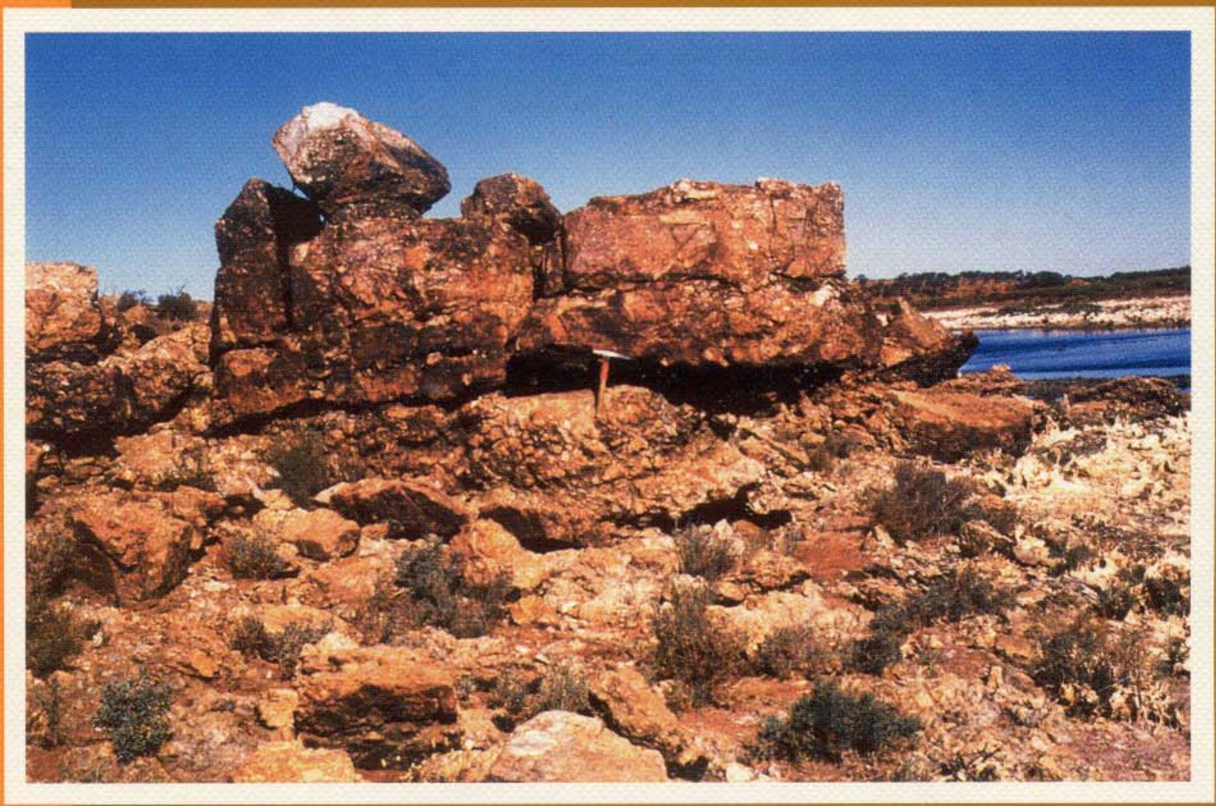
EXPLANATORY NOTES

GOVERNMENT OF WESTERN AUSTRALIA

GEOLOGY OF THE THADUNA 1:100 000 SHEET

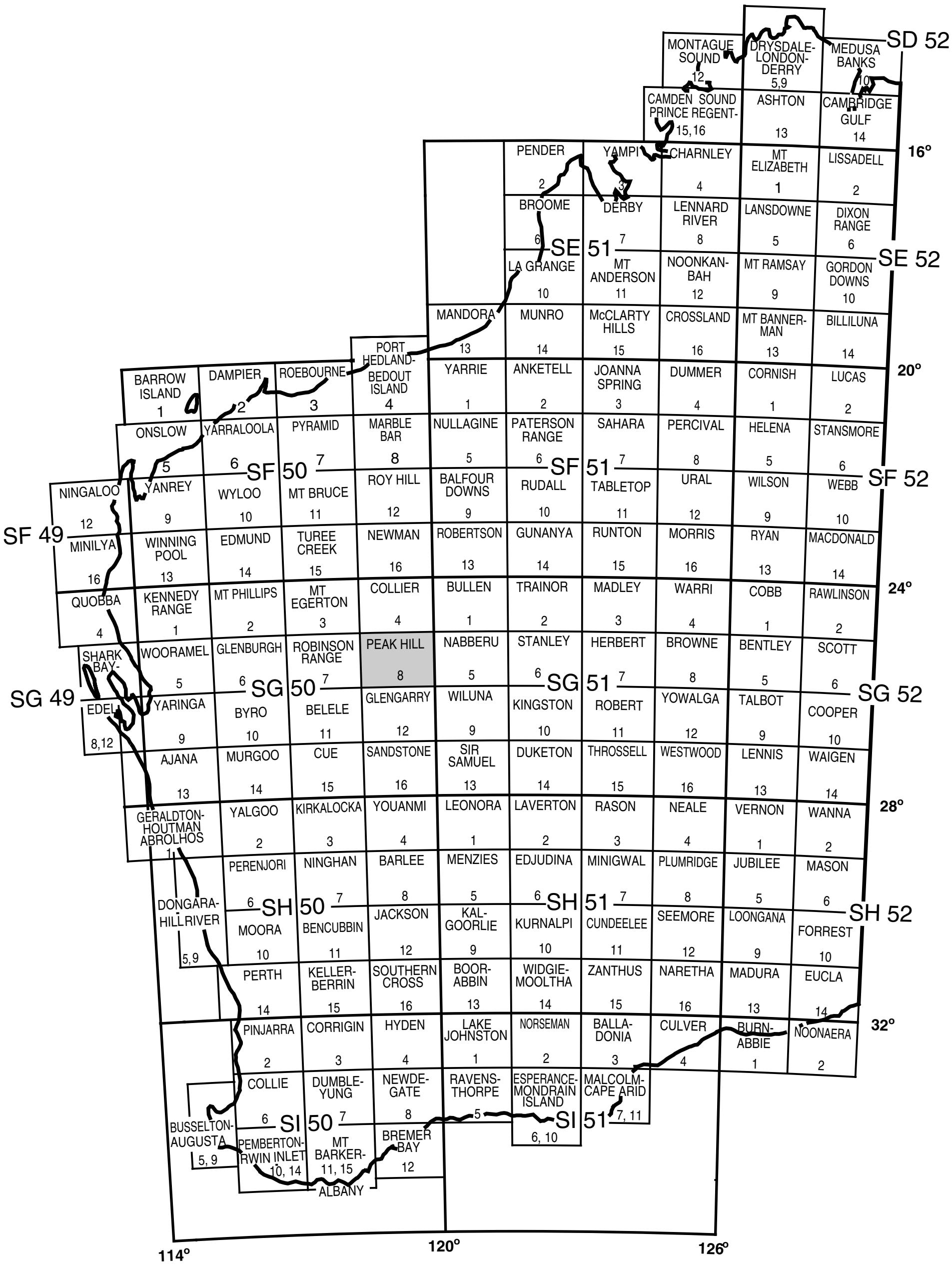
by F. Pirajno and N. G. Adamides

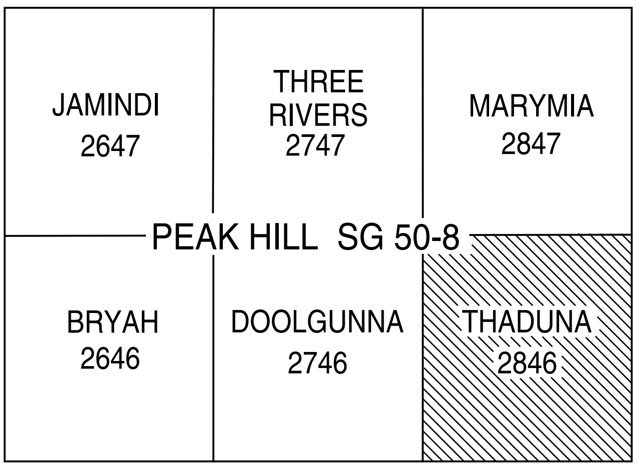
1:100 000 GEOLOGICAL SERIES



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DEPARTMENT OF MINERALS AND ENERGY





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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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Cover photograph:
Outcrop of chert breccia of the Yelma Formation, Earaheedy Group, on the west shore of Lake Gregory.

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F. Pirajno and N. G. Adamides

Abstract

The THADUNA 1:100 000 geological map sheet covers part of the Palaeoproterozoic Yerrida and Earaheedy Basins on the northern margin of the Yilgarn Craton. Both basins are considered to be part of the Capricorn Orogen that was formed as a result of the collision of the Pilbara and Yilgarn Cratons between about 2000 and 1800 Ma.

The Yerrida Basin is the depocentre of the Yerrida Group, which comprises a lower sag-basin succession (Windplain Subgroup) and an overlying rift-basin succession (Mooloogool Subgroup). The Mooloogool Subgroup forms the bulk of the Yerrida Group and, from oldest to youngest, includes the Thaduna, Doolgunna, Killara, and Maraloou Formations. The Thaduna and Doolgunna Formations comprise turbidite-facies rocks, mainly lithic and arkosic sandstones. The Killara Formation comprises continental mafic extrusive and intrusive rocks of tholeiitic affinity, and is overlain by the Maraloou Formation, which includes black shales.

The Yerrida Group is unconformably overlain by chertified carbonate and chert breccias of the Yelma Formation, the basal unit of the Earaheedy Group, in the northeast of the sheet area.

Rocks of the Thaduna Formation host fault-controlled epigenetic copper deposits. The Thaduna copper mine and nearby prospects contain a resource of about 17 000 t of copper metal. Regolith geochemical platinum and palladium anomalies associated with the mafic rocks of the Killara Formation suggest that these rocks may be prospective for platinum-group elements.

KEYWORDS: Palaeoproterozoic, Capricorn Orogen, Yerrida Group, Earaheedy Group, mafic rocks, volcanic rocks, stromatolites, mineralization, copper

Introduction

Location and access

The THADUNA* 1:100 000 map sheet (SG 50-8, 2846) covers the southwest corner of the PEAK HILL 1:250 000 sheet and is bound by latitudes 25°30' and 26°00'S, and longitudes 119°30' and 120°00'E. Access to the northern part of the sheet area is gained through the unsealed Neds Creek road joining the town of Wiluna, 100 km to the southeast, with the Great Northern Highway. In the northwest, access is provided from the Great Northern Highway by unsealed roads servicing the Neds Creek Homestead. Access to the rest of the area is poor and mainly by four-wheel drive vehicle tracks along fence lines.

Climate and vegetation

The climate in the THADUNA area is semi-arid to arid, with a mean annual rainfall of between 200 and 240 mm. Summers are hot, with temperatures commonly exceeding 40°C, whereas winters are mild, with temperatures ranging from 6 to 20°C in the months of June to August.

The southern part of THADUNA straddles the boundary between the Gascoyne and Murchison regions of the Eremaean Botanical Province (Beard, 1990). Numerous species of vegetation are present in the area, many of them characteristic of specific physiographic units. The most abundant of the bigger shrubs is mulga (*Acacia aneura*), which is present in almost all habitats, and is commonly

* Capitalized names refer to standard 1:100 000 map sheets, unless specified otherwise.

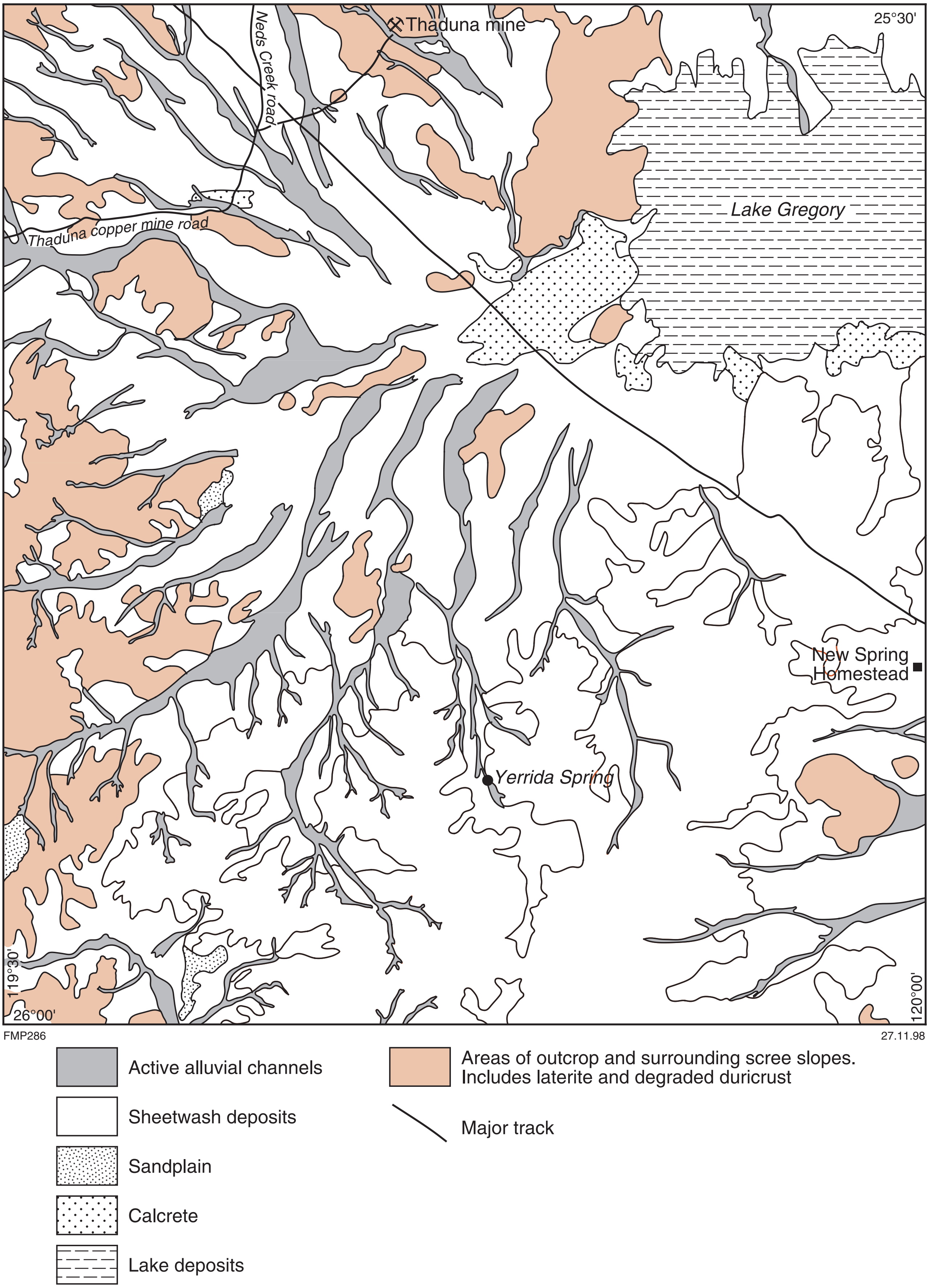

Figure 1. Physiography of Thaduna

associated with broad-leaf acacia species. Eucalypts, predominantly river red gum (*Eucalyptus camaldulensis*), line the major watercourses. Species of *Eremophila*, particularly Wilcox bush (*Eremophila forrestii*), are abundant as an understory to the mulga on rich soils, and generally associated with species of the *Cassia* group, predominantly crinkled cassia (*Cassia helmsii*) and white cassia (*Cassia luersenii*). Several species of everlasting daisies associated with larger annuals (purple mulla mulla and cotton bush) make colourful displays during spring. A detailed account of native shrubs of arid Western Australia is given in Mitchell and Wilcox (1994).

Physiography

A simplified physiographic map of THADUNA is shown in Figure 1. The physiography of THADUNA is dominated by a radial arrangement of sheetwash fans and poorly defined alluvial channels flowing into Lake Gregory. This radial pattern is particularly evident on Landsat Thematic Mapper images, highlighted by a characteristic regular arrangement of vegetation groves.

Lake Gregory is part of a playa-lake system, extending about 100 km eastward to the Shoemaker Impact Structure on NABBERU (Pirajno and Glikson, 1998). The playa-lake system includes the salt lake (covered by few centimetres of water only after heavy rain), gypsiferous and calcareous sand dunes along the margins of the lake, and calcrete in the valley floors of creeks draining into the salt lake.

The southern half of THADUNA mainly consists of low hills formed by rocks of the Killara, Doolgunna, and Maraloou Formations, and remnants of lateritic duricrust forming plateaus a few metres high. This laterite has a light-grey tone on monochrome photographs and is distinct from the darker grey tone of the finer grained detritus formed by the degradation of the duricrust (*Czf*). These finer grained products generally occupy the flat tops and slopes of mesas adjacent to laterite breakaways. Beneath the laterite, the mafic rocks of the Killara Formation are commonly fresh. The mafic rocks form low hills with close-spaced drainage. The lithic sandstones of the Doolgunna and Thaduna Formations are characterized by a generally smooth topography with low outcrops, and good exposures limited to areas of breakaways. Extensive sheetwash deposits flank areas of outcrop, and represent weathering products of these rocks. These materials are transported by ephemeral streams towards the Lake Gregory basin in the northeast.

Previous investigations

The earliest geological description of the area is that of Talbot (1920), who produced a geological map that included THADUNA. The first detailed geological account of the area is that of MacLeod (1970), who described the geology of PEAK HILL (1:250 000) and referred to the lithic sandstone that hosts the Thaduna copper deposit as the 'Thaduna beds'. PEAK HILL was subsequently described by Gee (1979, 1987). The area was also included in a major study of the Nabberu Basin and associated iron formations (Hall and Goode, 1978).

The sedimentary and mafic igneous rocks on THADUNA were initially included in the Palaeoproterozoic Nabberu Basin (Hall and Goode, 1975), a major depocentre covering an area of 60 000 km^2 (Bunting, 1986). This basin was subsequently subdivided by Gee and Grey (1993), on the basis of unconformable relationships, into the Glengarry and Padbury Basins to the west, and the Earaheedy Basin to the east. Recent work in the Glengarry Basin led to its redefinition into the Bryah, Padbury, and Yerrida Basins (Pirajno et al., 1995, 1996). The Yerrida Basin encompasses the eastern part of the former Glengarry Basin. The modified stratigraphy is discussed by Pirajno et al. (1996) and Occhipiniti et al. (1997).

Blockley (1968) gave a detailed account of the mineralization at the Thaduna copper mine. Petrographic features of rocks from the mine were described by Trendall (1968). Grey (1994) described stromatolites from the Earaheedy Group.

Regional geological setting and geochronology

THADUNA incorporates the northeastern part of the Yerrida Basin and the westernmost part of the younger Earaheedy Basin. The Yerrida and Earaheedy Basins, together with other basin structures to the west, are considered to be part of the Palaeoproterozoic Capricorn Orogen (Pirajno et al., 1988; Tyler and Thorne, 1990).

The Capricorn Orogen is a major zone of deformed, low metamorphic grade sedimentary and volcanic basins, high-grade metamorphic belts, and granitoid intrusions. The zone extends for more than 800 km in an east-southeast direction from near the coast towards the interior of the continent (Fig. 2). The orogen also includes older tectonic units (Narryer Terrane, Marymia Inlier, Sylvania Inlier, and parts of the Hamersley Basin) that were reworked to varying degrees. The Capricorn Orogen developed as a result of the collision between the Archaean Pilbara and Yilgarn Cratons between 2000 and 1800 Ma (Tyler and Thorne, 1990; Myers, 1993; Myers et al., 1996). The Capricorn Orogeny involved a continent–continent collision, the closure of an intervening ocean, opening of a back-arc basin, and accretion of a microcontinent (Myers et al., 1996; Tyler et al., 1998). The inception and evolution of basin structures in the Bryah–Yerrida–Earaheedy region may be attributed either to a back-arc – foreland-basin setting, or to transtensional movements in a series of pull-apart basin settings (Pirajno, 1996; Pirajno et al., 1998b).

THADUNA contains rocks of the Yerrida and Earaheedy Groups (Figs 2 and 3; Table 1). On THADUNA, the Yerrida Group is unconformably overlain by the Earaheedy Group, which is represented by the clastic and carbonate rocks of the Yelma Formation (Table 1). The Yerrida Group includes a sag-basin succession of siliciclastic and

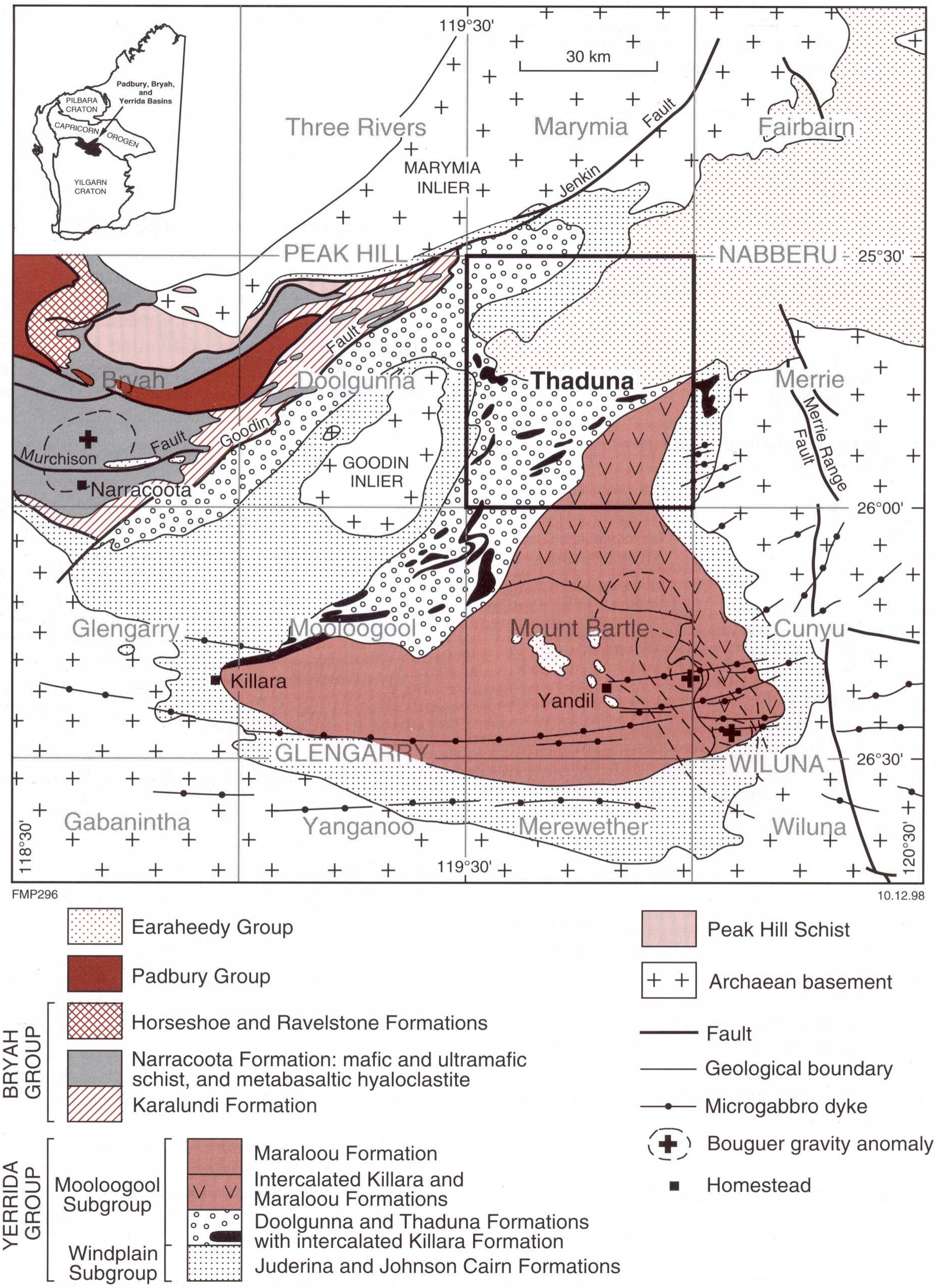

Figure 2. Simplified geology of the Bryah, Padbury, and Yerrida Basins, and the location of THADUNA

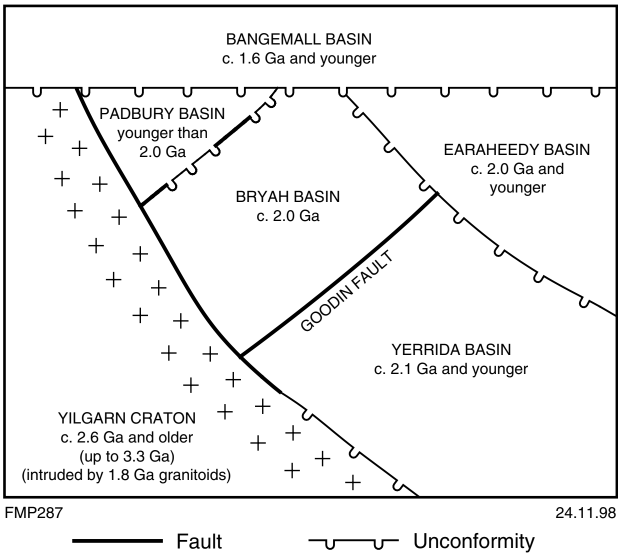

Figure 3. Schematic relationships between tectonic units on THADUNA

evaporitic rocks (Windplain Subgroup) and a volcano-sedimentary rift-basin succession (Mooloogool Subgroup).

The ages of the Yerrida and Earaheedy Groups are poorly constrained. The Yerrida Group is younger than 2.6 Ga because the basal Finlayson Member of the Juderina Formation lies unconformably on granite–greenstone rocks of the Yilgarn Craton, which are older than 2.65 Ga (Myers, 1995; Nelson, 1997). Woodhead and Hergt (1997) reported Pb–Pb isochron ages of 2173 ± 80 Ma from stromatolitic carbonate of the Bubble Well Member (Juderina Formation), and 2008 ± 68 and 1946 ± 71 Ma from carbonate units of the Yelma Formation (Earaheedy Group) on MEREWETHER. Thus, the age of the Yerrida Group is considered to be between 2.1 and 1.9 Ga.

The age relationships between the Yerrida and Earaheedy Basins and adjacent tectonic units are shown in Figure 3.

Proterozoic geology

The Proterozoic stratigraphy of THADUNA is shown in Table 1, relationships between stratigraphic units are shown in Figure 4, and a simplified geological map is presented in Figure 5.

Yerrida Group

The Yerrida Group is subdivided into the Windplain and Mooloogool Subgroups; their distribution in the Yerrida Basin is shown in Figure 2. The Windplain Subgroup contains the Juderina and Johnson Cairn Formations, which, on THADUNA, are characterized mainly by unmetamorphosed, undeformed or weakly deformed clastic rocks deposited in a predominantly shallow-marine, epicontinental environment (sag-basin succession; Pirajno et al., 1995). The Juderina Formation also contains stromatolitic carbonate of the Bubble Well Member, which was intersected in drillcore in the southeast of THADUNA, near Quartermaine Well (DDH QMW 83-1; Otterman, 1986).

The Mooloogool Subgroup contains the Thaduna, Doolgunna, Killara, and Maraloou Formations, all of

Table 1. Stratigraphy of the Yerrida and Earaheedy Basins

Basin/Group/Subgroup	*Formation/Member*	*Rock type*
EARAHEEDY BASIN **Earaheedy Group**	Yelma Formation	Conglomerate, arenite, stromatolitic carbonate, dolomite, and chert breccia
~~*unconformity*~~~~		
YERRIDA BASIN **Yerrida Group**	Maraloou Formation	Black shale, siltstone, and carbonate
Mooloogool Subgroup (rift succession)	Killara Formation	Mafic extrusive and intrusive rocks
	Bartle Member	Laminated chert
	Doolgunna Formation	Arkosic sandstone, siltstone, and minor conglomerate
	Thaduna Formation	Lithic sandstone, shale, and minor dolomite
Windplain Subgroup (sag-basin succession)	Johnson Cairn Formation	Siltstone, shale, dolomite, and minor lithic and quartz sandstone
	Juderina Formation	Quartz arenite, siltstone, and pebble beds
	Bubble Well Member	Silicified stromatolitic carbonate with evaporitic minerals
	Finlayson Member	Quartz arenite
~~*unconformity*~~~~		

SOURCE: Modified from Pirajno et al. (1996)

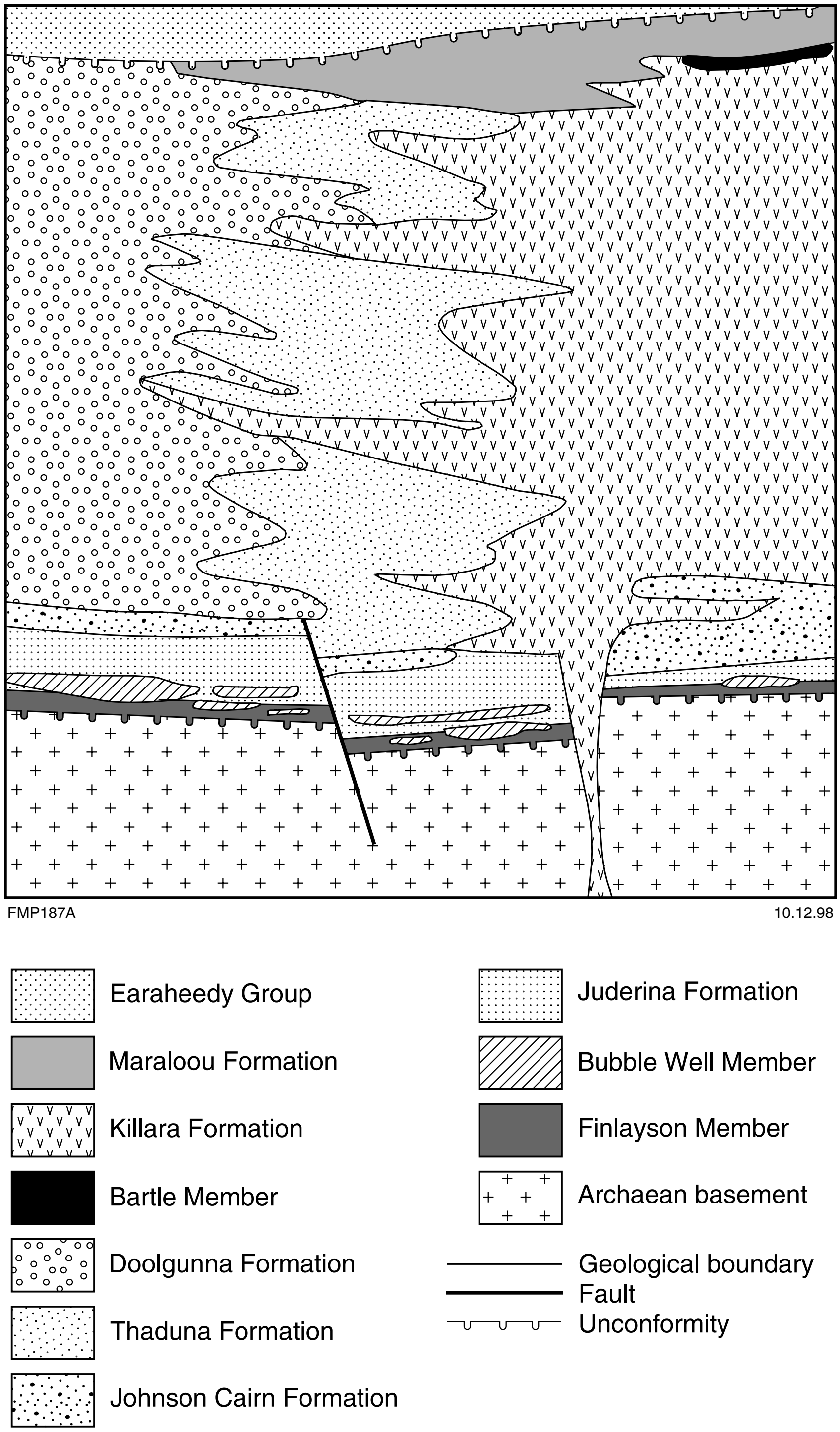

Figure 4. Relationships between stratigraphic units on THADUNA

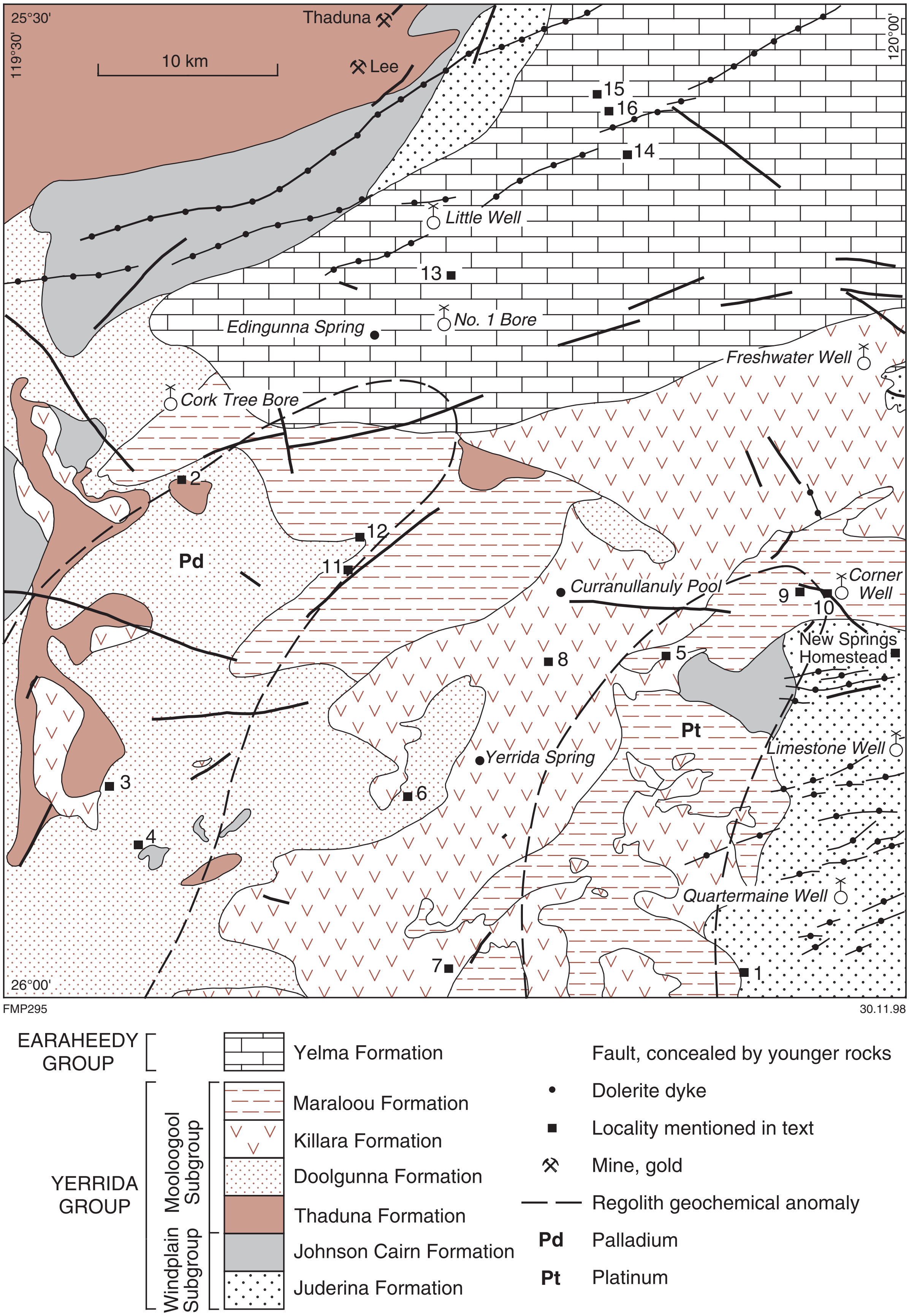

Figure 5. Simplified geology of Thaduna, showing localities mentioned in the text and approximate position of regolith platinum and palladium anomalies

which are represented on THADUNA. The Thaduna and Doolgunna Formations are turbidites that were deposited in a northeast-trending rift (Fig. 2) concurrently with the igneous activity that produced the rocks of the Killara Formation. The Doolgunna Formation is predominantly arkosic, and derived from a granite source, whereas the Thaduna Formation has a predominantly mafic provenance. The turbidite rocks are the result of high-energy terrigenous sedimentation sourced from uplifted blocks of basement inliers (Goodin and Marymia Inliers; Fig. 2) and, perhaps, mafic rocks of the Bryah Group (Narracoota Formation) uplifted along the Goodin Fault (Fig. 2). On THADUNA, the Killara Formation includes tholeiitic lava flows, dolerite, and gabbro intrusions. The emplacement of voluminous mafic extrusive and intrusive rocks of the Killara Formation was possibly controlled by northerly and northeasterly trending fissures. Gravity and coincidental aeromagnetic highs in the southeast of the Yerrida Basin (Fig. 2) are associated with the Killara Formation, and may be related to underplated mafic rocks. The end of this igneous activity is marked by a chemical–evaporitic unit (Bartle Member), followed by deep-water sedimentation represented by carbonaceous argillite and sulfidic shale of the Maraloou Formation. On THADUNA, the contact between the Killara and Maraloou Formations is transitional or locally discordant. However, in adjacent areas (MOOLOOGOOL and MOUNT BARTLE) this contact is solely transitional and characterized by about 100 m of intercalated mafic and sedimentary rocks (Pirajno et al., in prep.; Dawes and Pirajno, 1998).

Windplain Subgroup

Juderina Formation (ⱣYj, ⱣYjf, ⱣYjb)

On THADUNA, the Juderina Formation (*ⱣYj*), which comprises quartz arenite and subordinate siltstone, chert breccia, and pebble beds, is exposed in a few low-lying, scattered outcrops in the southeast (Fig. 5). The thickness of the Juderina Formation on MARYMIA (Bagas, 1998) and MOOLOOGOOL (Pirajno et al., in prep.) ranges from a few hundred metres to about 1000 m (Occhipinti et al., 1997). The formation is unconformable on Archaean granite–greenstone basement, and the unconformity is well exposed on MOUNT BARTLE (Dawes and Pirajno, 1998) to the south and on CUNYU (Adamides et al., in prep.) to the east.

The basal unit of the Juderina Formation is the Finlayson Member (*ⱣYjf*), which consists of ripple-marked quartz arenite, and is exposed at Limestone Well, 2 to 4 km west of New Springs Homestead, and along the southeastern corner of the sheet area.

The Bubble Well Member (*ⱣYjb*) is a unit of the Juderina Formation not exposed on THADUNA. However, it was intersected in a drillhole located in the southeast corner of the map area (1DDH QMW-83-1; AMG* 907396; Fig. 5, Locality 1) and reported by Otterman (1986). This drillhole intersected siltstone of the Johnson Cairn Formation from surface to about 149 m, and Juderina Formation from this depth to the unconformity with the Archaean greenstone rocks at 289 m (Fig. 6). The Bubble Well Member consists of dolomite, cherty microbial laminites, and stromatolitic carbonate, with interbeds of dolomitic shale, in the interval from 149 to 215 m depth (Fig. 6). This succession rests on interbedded purple siltstone and quartz arenite of the Finlayson Member, to basement depth at 289 m.

The Bubble Well Member outcrops in nearby areas, such as CUNYU (Adamides et al., in prep.), GLENGARRY (Pirajno et al., 1998a), and MEREWETHER (Gee and Grey, 1993), and consists of chert breccia (produced by collapse following dissolution of evaporite and microbial laminites) and variably chertified, stromatolitic carbonate beds (Gee and Grey, 1993).

Johnson Cairn Formation (ⱣYc)

The Johnson Cairn Formation (formerly Johnson Cairn Shale; Gee, 1987) consists of about 250 m of varicoloured, iron-rich shale with graded silty layers and dolomite bands to the northeast of THADUNA, and around the Goodin Inlier (Occhipinti et al., 1997). The boundary with the underlying Juderina Formation is conformable, and is taken as the topmost bed of quartz arenite.

Exposure of the Johnson Cairn Formation on THADUNA consists of a number of scattered outcrops throughout the map sheet area. Rock types include argillaceous siltstone, thin-bedded dolomite, and minor lithic sandstone. These rocks are commonly lateritized, making differentiation from the fine-grained units of the Thaduna Formation difficult.

Mooloogool Subgroup

Thaduna Formation (ⱣYt, ⱣYta)

The Thaduna Formation, originally named Thaduna Greywacke by Gee (1979), is estimated to reach 5 km in thickness in its type area, which is around the Thaduna copper mine in the northern part of THADUNA (Gee, 1987). The contact with the underlying Johnson Cairn Formation is conformable. Other than in the type area, the Thaduna Formation (*ⱣYt*) is typically deeply weathered, and includes lithic sandstone and shale units, and minor dolomite. The Thaduna Formation mainly outcrops in a north-trending belt near the western edge of THADUNA, where it is associated with units of the Killara and Doolgunna Formations, and in the northwest corner of the sheet area.

In the Thaduna mine area, fresh outcrops include coarse-grained, mafic, lithic sandstone and subordinate hematitic shale (*ⱣYta*) folded into a series of northeast-trending folds. The rocks exhibit turbidite features such as graded bedding and rip-up clasts, and shallow-trough laminations in the uppermost silty layers. Flame structures are common in the shaly layers. In the same area, Blockley (1968) noted rain-pitted surfaces suggesting periodic

* Localites are specified by the Australian Map Grid (AMG) standard six-figure reference system whereby the first group of three figures (eastings) and the second group (northings) together uniquely define position, on this sheet, to within 100 m.

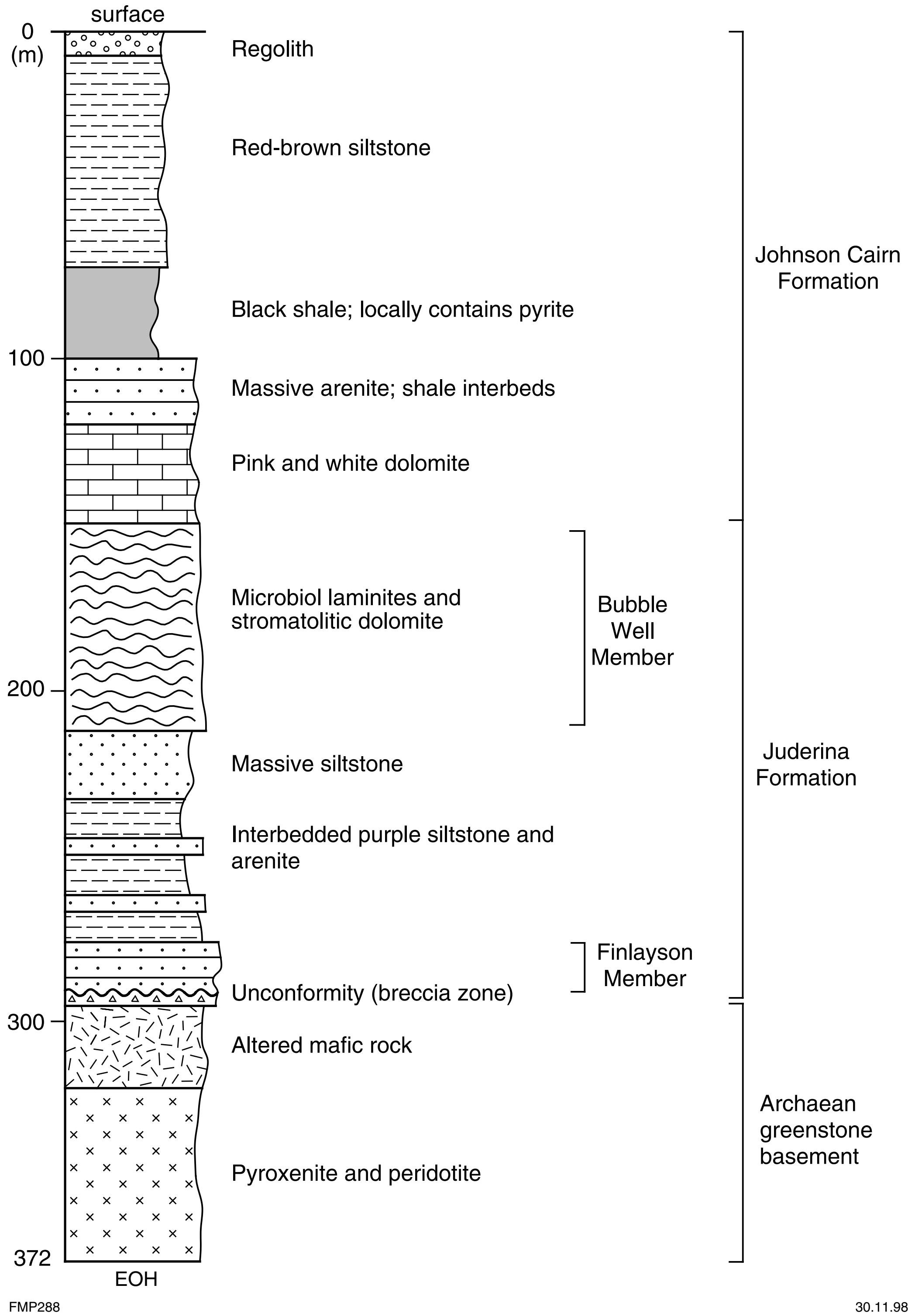

Figure 6. Summary log of drillhole DDH QMW 83-1 and details of the stratigraphy of the Juderina and Johnson Cairn Formations

emergence. Lithic fragments may reach 2–3 cm across. The rocks show well-developed cleavage parallel to the axial planes of the folds.

An interfingering relationship beteween the Thaduna and Doolgunna Formations (Fig. 4) can be seen about 4 km south of Cork Tree Bore (AMG 606506; Fig. 5, Locality 2), suggesting contemporaneous sedimentation.

The mineralogy of the lithic sandstone is dominated by epidote or clinozoisite, chlorite, and albitized plagioclase, mixed with clasts of basaltic rock (Fig. 7). Other clastic material includes micrographic intergrowths of quartz and feldspar, chert, argillaceous siltstone, angular and rounded quartz, microcline, and plagioclase. These minerals are replaced by chlorite, epidote, and fibrous amphibole. The mineral assemblages suggest a predominantly mafic provenance with limited input from granitic and sedimentary sources. This contrasts with the arkosic nature of turbidites of the Doolgunna Formation (Figs 7 and 8). However, a greater abundance of quartz and feldspar in rocks of the Thaduna Formation was noted by Gee (1987) in areas away from the Thaduna mine.

Doolgunna Formation (ꞒYd, ꞒYda, ꞒYds)

The type area for the Doolgunna Formation is on DOOLGUNNA, where it is represented by a thick arkosic wedge (Adamides, 1998). The base of the unit is defined by the first appearance of arkosic sandstone. The formation is thickest northwest of the Goodin Inlier, where Gee (1987) estimated the thickness to be up to 5 km. However, on the basis of recent mapping, Occhipinti et al. (1997) suggest it is more likely that the thickness is closer to 2 km when fold thickening is taken into account. The Doolgunna Formation thins considerably in areas away from the Goodin Inlier, providing evidence that rocks of this formation were sourced from the inlier.

The Doolgunna Formation (*ꞒYd*) outcrops over much of the western part of THADUNA (Fig. 5). It consists of thick-bedded arkosic sandstone, quartz siltstone, and subordinate pebble beds. The beds of arkosic sandstone are generally 1–2 m thick, but locally reach several metres in thickness, and exhibit graded bedding, scour channels, rip-up clasts, flame structures, and ripple and parallel laminations. Local coarser grained facies infilling channels are present, and contain subrounded pebbles of quartz and chert. Rocks of the Doolgunna Formation characteristically display angular to subrounded quartz and subordinate chert clasts, and feldspar, in a matrix of kaolinitic clays (Fig. 8). Low-grade metamorphism resulted in the partial alteration of kaolinite to illite or fine-grained sericite.

A unit of brown-weathering, unsorted arkosic sandstone with minor siltstone (*ꞒYda*) is restricted to a small area in the southwest of THADUNA (AMG 756335; Fig. 5, Locality 3). Exposures of thinly bedded, fissile, purple-grey sandstone with local diagenetic ironstone nodules (*ꞒYds*) have been mapped around breakaways nearby (for example, AMG 780303; Fig. 5, Locality 4).

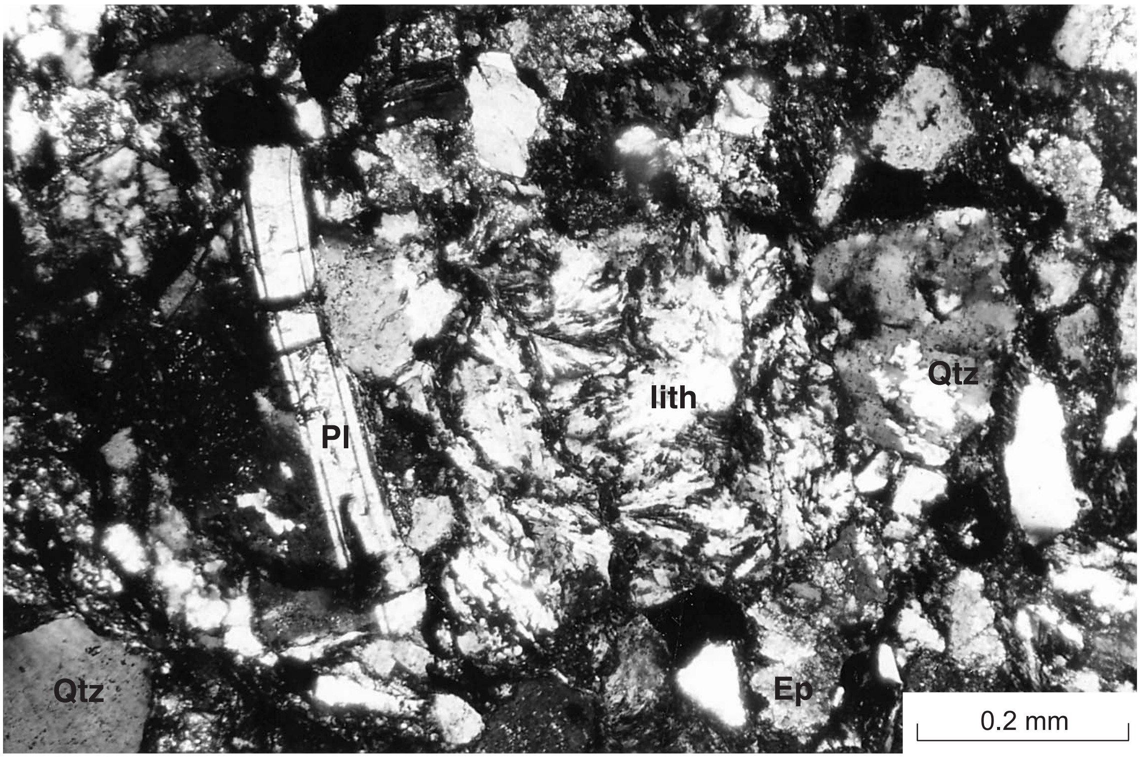

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Figure 7. Photomicrograph of lithic sandstone from the Thaduna Formation (Thaduna mine area), showing lithic fragments of basaltic rocks (lith), epidote (Ep), plagioclase (Pl), and quartz (Qtz) in an unsorted matrix. Note the difference to Figure 8. Cross polars

These are distinctly different from the typical arkosic units of the Doolgunna Formation (*ȽYd*) and the underlying argillaceous siltstones of the Johnson Cairn Formation (*ȽYc*).

Killara Formation (ȽYk, ȽYkd, ȽYkb, ȽYkbx, ȽYkx, ȽYkg, ȽYkc, ȽYkh, ȽYks)

On THADUNA, the Killara Formation (Occhipinti et al., 1997) includes dolerite, tholeiitic basalt, and subordinate gabbro, pyroxenite, chertified volcaniclastic rocks, and intercalated lithic sandstone. These rocks outcrop in a broad, northeast-trending band in the centre and southwest of THADUNA, where they are overlain conformably by the Maraloou Formation and unconformably by the Yelma Formation of the Earaheedy Group near Lake Gregory (Fig. 5). In the west, the Killara Formation is present as lenses mainly of tholeiitic basalt intercalated with rocks of the Thaduna and Johnson Cairn Formations.

Undivided mafic extrusive and intrusive rocks (*ȽYk*) are generally dark grey to black in the field. Weathering and poor exposure makes it difficult to assign an extrusive or intrusive origin to these rocks. Dolerites (*ȽYkd*) form small, terraced hills, are medium grained, and commonly show spheroidal weathering. Evidence of multiple intrusions is indicated by internal textural and grain-size variations, as well as the terraced morphology. Peperite margins are developed where rocks of the Killara Formation are in contact with rocks of the Maraloou Formation. A good example of a peperite margin is located approximately 14 km west of New Springs (AMG 872401; Fig. 5, Locality 5). Peperites develop as a result of interaction of lava with wet sediments (McPhie et al., 1993).

The main constituents of the dolerite are augite and plagioclase (An_{60} to An_{80}; labradorite and bytownite), with minor amounts of secondary epidote, quartz, leucoxene, carbonate, sericite, chlorite, and sulfides. Epidote is a major alteration phase of plagioclase, and also a significant groundmass phase. Granophyre (micrographic intergrowths of quartz and feldspar) is present as patches and in the interstices between the main mineral phases. Granophyre is generally confined to the upper parts of dolerite intrusions. Locally, sulfides, including pyrite, pyrrhotite, and lesser chalcopyrite, have replaced plagioclase crystals or have crystallized along microfractures.

Basaltic rocks typically form subdued, rubble-covered hills. The basalt (*ȽYkb*) is commonly brown to black, fine grained, and holocrystalline to microporphyritic. The distinction in the field between dolerite (*ȽYkd*) and tholeiitic basalt (*ȽYkb*) is based on textures. The basalts are finer grained and amygdaloidal. Thin, vesicular flows are common, and thicker flows may have scoriaceous tops. Pillow forms have been observed at some localities, with flattened, elongate shapes and thin, glassy rims, suggesting a hot, low-viscosity magma. Interbedded zones of hyaloclastite suggest quench fragmentation by subaqueous extrusion (McPhie et al., 1993).

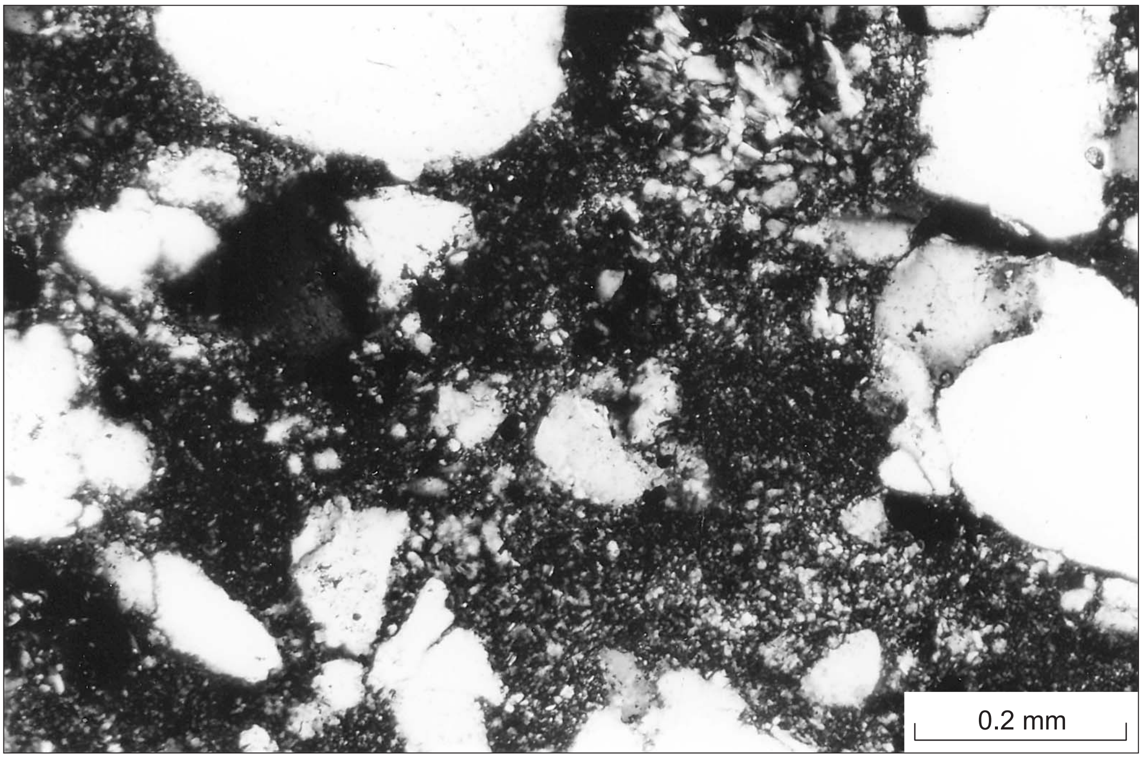

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Figure 8. Photomicrograph of arkosic sandstone from the Doolgunna Formation, showing subangular quartz grains and minor feldspar in a kaolinitic matrix. Note the difference to Figure 7. Cross polars

Vesicular basalt contains clinopyroxene crystals about 0.5 mm in size enclosed in a fine-grained groundmass of quartz, plagioclase, calcite, and clinozoisite. Vesicles are filled with one or more of the following minerals: quartz, calcite, devitrified glass, low-birefringence chlorite, and chalcedony. Very fine grained basaltic units are characterized by a groundmass that displays a quench-related plumose texture, with skeletal crystals of clinopyroxene and plagioclase, typically with feathery terminations. South of Lake Gregory and along the road to Neds Creek Homestead, basaltic rocks have vesicles filled with chlorite, quartz, calcite, and sulfide blebs (0.05 to 0.1 mm across), including chalcopyrite, pyrrhotite, smythite (Fe_3S_4) and a highly reflective, unidentified phase (possibly a lead arsenide). Coarser grained basalt contains augite crystals up to 1 mm long that are commonly subhedral to euhedral, and set in a groundmass altered to chlorite and calcite. Plagioclase laths, commonly subophitically enclosed in clinopyroxene, are replaced by quartz, chlorite, calcite, pumpellyite, and clinozoisite. Granular leucoxene, pumpellyite, quartz, chlorite, and fine-grained, granular epidote are common alteration products in the groundmass.

There are elongate, north-trending gabbroic sills (*ƂYkg*) and a pyroxenite outcrop (*ƂYkx*) in southeast THADUNA (Fig. 5). The gabbro is coarse grained and characterized by large clinopyroxene crystals and labradorite laths, partially altered to chlorite and sericite. Pyroxenite forms a small body, 8 km west of Limestone Well, that consists of cumulate orthopyroxene (crystals ranging in size from 0.7 to 2 mm), intercumulus plagioclase (An_{60}), and minor quartz, serpentine, and leucoxene.

Chert in isolated pods or discontinuous bands (*ƂYkh*) is present within the volcanic rocks. One of the most extensive chert bands lies approximately 4 km west-southwest of Yerrida Spring (AMG 726327; Fig. 5, Locality 6). This northeast-trending, massive to banded chert locally has a cavernous structure, and a pitted texture probably due to pyrite dissolution. Smaller pods or bands in central-eastern THADUNA are aligned in a northeasterly direction. Most of these cherts are featureless, but contain ghosts of lenticular structures possibly pyroclastic in origin. The cherts are interpreted as silicified basalt and/or volcaniclastic material, and are commonly fractured, with infillings of quartz, carbonate, and iron oxides.

In the south of THADUNA, small, north-trending bands of lithic sandstone (*ƂYks*) are intercalated with the basaltic lavas. South of Yerrida Spring (AMG 749231; Fig. 5, Locality 7), such lithic sandstone comprises angular and subrounded quartz and feldspar in a mafic matrix. Lithic clasts up to 2–4 cm in size are also present. This rock superficially resembles dolerite and is massive in the lower part with fine laminations higher up, suggesting that it may be a turbidite. Exposures with rip-up clasts are locally present. In other localities, these sedimentary units have an assemblage of rounded to subrounded quartz and feldspar in a fine-grained matrix. The matrix has been almost totally converted to clinopyroxene and scapolite as a result of thermal metamorphism. Calcite and chlorite partly replace the scapolite. Apart from a few chert fragments, no lithic clasts have been observed.

Outcrops of basaltic breccia (*ƂYkbx*) about 4 km south of Curranullanuly Pool (AMG 807400; Fig. 5, Locality 8) are enclosed in partly silicified volcanic rock, and are associated with chert pods (*ƂYkc*). These rocks are interpreted as the relic of a small volcanic vent. Similar breccias, associated with a well-defined circular structure, are present to the southwest on MOOLOOGOOL (Pirajno et al., in prep.).

Bartle Member (ƂYkc)

The Bartle Member (*ƂYkc*; Occhipinti et al., 1997) is well exposed on MOUNT BARTLE, and is described in detail by Dawes and Pirajno (1988). The only outcrop of this member on THADUNA is in the south, near the boundary with MOUNT BARTLE. This outcrop consists of chert containing a variety of textures, including spherulitic and microbial. Scattered lath-shaped crystals, probably derived from evaporite precursor minerals, are also present.

Geochemistry and tectonic setting of the Killara Formation

The geochemistry of the Killara Formation is discussed in some detail from the adjacent MOUNT BARTLE (Dawes and Pirajno, 1998) and in Pirajno et al. (1998b). Whole-rock, and major- and trace-element analyses were carried out for 12 samples of basalt and dolerite rocks from THADUNA. Analytical results are presented in Table 2. Major-element abundances were quantified using X-ray fluorescence spectrometry, following incorporation of the sample into a borate glass disk, or a pressed powder disk using a polyvinyl acetate (PVA) solution as a binder. Abundances of Co, Cr, Cu, Ni, Sc, V, and Zn were determined by inductively coupled plasma atomic-emission spectrometry (ICP-AES), with rare-earth element (REE) abundances determined by inductively coupled plasma mass spectrometry (ICP-MS).

The geochemical characteristics of mafic rocks of the Killara Formation are presented in Figure 9. These rocks are low-K basalt and basaltic andesite, with a distinct tholeiitic trend (Figs 9a,b). On a Jensen cation plot (Fig. 9c), these rocks lie within the high-Fe and high-Mg tholeiite fields.

The dolerite and basalt contain clinopyroxene, plagioclase (An_{60}–An_{80}), and Fe–Ti oxides. They do not contain olivine. Rocks of the Killara Formation are generally flat-lying or gently dipping, weakly metamorphosed or unmetamorphosed, and were emplaced as subaqueous and subaerial lava flows and intrusive sheets, some of which interacted with wet sediments of the Maraloou Formation, forming peperite margins. On MOOLOOGOOL (adjacent map sheet area to the west; Pirajno et al., in prep.), examination of a 90-m section of drillcore revealed the presence of 15 individual lava flows with no intervening sediments, indicating a high rate of eruption. The mafic rocks of the Killara Formation are associated with evaporitic and siliciclastic sedimentary rocks, suggesting an epicontinental geological environment and a tectonic setting similar to that of continental flood basalts. A within-plate tectonic setting is supported by a

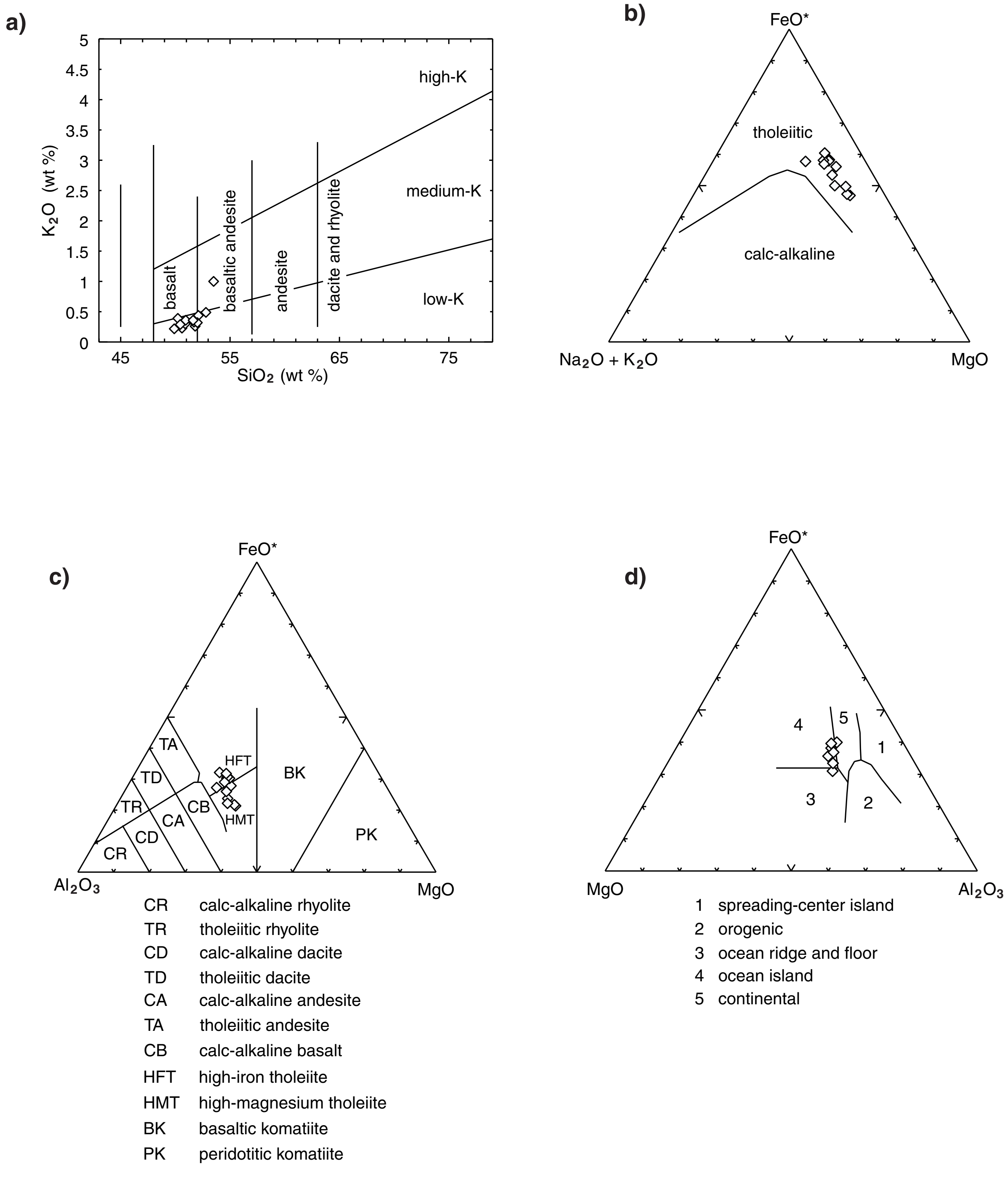

Figure 9. Geochemical diagrams of the Killara formation on THADUNA: a) K_2O versus SiO_2 (compositional fields after Le Maitre, 1989); b) triangular plot of ($Na_2O + K_2O$) – FeO* – MgO (after Irvine and Baragar, 1971), showing the tholeiitic character of the rocks (FeO* = Fe_2O_3 + FeO); c) Jensen (1976) cationic plot, showing the high-Fe, high-Mg, tholeiitic nature of the rocks; d) tectonic discriminant diagram after Pearce et al. (1977), where the rocks are shown to be within-plate basalts (ocean-island and continental basalts). See Table 2 for sample geochemistry

Table 2. Geochemical analyses of mafic volcanic rocks of the Killara Formation on THADUNA

GSWA sample *AMG coordinates*	*104378* *917496*	*104380* *917496*	*104349* *958459*	*104350* *958459*	*104351* *950468*	*112690* *663497*	*112701* *533324*	*112698* *531330*
				Percentage				
SiO_2	51.8	51.7	50.6	49.9	53.5	–	–	52.1
TiO_2	0.95	1.05	0.61	0.6	1.11	–	–	0.71
Al_2O_3	13.7	13.2	14.8	14.6	12.7	–	–	14.5
Fe_2O_3	2.82	1.88	1.54	2.18	1.88	–	–	2.06
FeO	0.05	10.4	7.94	7.34	10.3	–	–	8.01
MnO	0.2	0.2	0.17	0.18	0.21	–	–	0.17
MgO	7.22	6.38	8.64	8.34	5.33	–	–	7.43
CaO	10.6	10.2	11.7	11.8	8.54	–	–	10.7
Na_2O	1.59	1.74	1.7	1.81	2.44	–	–	2
K_2O	0.26	0.33	0.23	0.22	1	–	–	0.44
P_2O_5	0.09	0.1	0.05	0.05	0.11	–	–	0.07
LOI	3.06	3.02	2.64	3.47	3.61	–	–	2.88
Total	**101.34**	**100.2**	**100.62**	**100.49**	**100.73**	**–**	**–**	**101.07**
				Parts per million				
Ag	1	2	1	1	1	–	–	<1
As	4	4	4	4	4	–	–	<4
Au (ppb)	20	80	20	10	10	–	–	10
Ba	342	136	141	169	372	–	–	196
Ce	10	14	6	11	18	–	–	10
Co	–	–	–	–	–	–	–	75
Cr	71	40	112	86	16	–	–	–
Cu	140	156	129	149	117	–	–	115
Ga	16	15	12	14	15	–	–	15
La	6	6	6.9	5	11			7
Nb	–	–	7.5	–	–	6.9	6.4	<7
Ni	80	65	118	123	43	–	–	83
Pb	4	4	4	4	6	–	–	<4
Rb	5	8	5	8	28	–	–	13
Sc	–	–	81.7	–	–	70.3	69.8	–
Sr	114	132	152	174	198	–	–	198
Th	3	3	2	2	5	–	–	2
U	–	–	0.7	–	–	0.6	0.6	<2
V	284	281	203	208	294	–	–	223
Y	19	22	13	12	24	–	–	14
Zn	90	91	64	68	98	–	–	76
Zr	77	95	46	45	109	–	–	70
Hf	–	–	0.7	–	–	0.5	1.3	–
Pr	–	–	1.9	–	–	2	2.8	–
Nd	–	–	7.8	–	–	8.3	10.8	–
Sm	–	–	1.8	–	–	2.1	2.6	–
Eu	–	–	0.7	–	–	0.9	1	–
Gd	–	–	2.4	–	–	2.8	3.3	–
Tb	–	–	0.4	–	–	0.5	0.6	–
Dy	–	–	2.5	–	–	2.9	3.3	–
Ho	–	–	0.4	–	–	0.6	0.6	–
Er	–	–	1.5	–	–	1.8	1.9	–
Tm	–	–	0.2	–	–	0.3	0.3	–
Yb	–	–	1.4	–	–	1.7	1.8	–
Lu	–	–	0.2	–	–	0.2	0.3	–
Y	–	–	11.8	–	–	14.5	15.2	–

Table 2. (continued)

GSWA sample	*139230*	*139231*	*139235*	*139242*	*139247*	*139249*	*139250*
AMG coordinates	*538514*	*536526*	*524498*	*581421*	*526388*	*557422*	*532338*
				Percentage			
SiO_2	52.79	50.9	50.22	50.94	52	50.44	51.61
TiO_2	0.8	1.14	0.84	1.17	0.92	0.63	1.19
Al_2O_3	13.17	12.83	14.45	12.92	13.11	14.81	12.79
Fe_2O_3	2.22	2.49	2.26	1.7	1.8	2.28	1.83
FeO	7.9	9.62	8.88	10.49	9.62	7.23	10.71
MnO	0.19	0.2	0.2	0.22	0.2	0.19	0.22
MgO	6.53	6.51	6.04	6.3	6.17	7.63	6.06
CaO	10.31	10.82	11.42	10.27	10.11	11.87	10.31
Na_2O	1.62	1.68	1.51	2.01	2.03	1.48	1.67
K_2O	0.49	0.3	0.39	0.36	0.32	0.29	0.36
P_2O_5	0.08	0.1	0.07	0.1	0.08	0.05	0.11
LOI	3.59	3.2	3.4	3.31	3.24	2.8	2.68
Total	**99.69**	**99.79**	**99.68**	**99.79**	**99.6**	**99.7**	**99.54**
				Parts per million			
Ag	–	–	–	–	–	–	–
As	<4	0.5	<4	0.5	<4	0.5	<4
Au (ppb)	–	–	–	–	–	–	–
Ba	380	120	166	142	136	80	162
Ce	24	18	12	22	22	6	22
Co	57	64	62	60	60	56	59
Cr	58	118	67	97	31	151	93
Cu	101	99	123	116	121	100	107
Ga	14.5	16.5	14.5	16.5	16	13	16.5
La	10	6	5	9	8	3	10
Nb	6	6	3	5	4	2	6
Ni	67	93	65	77	52	70	70
Pb	7	2	2	2	3	<4	2
Rb	10	7.5	14	15.5	10	10.5	8.5
Sc	40	45	43	46	44	44	43
Sr	185	129	156	156	193	187	128
Th	4	1	1	1.5	3.5	0.5	2
U	1.5	<2	0.5	1	1	<2	<2
V	199	294	242	286	253	207	296
Y	18	22	16	21	18	12	23
Zn	90	100	90	104	92	72	101
Zr	82	79	53	83	72	39	86
Hf	–	–	–	–	–	–	–
Pr	–	–	–	–	–	–	–
Nd	–	–	–	–	–	–	–
Sm	–	–	–	–	–	–	–
Eu	–	–	–	–	–	–	–
Gd	–	–	–	–	–	–	–
Tb	–	–	–	–	–	–	–
Dy	–	–	–	–	–	–	–
Ho	–	–	–	–	–	–	–
Er	–	–	–	–	–	–	–
Tm	–	–	–	–	–	–	–
Yb	–	–	–	–	–	–	–
Lu	–	–	–	–	–	–	–
Y	–	–	–	–	–	–	–

NOTES: Analyses were performed at the Chemistry Centre, Department of Minerals and Energy (W.A.)
All trace-element analyses in ppm, unless otherwise stated
LOI loss on ignition

plot of the geochemical data on a tectonic discriminant diagram after Pearce et al. (1977), presented in Figure 9d.

Maraloou Formation (ꝐYm, ꝐYms, ꝐYmh, ꝐYmb)

The basal contact of the Maraloou Formation with the underlying Killara Formation is gradational, and characterized by intercalated black shale, and mafic lavas and sills (Pirajno et al., 1988b). The thickness of the formation is estimated to be around 1000 m (Occhipinti et al., 1997).

Thin-bedded siltstone and black shale of the Maraloou Formation (*ꝐYm*) are present in the west-central and southeastern parts of THADUNA (Fig. 5). Thin-bedded, khaki to light-grey, siltstone and ferruginous shale (*ꝐYms*) outcrop in the southeast and in the west-central parts of THADUNA. Along the track leading to Corner Well (AMG 948436 and AMG 963435; Fig. 5, Localities 9 and 10), good exposures consist of a succession of interbedded laminated siltstone and ferruginous shale, intercalated with subordinate marl beds. South of Cork Tree Bore, the contact with the underlying Doolgunna Formation is defined by a bed of grey, laminated chert (*ꝐYmh*), possibly of microbial origin. The upper contact, with rocks of the Killara Formation, can be observed about 2.5 km west of Corner Well, and about 14 km west of New Springs Homestead (AMG 872401; Fig. 5, Locality 5).

The siltstones of the Maraloou Formation are locally interbedded with, or overlain by, chert breccias (*ꝐYmb*) characterized by a combination of angular clasts and subordinate, rounded pebbles, as well as wavy laminations resembling microbial facies (AMG 695455; Fig. 5, Locality 11). The chert breccias are lithologically similar to those of the Yelma Formation (Earaheedy Group), but have been assigned to the Maraloou Formation in view of close spatial relationships. An unconformable contact between silcretized chert breccia and underlying kaolinitic quartz sandstone of the Doolgunna Formation is exposed in central THADUNA (AMG 703472; Fig. 5, Locality 12).

Siltstone of the Maraloou Formation consists of sericite, kaolinitic clay, silt-sized quartz grains, and finely disseminated Fe-oxide. Calcareous units (marl) contain microcrystalline dolomite with disseminated quartz grains, and are cut by chalcedonic and late calcite veinlets.

Earaheedy Group

Yelma Formation (ꝐEy, ꝐEyb, ꝐEyc, ꝐEyo)

The Yelma Formation is a unit of clastic and dolomitic sedimentary rocks at the base of the Earaheedy Group. This unit occupies much of the northeastern portion of THADUNA (Fig. 5) near and around Lake Gregory, and consists mainly of quartz arenite, stromatolitic dolomite, and chert breccia (*ꝐEy*). The base of the Yelma Formation includes lithic quartz sandstone and quartz conglomerate (*ꝐEyo*) that lie unconformably on quartz arenite of the Finlayson Member. The contact is exposed 1.5 km east of Freshwater Well at the boundary with FAIRBAIRN, on the southern edge of Lake Gregory. The main constituents of the lithic sandstone near the base of the formation (*ꝐEyo*) are quartzose and sericitized lithic grains, and subordinate polycrystalline quartz, chlorite, and turbid feldspar.

Two drillholes 3 km south of Little Well (CTW 001 and CTW002, AMG 759616; Fig. 5, Locality 13; Meakins and Watsham, 1994), together with field observations, provide a representative, 400 m-thick stratigraphic section of the Yelma Formation. This section, schematically represented in Figure 10, consists of grey to pink, massive, silicified dolomite beds at the bottom of the section. Thin, argillaceous interbeds are locally present between 350 m and about 200 m below surface. This interval is overlain by a 120 m-thick unit of dolomite with solution breccia interbeds, containing interstitial kerogen and sulfides. This is, in turn, overlain by about 80 m of pink to grey, thinly laminated dolomite, dolomite breccia, ferruginous sandstone, and arenite, followed by 20 m of dolomite with microbial laminae. The latter is a distinctive rock that may be part of the Sweetwaters Dolomite Member (new name for a proposed member of the Yelma Formation) that was found to be well exposed to the east on NABBERU (1:250 000) during recent mapping. Stromatolites in the Sweetwaters Dolomite Member include *Asperia digitata* (Grey 1984) Grey 1994, *Pilbaria deverella* Grey 1984, and *Ephyaltes edingunnensis* Grey 1994; they outcrop at a number of localities (AMG 859681, AMG 844716, and AMG 850707; Fig. 5; Localities 14, 15, and 16) on the northwest side of Lake Gregory (Fig. 11). Grey (1994) suggests that these stromatolite forms are indicative of an upward-shallowing, lagoon to supratidal environment.

Outcrops on the northwest side of Lake Gregory consist of dolomite breccia that is commonly chertified (Fig. 12), and cream-coloured, fine- to medium-grained, bedded and laminated dolomite (*ꝐEyb*). This unit is intercalated with minor lenses of ferruginous sandstone and siltstone associated with stromatolitic dolomite (*ꝐEyc*). In the area around Edingunna Spring (AMG 716583), outcrops of these units include silcretized chert breccia, underlain by coarse breccia, associated with granulestone containing rounded pebbles. This material is underlain by approximately 2 m-thick pebble beds comprising subrounded to rounded pebbles up to 5 cm, dominantly of quartz and chert, and a coarse-grained, poorly sorted quartz arenite, underlain by more pebble beds (*ꝐEyo*). The latter is interpreted as the base of the Yelma Formation.

Most of the dolomitic rocks consist of a packed aggregate of small (averaging 0.1 mm) dolomite rhombs with interstitial iron oxides. The dolomite also locally contains disseminated quartz grains and stylolites. Siltstone interbeds contain quartz, kaolinite, illite, and sericite. In drillhole CTW 002, sulfide mineralization (mainly pyrite and chalcopyrite) is associated with specks of kerogen in dolomite breccia (Fig. 13). Breccia clasts are rimmed by fine-grained pyrite and specks of kerogen (Fig. 14), and open spaces are filled with euhedral quartz and chalcedony.

Dolerite dykes (*Ꝑd*)

There are normal- and reverse-polarized, linear magnetic anomalies on total magnetic intensity images (aeromag-

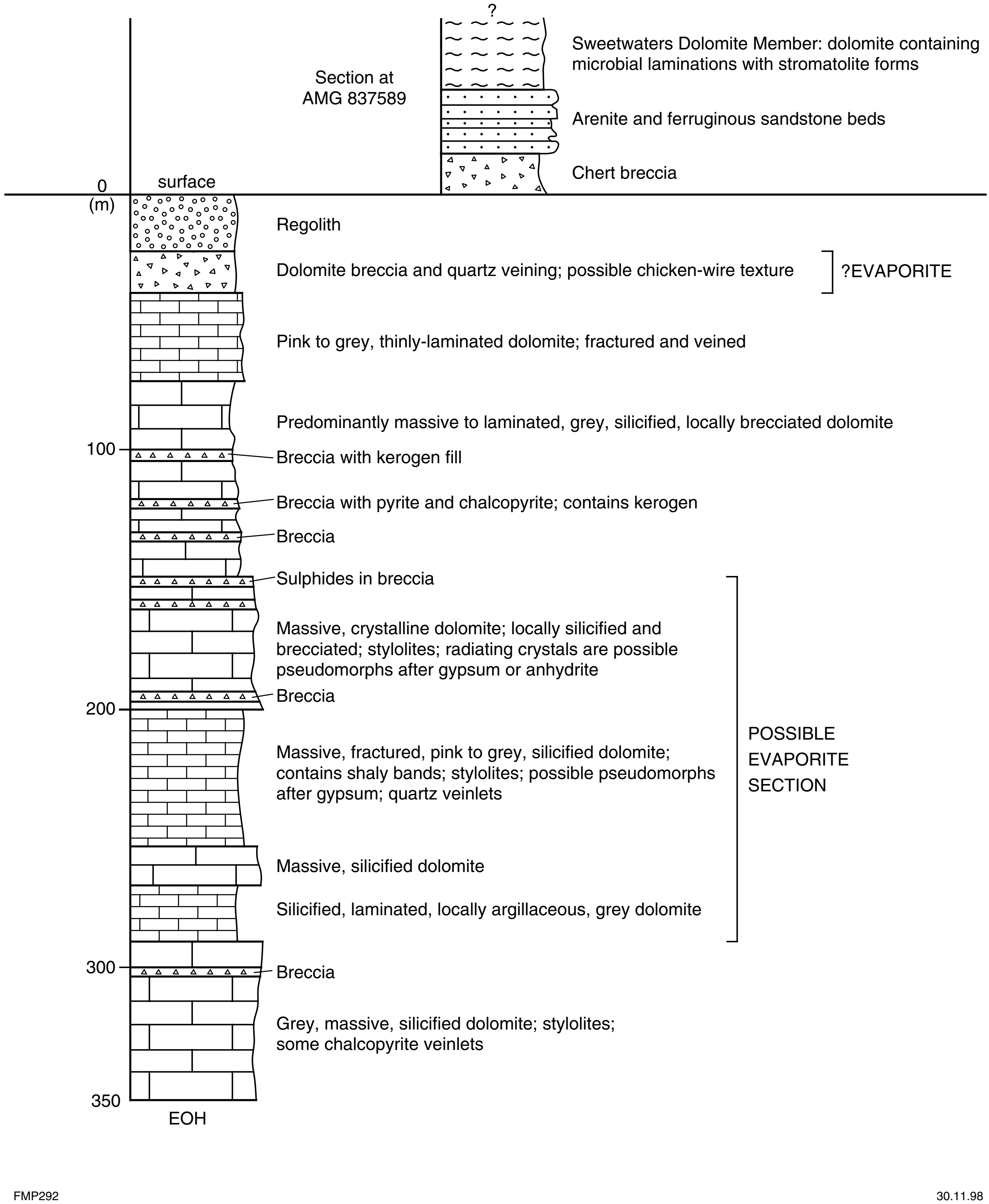

Figure 10. Details of the stratigraphy of the Yelma Formation on THADUNA, derived from drillhole DDH CTW 002 and outcrops near Lake Gregory

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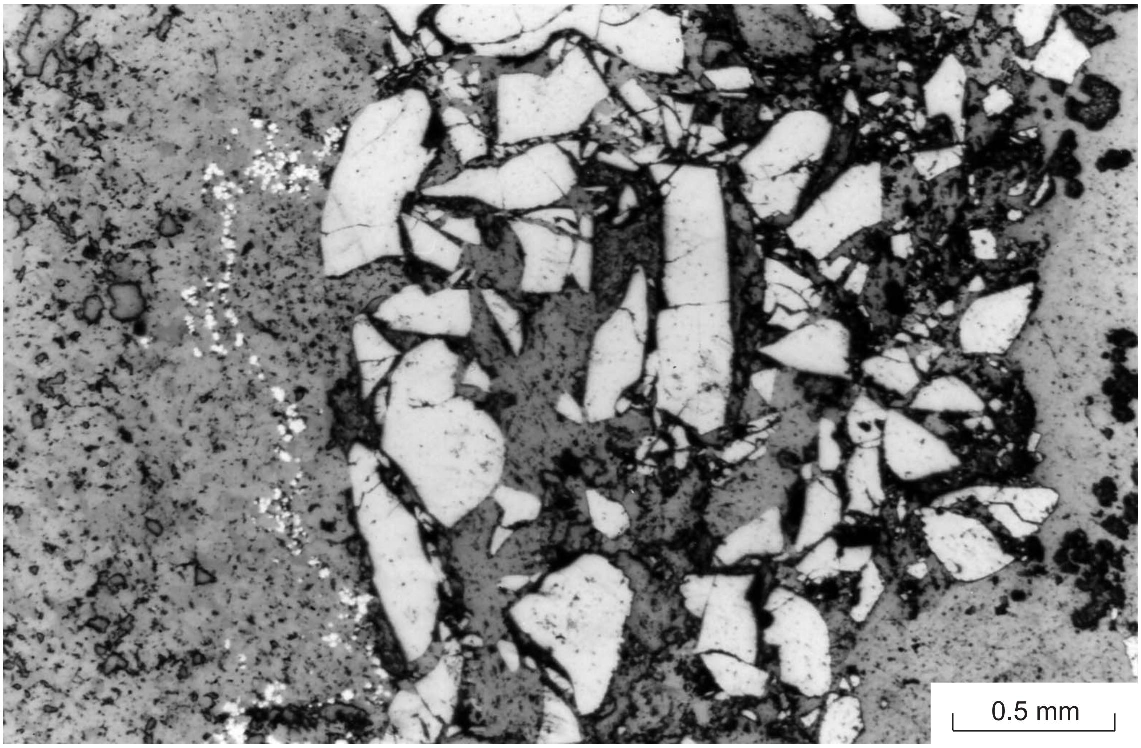
Figure 11. Stromatolite form *Ephyaltes edingunnensis* Grey 1994 in dolomitic rocks of the Yelma Formation on the northwest side of Lake Gregory (AMG 843717)

FMP294 3.11.98

Figure 12. Chert breccia derived from dolomite of the Yelma Formation, near Lake Gregory (AMG 828652)



FMP297 27.11.98

Figure 13. Photomicrograph of a drillhole (DDH CTW 0002) sample showing kerogen material in brecciated dolomite of the Yelma Formation. Reflected light

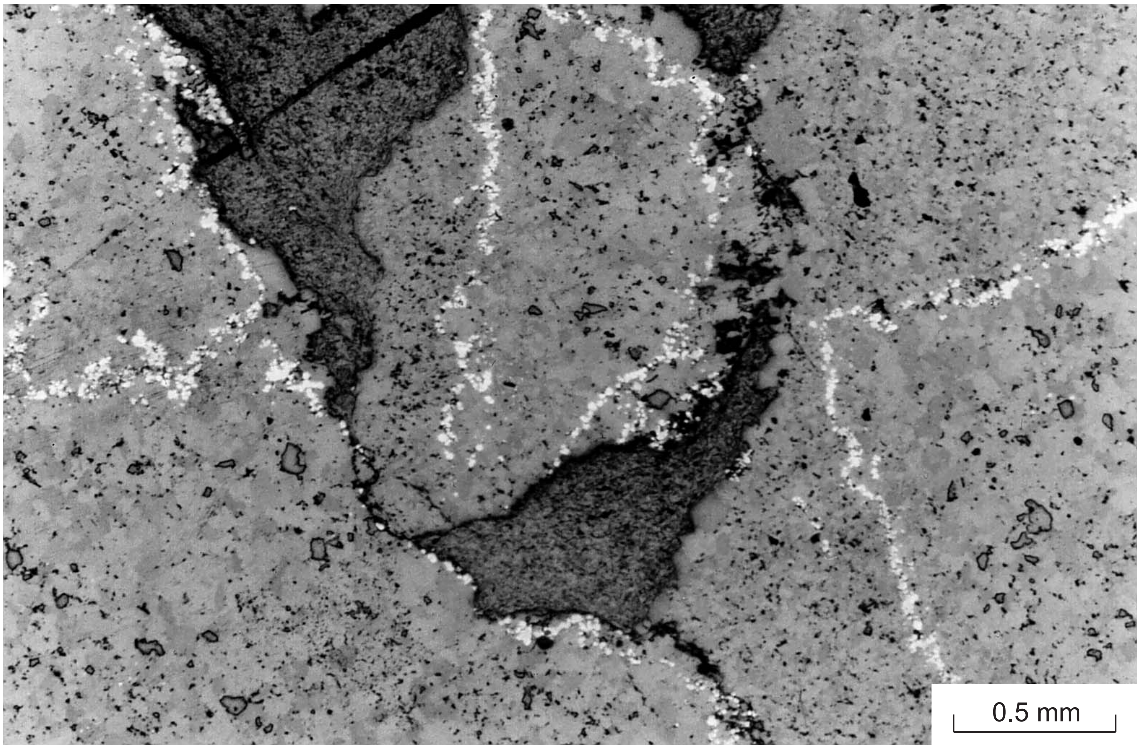


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Figure 14. Photomicrograph showing sulfides (pyrite and minor chalcopyrite) rimming clasts in brecciated dolomite. Reflected light

netic survey flown by Tesla Airborne Geoscience for GSWA in 1994 over the PEAK HILL 1:250 000 map sheet area) of THADUNA. These features are interpreted as dolerite dykes (*Ᵽd*), on the basis of outcrops associated with linear magnetic anomalies on MOOLOOGOOL (Pirajno et al., in prep.) and MOUNT BARTLE (Dawes and Pirajno, 1998). These dykes intrude rocks of the Maraloou Formation, and so are assumed to be of Proterozoic age, although no absolute age determinations are available.

Two groups of dykes have been identified on THADUNA. In the northern part of the map sheet area, mafic dykes trend northeast and are subparallel with the Jenkin Fault along the contact of the Marymia Inlier (Figs 2 and 5). Those in southeast THADUNA also trend northeast, and are locally associated with the Killara Formation.

Metamorphism

Rocks on THADUNA are unmetamorphosed to weakly metamorphosed. Low-grade metamorphism is indicated by the presence of quartz, calcite, pumpellyite, epidote, and chlorite in mafic volcanic rocks of the Killara Formation. Groundmass material in clastic sedimentary rocks of the Yerrida Group exhibits partial alteration of kaolinite to illite or sericite. These mineral assemblages suggest that temperatures of about 300°C and pressures equal to, or less than, 3 kb were reached (Bucher and Frey, 1994).

Structure

Deformation on THADUNA is associated with, and essentially confined to, the margins of the Goodin and Marymia Inliers (Fig. 2). This is particularly evident in the vicinity of the Thaduna mine, where northeast-trending, gently southwest-plunging folds affect units of the Thaduna Formation (Fig. 5). Open to tight, upright folds persist throughout most of the western part of THADUNA, and are characterized by a well-developed axial-plane cleavage and an associated gently plunging intersection lineation. Open folding in rocks of the Maraloou Formation 5 km southwest of Cork Tree Bore (AMG 570510; Fig. 5, Locality 17) is most prominent in the basal chert unit (*ⱣEmh*). Here, an east-northeasterly plunging synclinal structure is present (Fig. 5).

Other structures on THADUNA include a set of northwesterly trending faults that displace east-northeasterly trending faults (Fig. 5). These faults are mostly concealed, and are only observed as airphoto or aeromagnetic lineaments. West of Lake Gregory, some of these concealed faults appear to offset northeast-trending aeromagnetic lineaments that are interpreted as mafic dykes. A dolerite unit of the Killara Formation indicates sinistral displacement of about 1 km on an east-trending fault east of Curranullanuly Pool.

Cainozoic geology

Relics of lateritic duricrust are locally preserved in the form of breakaways (*Czl*). This laterite, which typically consists of generally massive or brecciated, ferruginous material, passes downwards through an intermediate saprolitic zone into fresh rock beneath. The duricrust is distinguished from the commonly fault-related ironstone (*Czli*), which, locally, may be associated with mineralization. The thickness of the saprolitic zone does not exceed a few metres, and fresh bedrock is common at the foot of laterite breakaways. The lateritic duricrust degrades into finer detritus, particularly around the aprons of the laterite mesas. This material is a mixture of laterite fragments, pisolites, and soil (*Czf*). Sandplain deposits (*Czs*) consisting of unconsolidated sand with minor silt and clay are poorly developed on THADUNA, and are present mainly in the west. Silcrete (*Czz*) is developed locally over silica-rich protoliths.

Areas adjacent to outcrop are commonly covered by a thin veneer of colluvium (*Czc*) comprising angular rock fragments mixed with finer grained soil, and laterite debris. Away from breakaways and steep slopes, finer grained depositional facies comprise sheetwash fans (*Cza*) and alluvial channels (*Qa*). Sheetwash deposits commonly have a distinctive ribbed pattern on aerial photographs and satellite images. These deposits are particularly extensive in the Lake Gregory area, and also near the major watercourses. They merge at topographically lower levels with the areas of active alluvial transport (*Qa*), represented by the main river channels. Claypans (*Qac*) form in depressions on floodplains.

Palaeodrainage is commonly indicated by the presence of calcrete (*Czk*), a calcareous deposit produced by the dissolution and subsequent reprecipitation of calcium carbonate as a result of fluctuating watertable levels (Hocking and Cockbain, 1990). These deposits are particularly widespread in the areas around Lake Gregory, where alluvial channels drain into the lake.

In the upper parts of streams, for example, near Yerrida Spring, relics of coarse-grained, cemented breccias are equated with the Wiluna Hardpan of Bettenay and Churchward (1974). This material comprises sub-horizontal, well-stratified, lateritic gravel with subrounded to subangular laterite clasts in a fine-grained, unsorted matrix. It is interbedded with layers of dark red-brown, lateritic soil containing fine laterite fragments. The sequence is laced by bedding-parallel veins, suggesting that calcrete is still being precipitated in these rocks. This indurated breccia is interpreted as cemented lateritic material deposited on broad alluvial plains.

Lake Gregory, in northeast THADUNA, contains saline silt and mud (*Ql*), and is surrounded by calcareous and gypsiferous dunes (*Qld*).

Mineralization

Copper

The only known mineral deposits on THADUNA are the Lee (Ricci) and Thaduna copper mines. These deposits, together with similar occurrences along strike on MARYMIA (for example, Rooneys and Green Dragon) constitute the

Thaduna copper deposits, none of which are currently in production. The Thaduna copper deposits produced a total of 2823 t of copper metal and have a total remaining resource of about 17 000 t of copper metal at an average grade of 3.4% (Pirajno and Preston, 1998). The deposits are epigenetic and related to a northeast-trending fault within the Thaduna Formation. The mineralization is found within northwest-trending, quartz-filled shear zones. Host rocks in the vicinity of Thaduna mine include two lithic sandstone units separated by siltstone. These rocks are folded about northeast-trending axes that plunge 10–15° northeast. The folded rocks are cut by a number of northwest-striking faults.

The Thaduna mine produced oxide ore (malachite, cuprite, and chrysocolla), and was mined to a depth of about 50 m (Pirajno and Preston, 1998). The Thaduna copper lode follows the northwest-trending Thaduna Fault, in which the mineralization is up to 23 m wide. The bulk of the lode consists of sheared and brecciated sedimentary rock containing abundant hydrothermal graphite associated with quartz and carbonate minerals. Below the depth of mining, ore minerals are chalcopyrite and bornite with supergene chalcocite and rare covellite. The ore contains anomalous gold (up to 260 ppb).

The Lee (or Ricci) copper deposit, 3 km south-southwest of the Thaduna mine, is hosted by weathered lithic sandstone and shale. The principal mineralized shears strike 350°. The mineralization is in the form of a 1–3 m-wide zone of graphitic breccia cemented by limonite and quartz associated with secondary copper minerals.

Disseminations of chalcopyrite and pyrite are associated with kerogen in dolomite breccia of the Yelma Formation (Figs 13 and 14) in drillcore from Cork Tree Well (Meakins and Watsham, 1994). Lead, zinc, and copper sulfides are present in the same stratigraphic unit at Sweetwaters Well, about 55 km to the east (MERRIE).

Distinct regolith-geochemistry palladium anomalies along the western edge of THADUNA, and platinum anomalies in south-central THADUNA, are associated with rocks of the Killara Formation (Fig. 5). The area of platinum anomalism is associated with north-trending gabbro units, suggesting possible magmatic segregation. The area of palladium anomalism is associated with a zone of intercalated Killara Formation units and sedimentary rocks of the Thaduna and Doolgunna Formations, suggesting hydrothermal interaction. Discussion of the regional regolith geochemistry for the PEAK HILL 1:250 000 map sheet can be found in Subramanya et al. (1995).

On THADUNA, the presence of sulfides associated with kerogen in carbonate rocks of the Yelma Formation, and the platinum–palladium regolith anomalism associated with mafic rocks of the Killara Formation, suggest that the potential exists for carbonate-hosted Mississippi Valley-type base-metal mineralization and mafic-rock-hosted platinum-group element mineralization.

Hydrogeology

The most abundant and best-quality supplies of groundwater are obtained from the extensive zones of calcrete along drainage channels. The water contains between 1000 and 3000 ppm total dissolved solids (MacLeod, 1970).

On THADUNA, calcrete is located mainly in the areas surrounding Lake Gregory and, in particular, along the major northeast-flowing channels that drain into the lake in the area east of No. 1 Bore. Increased salinity with depth is common in most areas, with fresh water in higher levels generally passing into brackish or saline water at depth (MacLeod, 1970).

Regional watertables, as established from drilling, are generally located 10–20 m below surface, except in areas of high relief where they have a subdued configuration subparallel to the topography (Allen and Davidson, 1982).

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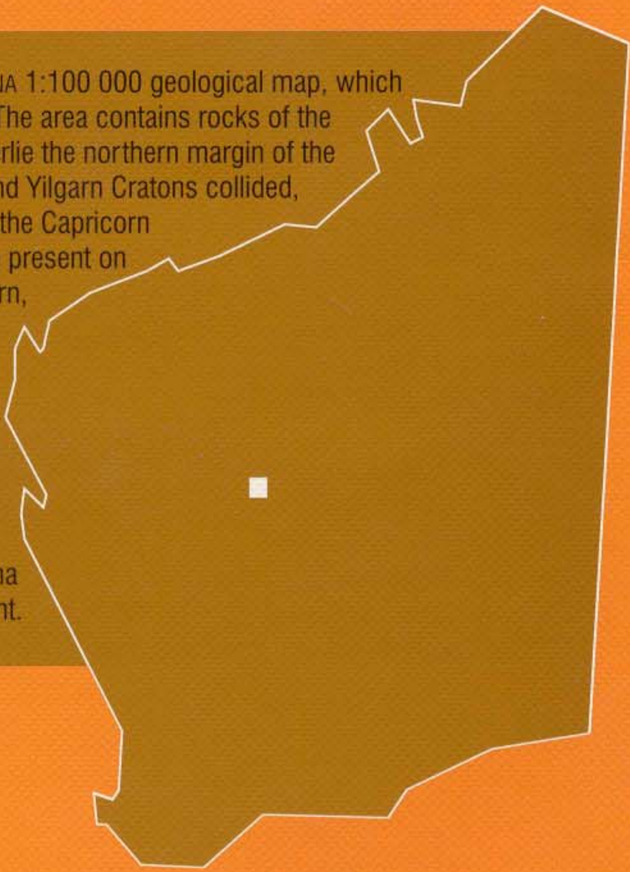
Appendix

Gazetteer of localities

Locality[(a)]	*Latitude (S)*	*Longitude (E)*	*AMG coordinates*	
			easting	*northing*
Cork Tree Bore[(b)]	25°42’05"	119°35'31"	760100	7154800
Corner Well	25°47'47"	119°57'49"	797200	7143500
Curranullanuly Pool	25°47'48"	119°48'30"	781600	7143800
Doolgunna Homestead	25°41'16"	119°13'34"	723400	7157000
Edingunna Spring[(b)]	25°40'04"	119°42'20"	771600	7158300
Freshwater Well	25°41'01"	119°47'16"	779800	7156400
Goodin Inlier	25°56'21"	119°18'24"	731000	7129000
Green Dragon mine	25°22'24"	119°43'44"	774600	7190900
Lake Gregory	25°35'07"	119°55'00"	793000	7167000
Lee (Ricci) copper mine	25°31'51"	119°41'48"	771000	7173500
Limestone Well[(b)]	25°52'34"	119°59'48"	800300	7134600
Little Well	25°36'41"	119°44'21"	775100	7164500
Marymia Inlier	25°19'09"	119°40'55"	770000	7197000
Neds Creek Homestead	25°28'52"	119°38'52"	766200	7179100
New Springs Homestead	25°49'28"	119°59'54"	800600	7140300
No. 1 Bore[(b)]	25°39'46"	119°44'40"	775500	7158800
Quatermaine Well	25°56'59"	119°57'49"	796800	7126500
Rooneys Mine	25°28'01"	119°41'46"	771100	7180600
Shoemaker Impact Structure[(c)]	25°50'35"	120°53'41"	289000	7140000
Thaduna mine	25°30'29"	119°42'40"	772500	7176000
Wiluna[(c)]	26°35'39"	120°13'25"	723500	7155500
Yerrida Spring[(b)]	25°52'54"	119°45'46"	776800	7134500

NOTES: (a) Localities are within Australian Map Grid (AMG) Zone 50 unless specified otherwise
(b) Position doubtful
(c) Locality within AMG Zone 51

These Explanatory Notes complement the published THADUNA 1:100 000 geological map, which covers the southeastern portion of PEAK HILL (1:250 000). The area contains rocks of the Palaeoproterozoic Yerrida and Earaheedy Basins, which overlie the northern margin of the Yilgarn Craton. The basins were formed when the Pilbara and Yilgarn Cratons collided, between about 2000 and 1800 Ma. This event is known as the Capricorn Orogeny. All formations that comprise the Yerrida Group are present on THADUNA. The Maraloou, Doolgunna, Thaduna, Johnson Cairn, and Juderina Formations contain turbiditic sandstone, siltstone, and black shale, and the Killara Formation contains mafic intrusive and extrusive rocks. The Earaheedy Group is represented by the Yelma Formation, which contains chertified carbonate and chert breccia. Copper deposits on THADUNA are hosted by the Thaduna Formation, and platinum-group element anomalies are associated with the Killara Formation. Rock types in the Yelma Formation suggest base-metal mineralization may be present.



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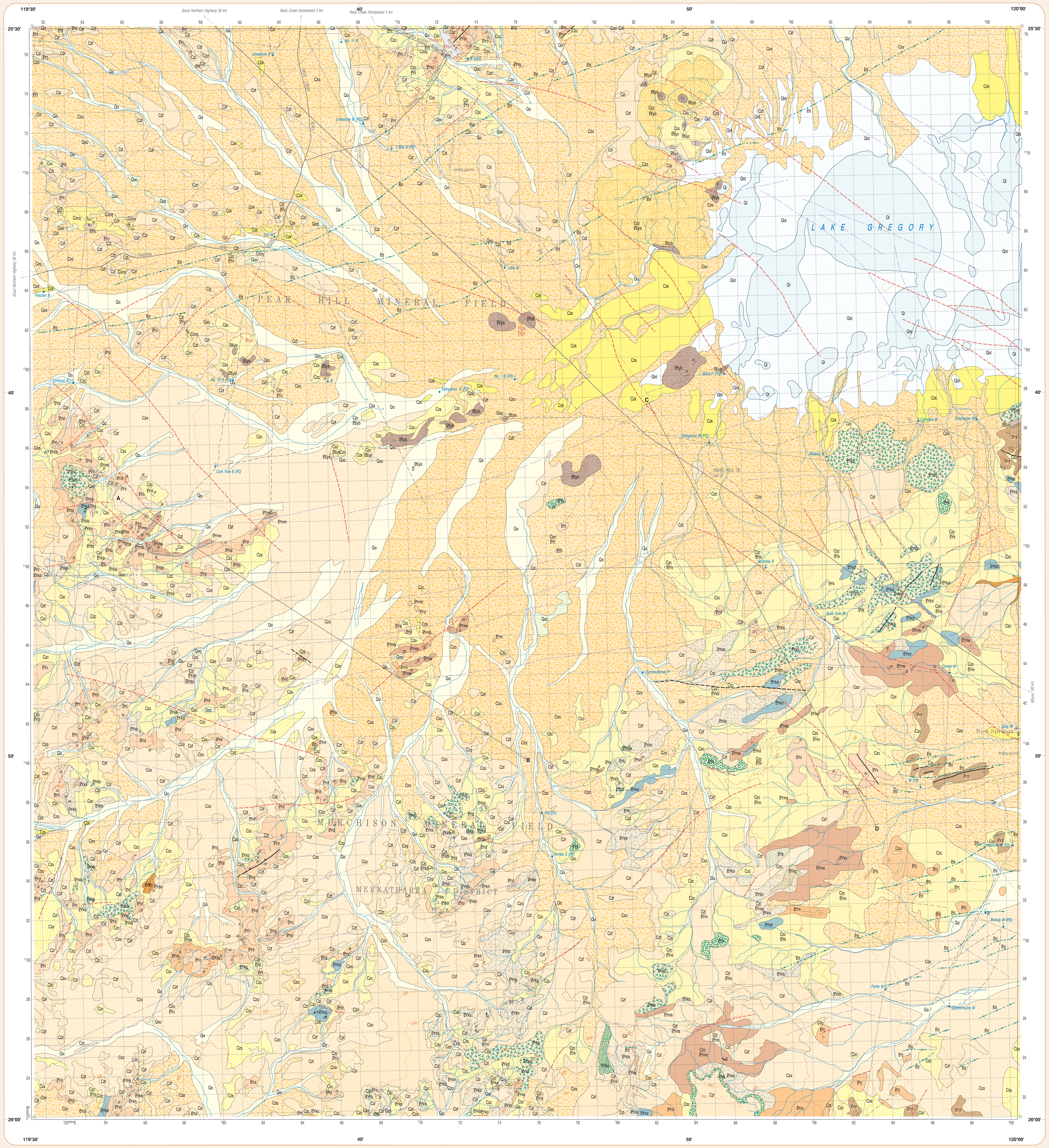
AUSTRALIA 1:100 000 GEOLOGICAL SERIES

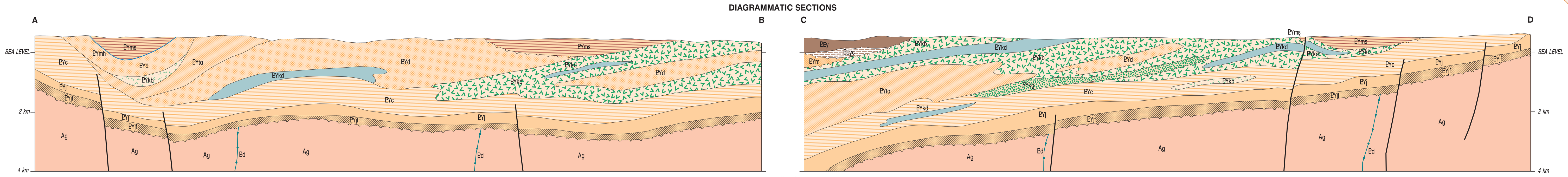
THADUNA

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET 2846



DIAGRAMMATIC SECTIONS



Unconformity

Reference

PHANEROZOIC — CAINOZOIC — QUATERNARY

Qa Alluvial deposits—sand and silt in channels and floodplains
Qac Clay and silt in claypans
Ql Saline silt and mud on salt lakes
Qld Gypsiferous and calcareous sand in dunes around salt lakes

Czs Sheetwash deposits—ferruginous clay, silt, and sand as extensive fans
Czc Colluvium—gravel, sand, and silt as scree and sheetwash
Czcq Quartz vein rubble and debris
Czk Calcrete
Czs Sandplain deposits—unconsolidated sand, minor silt and clay; includes low, vegetated dunes
Czz Silcrete

Czf Ferruginized rubble and colluvium—dominantly ferruginized pisolites and nodules, ferruginized rock, and ironstone rubble; degraded lateritic duricrust
Czl Lateritic deposits—nodular and pisolitic laterite, and associated debris
Czi Ironstone duricrust; massive and rubbly

PROTEROZOIC

q Quartz vein

Ed Dolerite dyke; dashed where interpreted from aeromagnetic data: + positive magnetic anomaly, - negative magnetic anomaly

Earaheedy Group (EARAHEEDY BASIN)

EEy **YELMA FORMATION:** quartz arenite, stromatolitic dolomite, and associated chert breccia; minor conglomerate
EEyb Dolomite breccia; predominantly chertified; well bedded dolomite and thinly laminated dolomite; minor lenses of ferruginous sandstone and siltstone
EEyc Stromatolitic dolomite
EEyo Conglomerate and quartz lithic sandstone

Yerrida Group — Mooloogool Subgroup (YERRIDA BASIN)

EYm **MARALOOU FORMATION:** thin-bedded siltstone and black shale
EYmb Chert breccia
EYmh Laminated chert; subordinate intercalated shale
EYms Thin bedded siltstone, marl, and ferruginous shale

EYk **KILLARA FORMATION:** undifferentiated mafic intrusive and extrusive rocks, and intercalated thin chertified volcaniclastic rocks
EYkd Medium- to coarse-grained dolerite in dykes and sills
EYkb Tholeiitic lava; aphyric
EYkbx Basaltic breccia
EYkx Pyroxenite
EYkg Gabbro
EYkc **Bartle Member:** laminated chert; locally with barite and anhydrite nodules
EYkh Chertified volcaniclastic rocks and chert pods associated with mafic volcanic rocks
EYks Lithic sandstone, intercalated with mafic flows

EYd **DOOLGUNNA FORMATION:** arkosic sandstone and quartz siltstone; minor pebble beds
EYda Arkosic sandstone with subordinate siltstone; minor conglomerate
EYds Laminated quartz sandstone and kaolinitic siltstone

EYt **THADUNA FORMATION:** lithic sandstone and shale; minor dolomite
EYta Lithic sandstone; minor shale

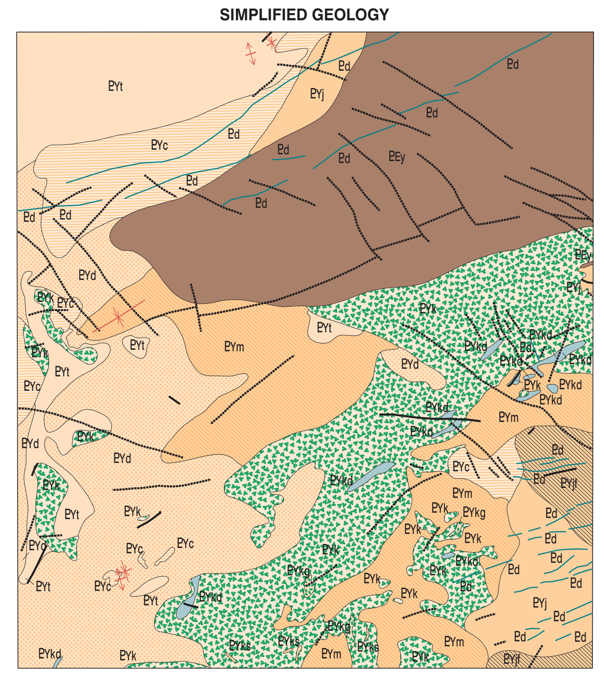
Yerrida Group — Windplain Subgroup

EYc **JOHNSON CAIRN FORMATION:** argillaceous siltstone and thin bedded dolomite, minor lithic and quartz sandstone
EYj **JUDERINA FORMATION:** quartz arenite; local siltstone, chert breccia, and pebble beds
EYjf **Finlayson Member:** quartz arenite; commonly ripple-marked

ARCHAEAN (YILGARN CRATON)

Ag Undivided granitoid rock and minor greenstones (section only)

SIMPLIFIED GEOLOGY



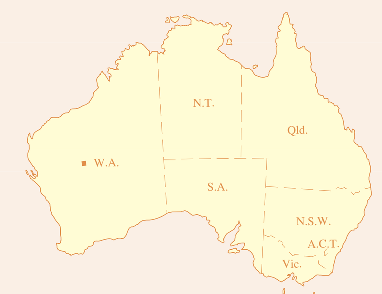
EARAHEEDY GROUP (EARAHEEDY BASIN): Ed Dolerite dyke; EEy Yelma Formation

YERRIDA GROUP (YERRIDA BASIN): EYm Maraloou Formation; EYk Killara Formation: predominantly basalt; EYkd Dolerite; EYkg Gabbro; EYkh Intervolcanic sedimentary rocks; EYd Doolgunna Formation; EYt Thaduna Formation; EYc Johnson Cairn Formation; EYj Juderina Formation; EYjf Finlayson Member

Fault concealed by younger rocks

Symbols

Geological boundary: exposed; concealed
Fault, showing dip of fault plane: exposed; concealed; thrust, showing dip; concealed, interpreted from aeromagnetic data
Fold: anticline, exposed; syncline, exposed, concealed
Small scale fold, showing plunge: minor anticline; minor syncline; minor fold, showing nature of vergence
Bedding, showing strike and dip: inclined; vertical; horizontal; interpreted from aerial photography, 0 – 15°
Cleavage, showing strike and dip: inclined; vertical
Intersection lineation, showing direction of plunge: inclined
Fracture or joint, showing strike and dip: inclined
Stromatolite locality
Airphoto lineament, unspecified
Aeromagnetic lineament
Formed road
Track
Fence, generally with track
Homestead — New Springs
Building
Yard
Horizontal control, minor
Breakaway
Contour line, 20 metre interval
Watercourse, ephemeral
Pool
Rockhole
Spring
Bore
Well
Windpump
Dam
Abandoned
Position doubtful
Mineral field boundary
Mine
Mining area: Opencut; Tailings or stockpile
Mineral exploration drillhole, showing subsurface data
Mineral occurrence: Copper — Cu



SHEET INDEX

JAMINDI 2647	THREE RIVERS 2747 (PEAK HILL)	MARYMIA 2847	FAIRBAIRN 2947	METHWIN 3047 (NABBERU)	RHODES 3147
BRYAH 2646	(SG 50-8) DOOLGUNNA 2746	THADUNA 2846	MERRIE 2946	(SG 51-5) NABBERU 3046	GRANITE PEAK 3146
GLENGARRY 2645	MOOLOOGOOL 2745 (GLENGARRY)	MOUNT BARTLE 2845	CUNYU 2945	MILLROSE 3045 (WILUNA)	BALLIMORE 3145
GABANINTHA 2644	(SG 50-12) YAGANOO 2744	MEREWETHER 2844	WILUNA 2944	(SG 51-9) LAKE VIOLET 3044	SANDALWOOD 3144

1:100 000 maps shown in black
1:250 000 maps shown in brown

TN GN MN
GRID / MAGNETIC ANGLE 1.0°
GRID CONVERGENCE 0.8°

True north, grid north and magnetic north are shown diagrammatically for the centre of the map. Magnetic north is correct for 1995 and moves easterly by about 0.1° in 5 years.

DEPARTMENT OF MINERALS AND ENERGY — L. C. RANFORD, DIRECTOR GENERAL
GOVERNMENT OF WESTERN AUSTRALIA — HON. NORMAN MOORE, M.L.C. MINISTER FOR MINES
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA — PIETRO GUJ, DIRECTOR

SCALE 1:100 000

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

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
HORIZONTAL DATUM: GEOCENTRIC DATUM OF AUSTRALIA 1994
VERTICAL DATUM: AUSTRALIAN HEIGHT DATUM

Grid lines indicate 1000 metre interval of the Map Grid Australia Zone 50

The Map Grid Australia (MGA) is based on the Geocentric Datum of Australia 1994 (GDA94)
GDA94 positions are compatible within one metre of the datum WGS84 positions

Reference points to align maps based on the previous datum, AGD84, have been placed near the map corners

Geology by F. Pirajno and N. G. Adamides 1996

Edited by D. Ferdinando and G. Loan

Cartography by E. Green and M. Ward

Topography from the Department of Land Administration Sheet SG 50-8, 2846, with modifications from geological field survey

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The recommended reference for this map is: PIRAJNO, F., and ADAMIDES, N. G., 1997, Thaduna, W.A. Sheet 2846: Western Australia Geological Survey, 1:100 000 Geological Series

THADUNA

SHEET 2846 FIRST EDITION 1997
Version 1.1 — August 2004