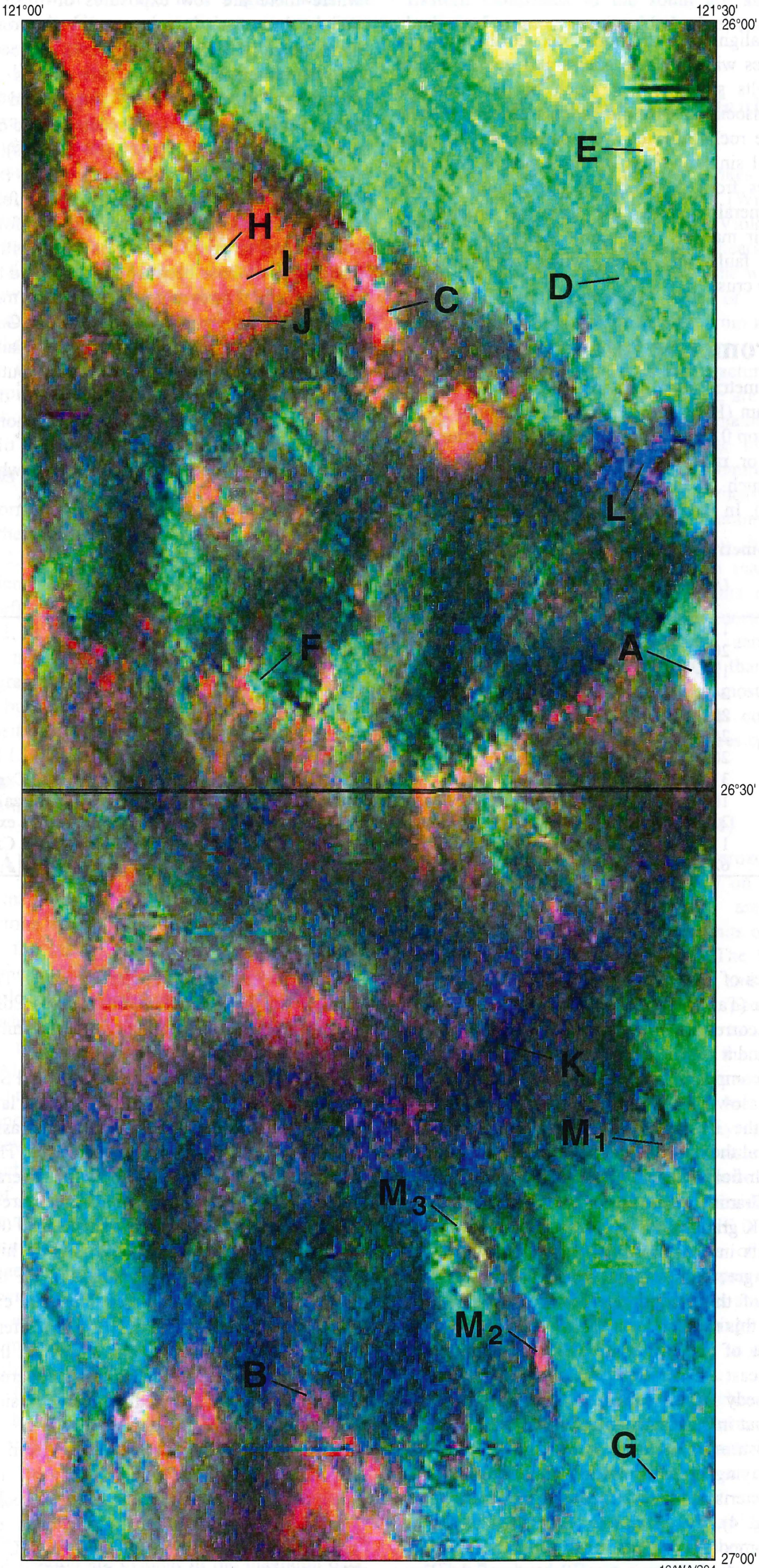

Figure 4. γ-ray spectrometric image of BALLIMORE and SANDALWOOD

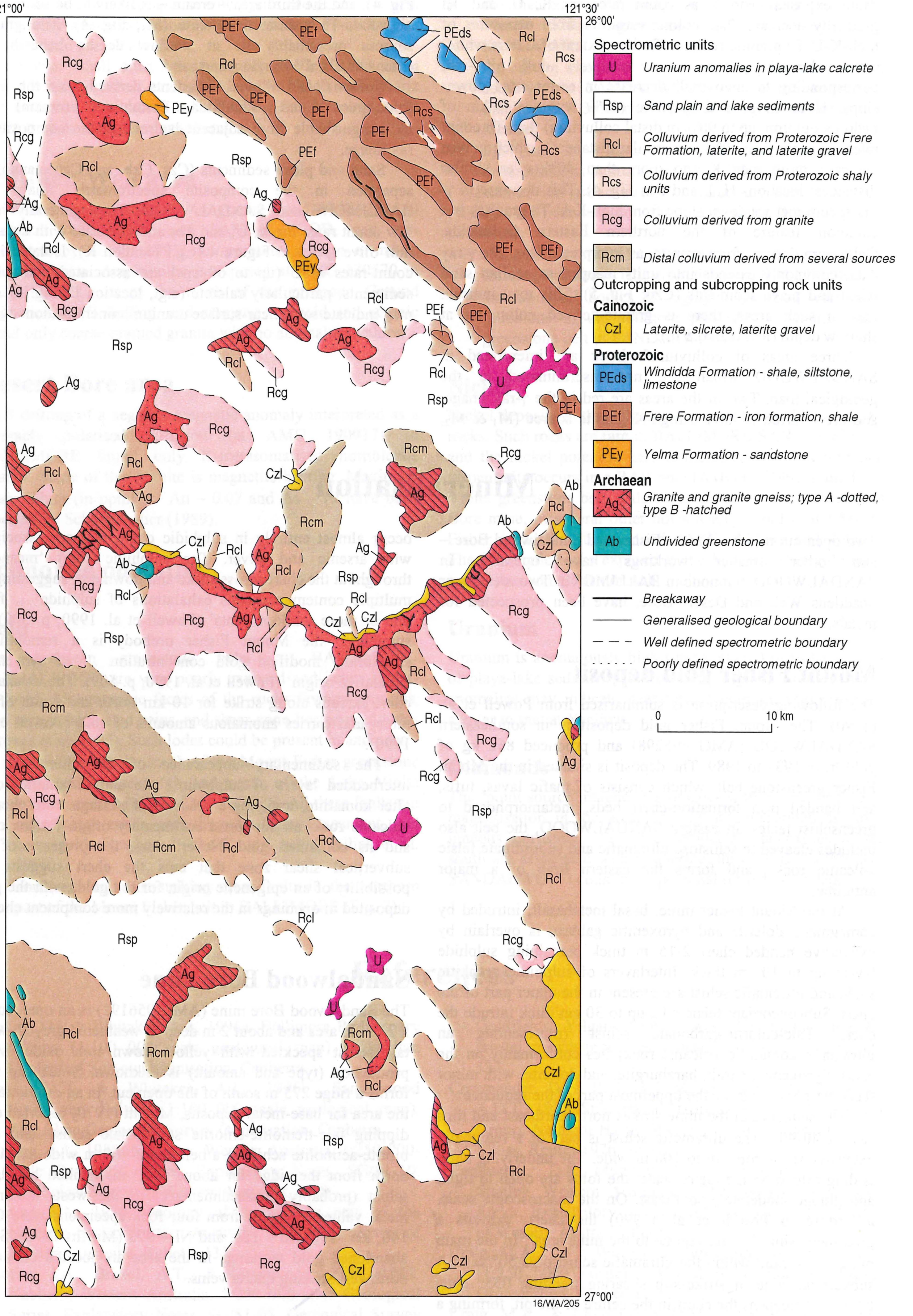

Figure 5. Generalised geological map of BALLIMORE and SANDALWOOD based on outcrop geology and interpretation of γ-ray spectrometric units

from exposed bedrock as count rates for K, U, and Th gradually decrease. The colour variation from exposures of high-K-U-Th granitic rocks to farthest extent of Cza is white-cream through yellow to a relatively dull pink-red, corresponding to an overall decrease in count rates downslope. U count rates drop more (60% within 1-2 km of bedrock outcrop, up to 90% in distal colluvium) than Th count rates (no more than 60% over similar distances), which in turn decrease more than K (no more than 40% over similar distances; locations H, I, and J in Fig, 4). This decrease in γ-ray spectrometrics down slope from high-K-U-Th granites is a common feature of the northern Eastern Goldfields. Colluvium derived from granite, as interpreted from the γ-ray data, commonly extends into units mapped as aeolian sand (Czs) and playa sediments (Czp; Fig. 5). This may indicate that in such areas, there is granite-derived colluvium at shallow depth (less than 0.5 m).

Three areas of colluvium/bedrock are interpreted in SANDALWOOD which are not discriminated in the geological map. Two of the areas are red in the γ-ray image, and are inferred to have a high-K granite source (M_1 & M_2, Fig. 4), and the third area – cream – is likely to be sourced by high-K-U-Th granite or syenite (M_3, Fig. 4). The granite sources presumably lie at shallow depths beneath the extensive distal colluvium and sand.

Colluvial and alluvial sediments derived from the Frere (blue-green) and Windidda Formations (cream) are indistinguishable from adjacent bedrock in the composite γ-ray image.

Sand and playa sediments (Czs, Czb, and Czp) cannot be separated in the composite spectrometric image for BALLIMORE and SANDALWOOD. They generally have low count rates for K, U, and Th, and correlate with areas of dull olive green in Figure 4 (e.g., location K). Isolated high count-rates of U (up to 60 cps) are associated with playa sediments, particularly calcrete (e.g., location L, Fig. 4), and may indicate some near-surface uranium mineralisation.

Mineralisation

Two open-cut mines – Mount Fisher and Sandalwood Bore – and other smaller workings have operated in SANDALWOOD, but none in BALLIMORE. Two areas, near Scaddens Well and Desert Bore, have been prospected for metals.

Mount Fisher gold deposit

The following description is summarised from Powell et al. (1990). The Mount Fisher gold deposit is in southeastern SANDALWOOD (AMG 495298) and produced 852 kg of gold from 1937 to 1989. The deposit is situated in the Mount Fisher greenstone belt, which consists of mafic lavas, tuffs, and banded iron formation-chert beds, metamorphosed to greenschist facies. In eastern SANDALWOOD, the belt also includes cleaved to schistose ultramafic and subordinate felsic volcanic rocks, and forms the eastern limb of a major anticline.

At the Mount Fisher mine, basal metabasalt, intruded by comagmatic dolerite and pyroxenitic gabbro, is overlain by exhalative banded chert 2-15 m thick containing sulphide layers up to 10 cm thick. Interlayers of sulphidic graphitic shale and ultramafic schist are present in the upper part of the chert. Subconcordant felsic sills up to 30 cm thick intrude the chert. Talc-chlorite-carbonate schist (representing an ultramafic komatiitic volcanic rock) lies conformably on the chert. Pyroxenite, basalt, harzburgite, and dolerite, with minor felsic porphyry, intrude the uppermost part of the sequence.

The sequence at the mine strikes north-northeast and dips east at 40-90°. The ultramafic schist is part of a regionally extensive shear zone up to 100 m wide. The underlying chert is drag-folded on the metre-scale; the folds are open to tight, and plunge moderately southeast. On the macroscopic scale, according to Powell et al. (1990) the chert 'exhibits a prominent kink flexure, unique to the mine area'. In the main pit, a thrust fault within the ultramafic schist dips 50° east. A subvertical zone of strike-slip shearing trending 055° cuts, thins, and steepens the chert in the centre of the pit, forming a barren zone between ore shoots.

The gold mineralisation is confined to the chert. The ore forms two northeast-plunging shoots separated by the strike-slip shear zone. Gold particles range from 30 μm to 1 mm, occur almost entirely in sulphidic chert, and are associated with arsenic and silver. The sulphidic chert 'meanders throughout the chert across strike and down dip, suggesting ... multiple contemporaneous exhalations of sulphide ... from one or more seafloor vents' (Powell et al. 1990, p. 509). In summary, 'the Mount Fisher orebody is a remobilised, structurally modified gold concentration ... of syngenetic exhalative origin' (Powell et al. 1990, p. 509). The exhalative chert extends along strike for 10 km north and south of the mine, and carries anomalous amounts of gold (Powell et al. 1990).

The sedimentary appearance of the chert and its interbedded layers of sulphidic shale and ultramafic schist after komatiite, implying a gradational passage from chert to volcanic rock, all support a sedimentary origin for the chert and its contained gold. Nevertheless, the presence of the subvertical shear zone that cuts the chert suggests the possibility of an epigenetic origin for the gold, with the gold deposited in openings in the relatively more competent chert.

Sandalwood Bore mine

The Sandalwood Bore mine (AMG 056192) is an open cut 70 x 25 m in area and about 2 m deep in weathered greyish-white talc schist speckled with yellow-brown iron oxide. Metal production (type and amount) is unknown. Silica cap rock forms a ridge 275 m south of the open cut. In an evaluation of the area for base-metal deposits, Murfitt (1970) reported east-dipping talc-tremolite-chlorite schist, talc schist, and talc-biotite-actinolite schist in a belt about 460 m wide extending north from the ridge for about 1400 m, flanked by clayey schist (probably metasedimentary) to the west. Maximum metal values (in ppm) from four rock specimens were Cu – 146, Zn –160, Co – 124, and Ni – 975 (Murfitt 1970). Small abandoned gold workings in the area are located on north-northwest-striking quartz veins.

Unnamed mine at AMG 500280

Several shafts, pits, and costeans at AMG 500280 are located on a vertical north-striking quartz vein at least 150 m long.

Ore piled nearby is vein quartz with pyrite and gold. The vein host is very weathered probable basalt overlain by about 1 m of pisolitic to gravelly laterite.

Another small open cut nearby at AMG 501283 is in veined/fractured basalt cut by shear zones filled with quartz and ironstone. An altered raft of basalt has bleached spots which may be amygdales or spherules.

Scadden Well area

A linear magnetic anomaly in granite near AMG 239520 straddles BALLIMORE and SANDALWOOD, and was postulated by Smith (1993) to represent a zone of mafic volcanic rocks. Amphibolite is exposed at AMG 130570 in BALLIMORE, just to the north of the prospect. Ground magnetics, RAB drilling, and assaying for gold and arsenic found only coarse-grained granite with no anomalous values.

Desert Bore area

RAB drilling of a negative magnetic anomaly interpreted as a reversely polarised intrusion (at AMG 190917) in BALLIMORE found only K-metasomatised hornblende granite. Some of this granite is magnetite-bearing. Maximum assay values (in ppm) of Au – 0.07 and As – 19 have been reported by Schusterbauer (1989).

Economic potential

Gold

The Archaean greenstone belts in BALLIMORE-SANDALWOOD are very poorly exposed and hence under-explored. Metamorphic facies of the rocks favours breccias, vein arrays, laminated veins, and shear-zone-hosted gold lodes (Groves et al. 1995). Such lodes could be present in and near:

- cross-faults in the south of the Mount Fisher greenstone belt, and in the south and north of the Lake Violet greenstone belt (in SANDALWOOD). All these faults cut major shear zones, including the Celia Lineament, and carry gold elsewhere in the Yandal belt (Phillips et al. 1998);
- northeast- and east-striking cross-faults in the northern part of the Mount Fisher belt in BALLIMORE (Fig. 3);
- the sheared western margin of the southern part of the Mount Fisher greenstone belt in southeastern SANDALWOOD;
- the eastern margin of the Lake Violet greenstone belt in southwestern SANDALWOOD, where the abandoned Sandalwood Bore mine and other gold workings are located;
- the Bartletts Bore greenstone belt of mainly metasediments in northwest BALLIMORE.

Sites of low mean stress at granite-greenstone contacts (Ridley 1993) can also contain gold deposits. Such sites may be present:

- along the eastern and western margins of the granite body forming Prominent Hill in southeastern BALLIMORE;
- around small bodies of highly magnetised interpreted intrusions in the southern part of the Mount Fisher greenstone belt in SANDALWOOD.

Nickel

Nickel deposits in the Yilgarn region are hosted by komatiitic rocks. Such rocks are rare in BALLIMORE-SANDALWOOD, and the nickel potential here is therefore low. Even-grained serpentinite occurs in a RAB hole (AMG 055199) in the Lake Violet greenstone belt. Talc schist occurs at the Sandalwood Bore mine, in several other holes nearby, and in the Mount Fisher greenstone belt around AMG's 440240 and 430197. The ultramafic rocks exposed at the Mount Fisher gold mine are neither komatiitic nor rich in olivine.

Uranium

Uranium is anomalously high (up to 60 cps) in isolated areas of playa-lake sediments and calcrete (Fig. 4). Some of these anomalies may indicate near-surface uranium mineralisation similar to that at Yeelirrie.

Diamonds

The 'point source' magnetic anomalies with normal or reverse magnetisation in the area (Fig. 3) are interpreted as small igneous intrusions. As some comparable anomalies to the south are associated with kimberlite, those in BALLIMORE-SANDALWOOD could have potential for diamond deposits.

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Appendix 1. List of samples from BALLIMORE-SANDALWOOD

Sample No.	*AMG reference*[1]	*Rock type*	*Map unit*	*Remarks* [2,3]
BALLIMORE				
95964007A	130754	Amphibolite	Agl	In banded gneiss
4010a	251711	Amphibolite	Agl	Veined by granite
4010b	251711	Amphibolite	Agl	Veined by granite
4010c	251711	Amphibolite	Agl	Veined by granite
4010d	251711	Amphibolite	Agl	Veined by granite
4016	023017	Granite	Agng	Weathered
4018A	006028	Felsic gneiss	Anc	Not weathered
4018B	006028	Felsic gneiss	Anc	Not weathered
4018C	006028	Felsic gneiss	Anc	Not weathered
4018D	006028	Felsic gneiss	Anc	Not weathered
4021A-C	002050	Gneiss	Anc	Metasedimentary
4027	052075	Granite	Agl	Fresh to weathered
4029	152078	Leucogranite	Agl	Weathered; with aplite and quartz veins
4032	101130	Leucogranite	Agl	Weathered
4033	118160	Sandstone	PEy	Yelma Formation
4037	135194	Ironstone	PEf	Frere Formation; oolitic?
4038	143205	Chert	PEf	Frere Formation; oolitic
4042	191191	Ironstone	PEf	Frere Formation; oolitic
4044	194127	Siltstone	PEf	Frere Formation
4048	253221	Ironstone	PEf	Frere Formation; oolitic, cherty
4055	379231	Limestone	PEd	Windidda Formation; stromatolitic
4056	374219	Limestone	PEd	Windidda Formation; also siltstone and shale
4059	315175	Siltstone	PEfs	Frere Formation; also oolitic chert
4066	434059	Siltstone	PEf	Frere Formation; also oolitic sandstone
4068	472026	Siltstone	PEfs	Frere Formation; also oolitic ironstone and sandstone
4071	402982	Ironstone	PEf	Frere Formation; partly oolitic
4082	272137	Sandstone	PEf	Frere Formation; also siltstone and chert
4155	004084	Granite	Agl	-
4156	097127	Granite	Agl	-
4157	151066	Granite	Agl	Leucocratic
4158	151061	Granite	Agl	Leucocratic
4160	237069	Granite	Agl	Leucocratic
4173a, b	295953	Granite	Agl	Leucocratic, weathered
4179	475903	Ironstone	PEf	Frere Formation; cherty
4191A-C	449769	Granite	Agl	Weathered
4195	491759	Granite	Agmp	Porphyritic, fresh
4199	500768	Gabbro	Aog	DH
4200	501775	Greenstone	Aba	Mafic extrusive
4201	500775	Greenstone	Aba	Mafic extrusive and epidotic quartzite
4203	500787	Metabasalt	Aba	Intruded by granite
4205A, B	500790	Metabasalt	Aba	With epidotic quartzite
4229	127750	Granite	Agl	DH; with amphibolite
4237	130908	Granite	Agl	Fresh
4247A	195727	Granite	Agl	Leucocratic, fine to medium-grained
4249	230704	Biotite monzogranite	Agmf	DH
4255	292688	Granite	Agmf	Fresh, fine-grained
4264	489776	Dolerite	d (PEdy)	Fresh
SANDALWOOD				
4261	363655	Granite	Czg	Fresh, fine-grained
4269a,b,c	503618	Basalt	Aba	Fresh
4281	440240	Talc-chlorite schist	Aut	DH
4282	485243	Ironstone	Ac	Metasedimentary
4283a	488271	Rhyolite	Af	Weathered
4287a,b,c	500280	Laterite	Ab	From mine dump
4288a-d	492295	Basalt	Au/Czf contact	-
4294	070226	Schist	Af	Weathered; felsic extrusive
4295	070221	Schist	Af	Weathered; felsic extrusive
4300	151255	Granite	Agl	Weathered; gneissic
4307	234209	Amphibolite	Abam	Fresh
4308	231198	Granite	Agl	Fresh
4313	276176	Amphibolite	Czl	Weathered; quartz-veined
4314a, b	279172	Amphibolite	Agl/Czl contact	With some metasediments
4320	430196	Talc-chlorite schist	Aut	DH
4321	432196	Talc-chlorite schist	Aut	DH
4324	501283	Basalt	Ab	Weathered
4338	219575	Granite	Cza	Fresh
4345	090536	Granite	Agl	Weathered; porphyritic,
4346	067570	Granite	Agl	Weathered, fine-grained
4356	037593	Granite	Agl	DH; leucocratic, fine-grained

4359	009540	Tonalite	Czg	DH; hbl and biot present
4360	012370	Schist	Abf	Weathered; with amphibolite
4361a	011372	Amphibolite	Abf	DH
4364	039299	Schist	As	Weathered; metasedimentary
4366	041294	Amphibolite	Abam	Fresh, intruded by granite
4367	046284	Sandstone	As	Weathered; intruded by granite
4371a,b	056195	Schist	Au	DH
4372	056193	Schist	Au	Weathered; talcose, with some sediments
4374	060176	Talc-chlorite schist	Aut	DH
7335	017201	Granodiorite	Agl	Medium-grained
96960220	056192	Talc schist	-	Sandalwood Mine
0226	056208	Amphibole-chlorite schist	Aur	DH; also has act, ep, and possible ill or mont
0227	061210	Quartz-kaolin schist	Alf	DH; qz, kln, smect
0228	055199	Serpentinite	Aus	DH; serp, opq
0229	056195	Talc schist	Aut	DH; has relict spinifex texture
0230	056191	Chlorite-quartz rock	Alqc	DH; also has kln and smect (or possible mont)
0231	057175	Chlorite-quartz rock	Alqc	DH; also has kln and possible mont
0233	062177	Chlorite-amphibole schist	Aul	DH; also has smec (possible mont) and clay (possible mixed-layer)
0234	075141	Slaty shale	Ash	DH; qz, kln, smect or mont (trace)
0236	023167	Granite	Agf	Fresh, medium-grained

[1] AGD 66

[2] DH – Drillhole sample

[3] act – actinolite; biot – biotite; ep – epidote; hbl – hornblende; ill – illite; kln – kaolin; mont – montmorillonite; opq – opaque grains; qz – quartz; serp – serpentine; smec – smectite