EXPLANATORY NOTES

GOVERNMENT OF WESTERN AUSTRALIA

GEOLOGY OF THE DUKETON 1:100 000 SHEET

by R. L. Langford and T. R. Farrell

1:100 000 GEOLOGICAL SERIES

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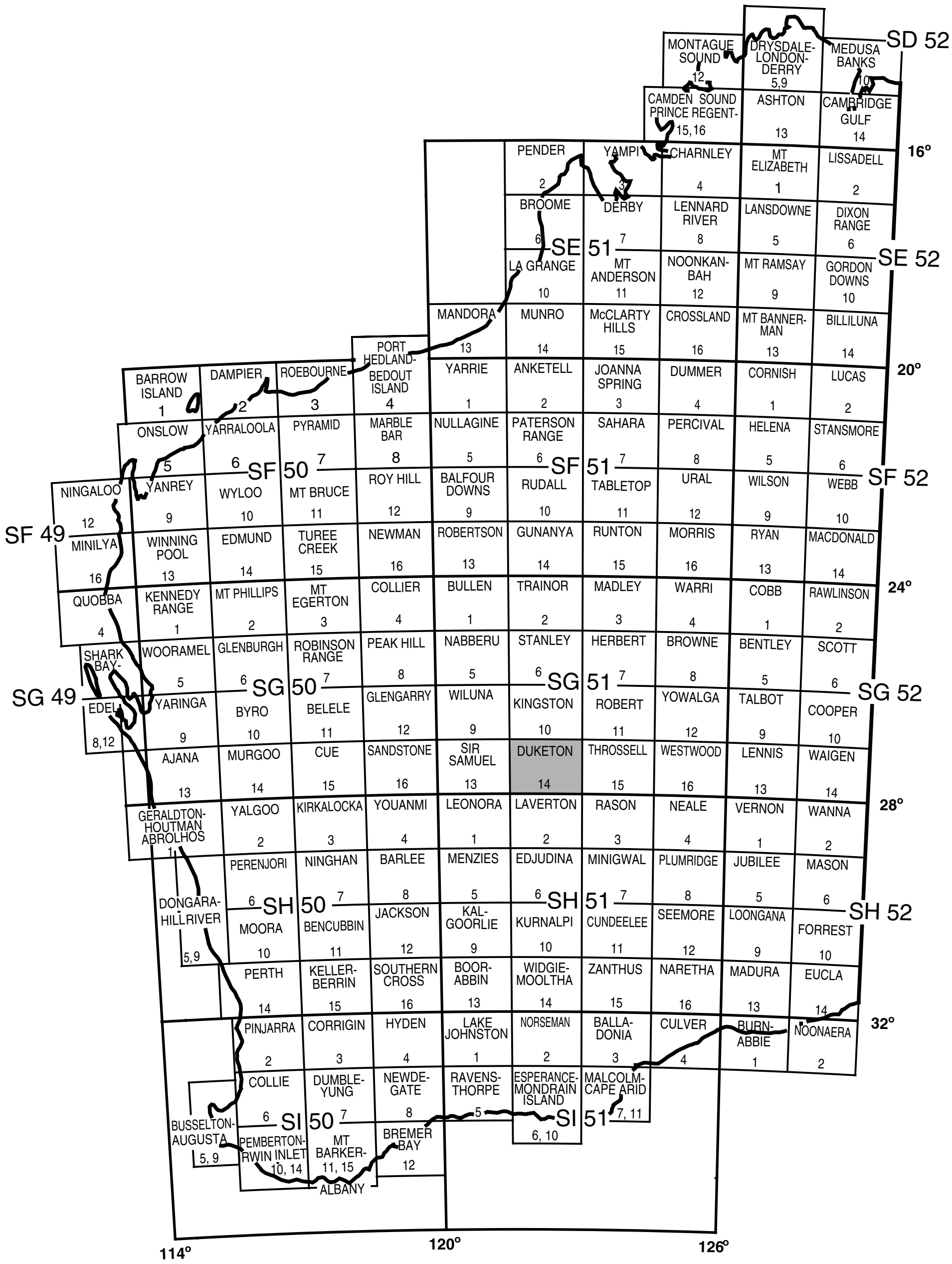
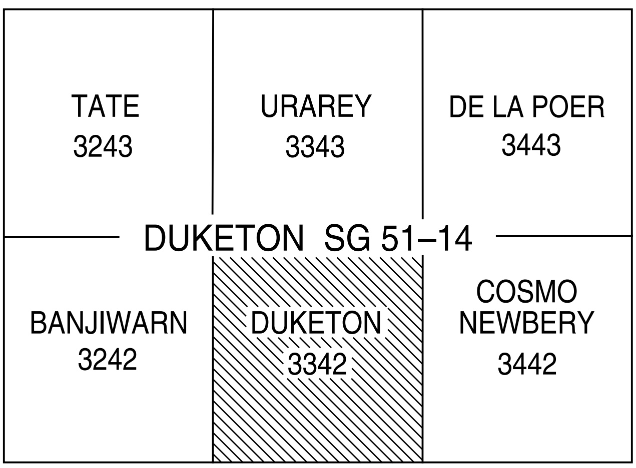
DEPARTMENT OF MINERALS AND ENERGY





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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGY OF THE DUKETON 1:100 000 SHEET

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Perth 1998

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Cover photograph:

View to the northeast of metamorphosed porphyritic rhyolite–dacite lava (*Afr*) at Pinjanie Hill (AMG 287376). The metalava has a well-developed, relatively coarse-grained mineral lineation that is particularly well formed in fold hinge zones.

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Geology of the Duketon 1:100 000 sheet

by

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Abstract

DUKETON lies in the northern part of the Eastern Goldfields Province of the Archaean Yilgarn Craton. The Eastern Goldfields Province is a typical Archaean granite–greenstone terrain, characterized by large areas of granitoid and gneiss adjacent to linear to arcuate, north-northwesterly trending greenstone belts.

At its widest point, the Duketon greenstone belt is approximately 30 km across. The belt comprises a deeply weathered sequence of deformed and metamorphosed ultramafic, mafic, and felsic volcanic rocks, with associated volcaniclastic sedimentary rocks, and thin units of banded chert.

The Duketon greenstone belt is a structurally complex assemblage of sheared, elongate fault slices and dismembered folds. The dominant stratigraphic and structural trend is north-northwesterly, parallel to the length of the belt. Four major discontinuities or shear zones have been interpreted to lie parallel to the overall trend of the belt. The belt can also be broadly divided into two metamorphic zones; an extensive greenschist-facies zone, and a restricted area of amphibolite-facies metamorphism adjacent to granitoids.

There are minor outliers of presumed Permian sedimentary rocks overlying the Archaean rocks. The regolith is extensive, consisting of residual and transported deposits ranging in presumed age from Early Tertiary to Holocene.

Mineral production from DUKETON is restricted to gold and accessory silver. Despite extensive exploration, no economic base-metal deposits have been discovered. DUKETON includes two gold-mining centres; Erlistoun and Duketon–Hootanui. These centres were most active between 1900 and 1910, although some mines worked sporadically up to 1945. There was renewed gold mining activity between 1988 and 1993, and openpits were worked at Baneygo, Russell Find and Christmas Well. In addition, there has probably been a significant but largely unrecorded production of alluvial gold.

KEYWORDS: Archaean, deformation events, greenstone, granitoid, gold exploration, mineral exploration, mineral occurrences, regional geology

Introduction

The DUKETON* 1:100 000 geological sheet (SG51–14–3342) covers an area in the northern part of the Eastern Goldfields bounded by latitudes 27°30' and 28°00'S, and longitudes 122°00' and 122°30'E, (Fig. 1). The closest town is Laverton, which lies about 70 km south of the southern boundary of the sheet area. There is a small aboriginal settlement at Mulga Queen in the north of DUKETON.

The earliest publication dealing with the geology and mining of the area is Gibson (1906). Clarke (1925) subsequently completed reconnaissance mapping, and the first detailed geological survey was by Hobson and Miles (1950). The first systematic description of the geology on DUKETON was presented in the explanatory notes and accompanying map for the first edition of the DUKETON 1:250 000 sheet by Bunting and Chin (1977, 1979).

The present geological survey (Farrell and Langford, 1996) was carried out as part of the National Geoscience Mapping Accord (NGMA) between February and August 1994, using 1:25 000-scale colour aerial photographs, supplemented by Landsat TM5 (Thematic Mapper) imagery, and both magnetic and radiometric geophysical surveys. Additional information was obtained from mining company reports held in the Geological Survey of Western Australia (GSWA) M-series open-file system (WAMEX).

Access

DUKETON can be accessed from Laverton via the Bandya Road, from the west via the Bandya–Banjawarn Road, or from the northeast via the Urarey–Warren Bore Road

* Capitalized names refer to standard 1:100 000 map sheets

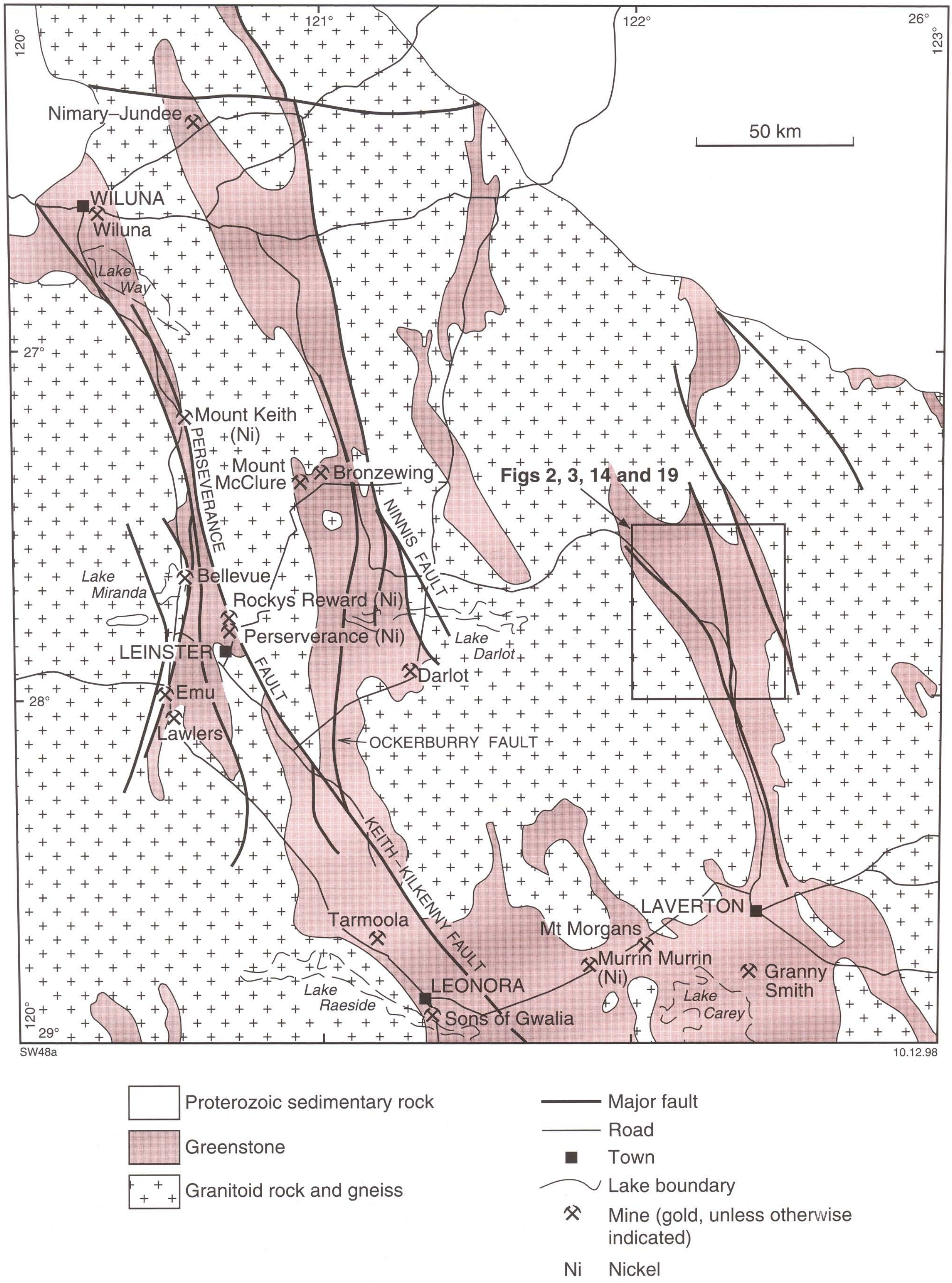

Figure 1. Regional setting of DUKETON

(Fig. 2). There are numerous fence lines and tracks that provide good access to most of the greenstone areas. Access to the areas underlain by granite is generally difficult due to the scarcity of tracks.

Physiography

The landforms in the DUKETON area have largely formed by the erosion and dissection of a deeply weathered Tertiary land surface (the Old Plateau *of* Jutson, 1950). There are two characteristic groups of landforms related to the underlying geology. Areas underlain by greenstone are characterized by subdued strike ridges and low, rounded hills of lateritic duricrust and ironstone debris, whereas areas underlain by granite are characterized by extensive sand sheets and scattered exposures of weathered rock with well-developed breakaways.

The DUKETON area is generally flat to undulating, ranging in altitude from an average of 560 m Australian Height Datum (AHD) in the north, to 480 m in the south (Fig. 2). The main physiographic features are the broad valley of Borodale Creek, which trends southeasterly through the centre of the area, and subdued topographic highs along each side of the valley (Fig. 2). The topographic high to the east of the Borodale drainage system marks the divide between the northerly draining Disappointment Palaeoriver system and the southerly draining Carey Palaeoriver system (Hocking and Cockbain, 1990). The divide is marked in the northern part of the area by a line of low ridges (Grant Duff Range and Sandstone Range) and scattered prominent hills, including Mount Maiden (590 m), Mason Hill (578 m), Ingi-jingi Hill and Pinje-Eda Hill (574 m). The area northeast of the divide is characterized by undulating sand plains over silcrete and calcrete, with small breakaways in areas of recent erosion. By contrast, southwest of the divide, the Tertiary land surface has been largely eroded, exposing low rocky ridges in greenstone areas and breakaways along the margins of plateau remnants.

Climate and vegetation

The climate is semi-arid to arid with an annual rainfall of about 200 mm per year, most of which falls between January and June. Potential evaporation, at approximately 3000 mm per year, far exceeds the annual rainfall. The summers are hot, with temperatures commonly in excess of 40°C between December and March. Winters are cool and mild with occasional frosts.

DUKETON lies between the Murchison and Great Victoria Desert natural regions of the Eremaean Province (Beard, 1974, 1990). The Murchison Region (Austin Botanical District) is dominated by low mulga woodland (*Acacia aneura*) on plains, reduced to mulga scrub on hills, and by spinifex (*Triodia basedowii*) and *Eucalyptus* spp. on sand plains. The Great Victoria Desert Region (Helms Botanical District) is dominated by spinifex-covered sand plains with stands of marble gum (*E. gongylocarpa*) and mallee *(E. youngiana).*

Nomenclature

All greenstone rocks and many of the granitoids on DUKETON have been deformed and metamorphosed, with hydrothermal alteration in some of these rocks. However, in many instances primary textures are preserved and it is possible to identify the parent rock. For this reason, igneous or sedimentary rock terminology has been used in these Notes wherever possible. In particular, the nomenclature of the igneous rocks, including pyroclastic rocks, follows the recommendations of the International Union of Geological Sciences (Le Maitre et al., 1989). Only in areas where the rocks have been extensively recrystallized have metamorphic rock names been used.

Regional geological setting

DUKETON lies in the northern part of the Eastern Goldfields Province of the Archaean Yilgarn Craton (Gee et al., 1981; Griffin, 1990). The Eastern Goldfields Province is a typical Archaean granite–greenstone terrain (Condie, 1981), characterized by large areas of granitoid and gneiss with linear to arcuate, north-northwesterly trending greenstone belts (Griffin, 1990). The greenstone belts are heterogeneously deformed, and comprise metamorphosed mafic to ultramafic volcanic sequences and intrusions, together with felsic volcanic and sedimentary sequences.

As in many other granite–greenstone terrains, the greenstone belts in the Eastern Goldfields Province have been metamorphosed to greenschist or amphibolite facies, with the highest metamorphic grade occurring at granite–greenstone contacts (Binns et al., 1976). Structurally, upright folds and near-vertical foliations dominate the greenstone sequences. The major faults and folds are typically parallel to the long axes of the belts. Also, in common with other granite–greenstone terrains, late discordant plutons intrude both granitoids and greenstones.

There are minor outliers of presumed Permian sedimentary rocks related to the sequence in the Officer Basin to the east. The regolith on DUKETON is extensive, consisting of residual and transported deposits ranging in presumed age from Early Tertiary to Holocene.

Precambrian geology

DUKETON encompasses the northern part of the Duketon greenstone belt, an elongate, north-northwesterly trending zone of Archaean supracrustal rocks flanked by granitoid and gneiss (Fig. 3). At its widest point the greenstone belt is approximately 30 km across. The belt contains a deeply weathered, deformed and metamorphosed sequence of ultramafic, mafic, and felsic volcanic rocks with associated volcaniclastic sedimentary rocks and thin units of banded chert. Most of the sequence is poorly exposed.

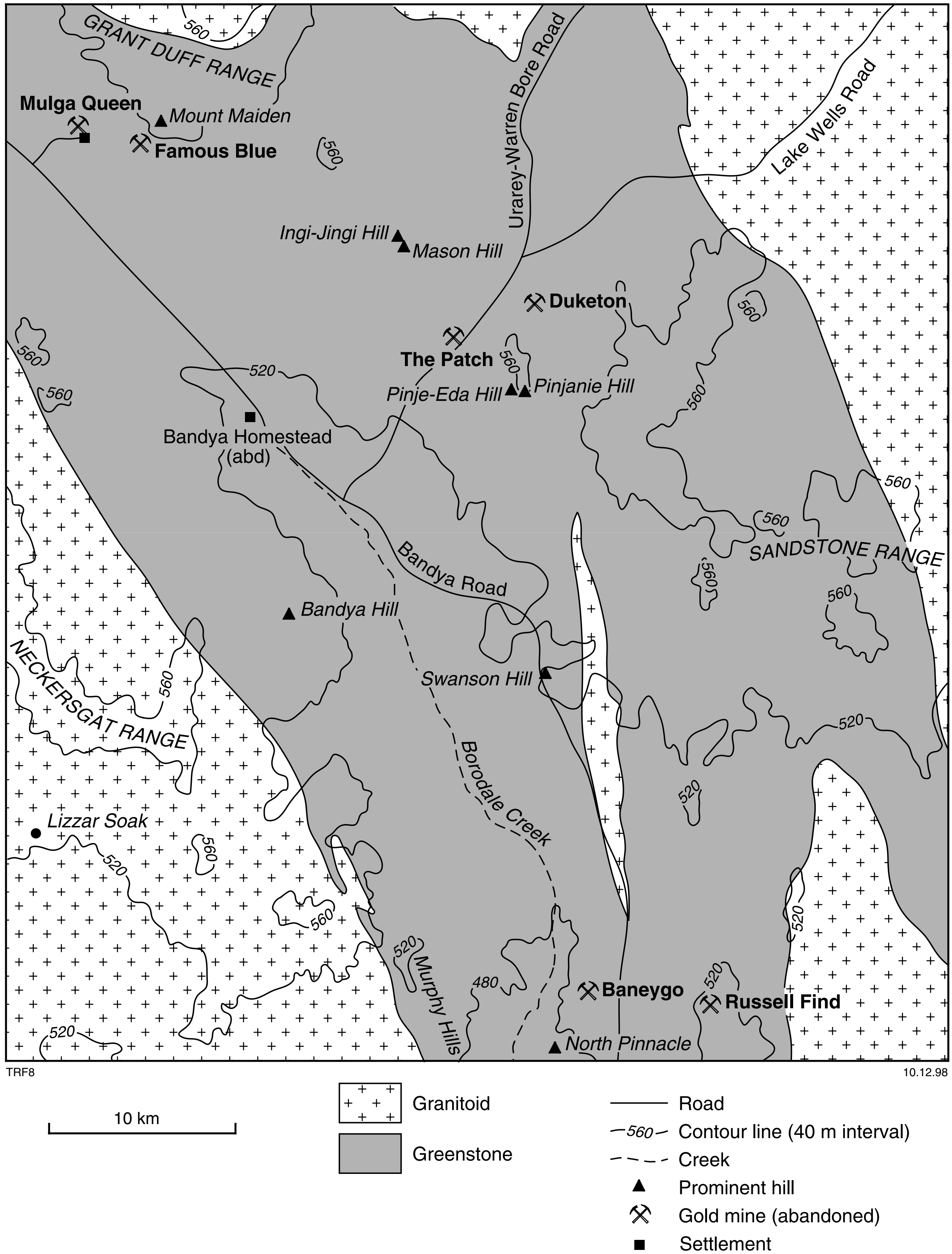

Figure 2. Principal localities, roads and topographic features on DUKETON

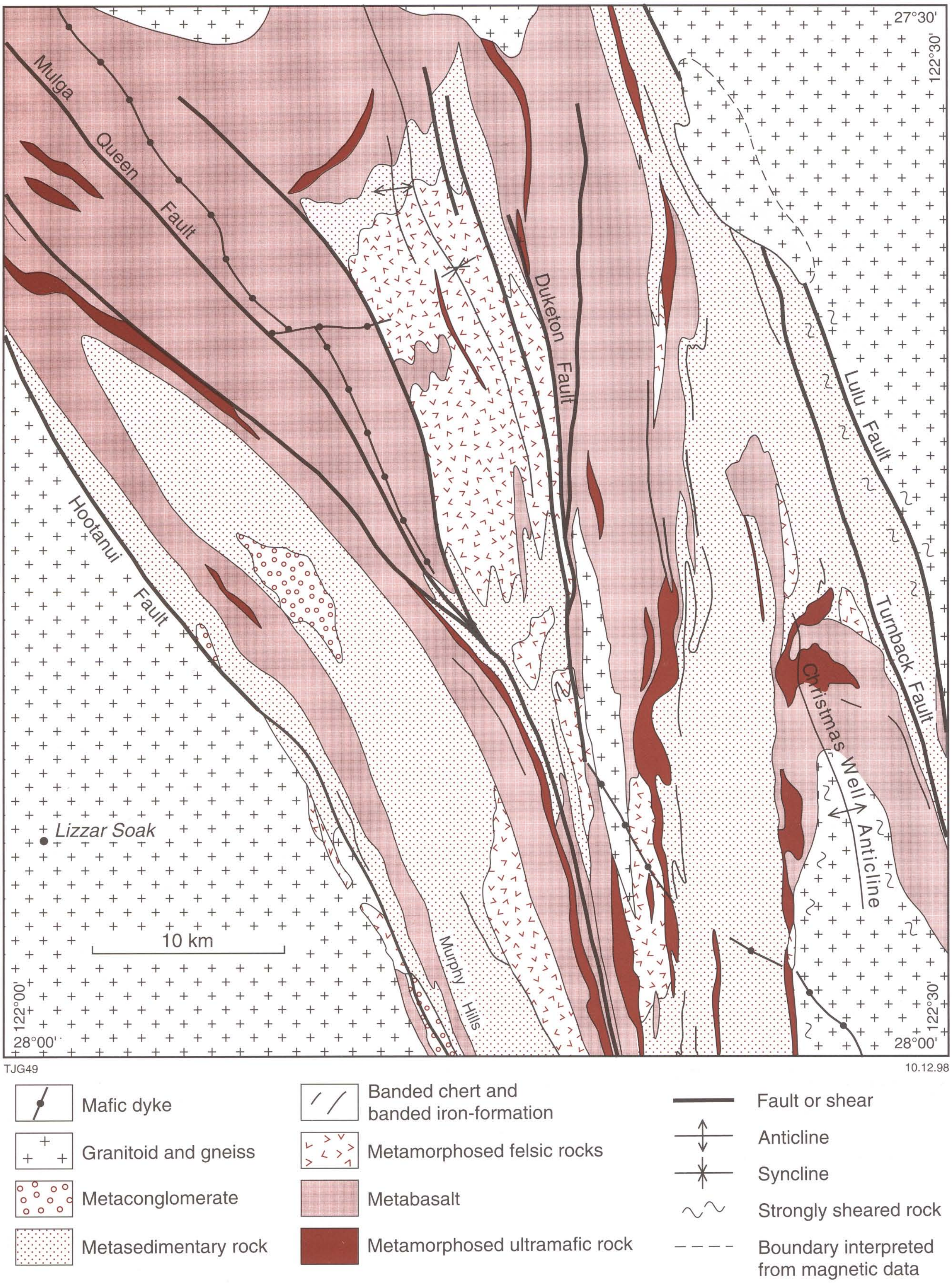

Figure 3. Simplified tectonic interpretation map of DUKETON

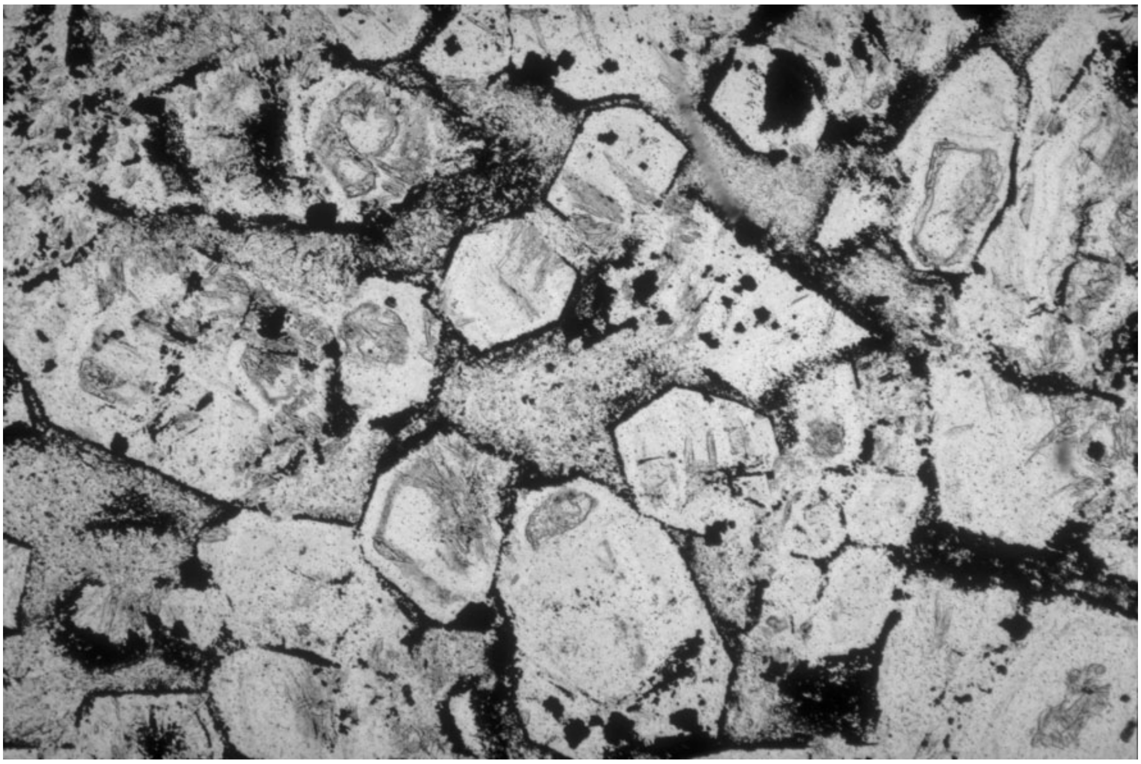

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Figure 4. Relict orthocumulate texture in a serpentinized peridotite. The subhedral–euhedral olivine crystals are replaced by serpentine-group minerals and small amounts of chlorite and tremolitic amphibole. Plane polarized light. Field of view 2.0 mm. GSWA 121412 (AMG 340077)

Archaean rock types

Metamorphosed ultramafic rocks (*Au, Auc, Aud, Aup, Aur, Aut*)

Metamorphosed ultramafic rocks are widespread on DUKETON, occurring typically as thin, laterally extensive units (Fig. 3). They are generally poorly exposed in the northern half of DUKETON, and in most cases are seen only in drillholes, costeans or exposures adjacent to old mine shafts. Good exposures are more common in the southern half of the sheet area, but many are deeply weathered. In many cases it is not possible to positively identify the original rock types, as they are typically silicified, serpentinized or altered to talc–carbonate (*Auc*), talc–chlorite (*Aut*) or tremolite schists (*Aur*). Where there is deep weathering, poor exposure, and/or the presence of different types of alteration within the one exposure, these rocks have generally been mapped as undivided metamorphosed ultramafic rocks (*Au*).

Talc–carbonate rock (*Auc*) is composed mainly of talc and carbonate-group minerals, with chlorite as a minor constituent. This rock is recognizable in the field by the presence of brown iron-oxide spots or cavities resulting from the breakdown of the carbonates. Talc–carbonate assemblages may have formed by alteration of an ultramafic parent at higher fluid CO_2 concentrations than talc–chlorite schist (Winkler, 1994). There are exposures of talc–carbonate rock at a number of locations on DUKETON, for example 5 km northeast of Erlistoun (AMG 365091*) and at the Ballintraye mine (AMG 063477), where the well-foliated talc–carbonate schist is exposed beneath 1 m of duricrust.

In the few areas with fresh outcrop, the predominant metamorphosed ultramafic rock types are serpentinized dunite (*Aud*) and serpentinized peridotite (*Aup*). These are typically fine- to medium-grained, granular, weakly foliated rocks, with well-preserved cumulate textures. The serpentinized dunite contains relict adcumulate and/or mesocumulate textures, whereas the serpentinized peridotite is typically orthocumulate (Fig. 4). In both rock types, serpentine group minerals and minor amounts of very fine grained magnetite, talc or chlorite typically replace the former olivine crystals. The olivine crystals are less commonly replaced by carbonates. The intercumulus material, which was probably dominantly pyroxene, is replaced by fine-grained aggregates of magnetite plus one or more of talc, chlorite and tremolite.

Good exposures of serpentinized, orthocumulate-textured peridotite occur at Baneygo, on the eastern side of the Bandya Road (AMG 340077), and serpentinized

* Localities are specified using 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. To convert this reference number to a Universal Grid Reference, the zone and 100 000 Metre Square identification should precede this number, which for DUKETON is 51JVK.

dunite is well exposed to the north of the Baneygo Mine (AMG 320070). Serpentinized peridotite is exposed in a station track about 3 km southeast of Pinjanie Hill (AMG 313364). The rock is reddish brown, with brownish white veins both cross-cutting and interstitial to pseudomorphs after olivine up to 1 mm across.

Metapyroxenite is a very minor rock type, and is typically associated with metamorphosed high-Mg basalt. The rock is weakly deformed and rich in tremolite–actinolite with minor amounts of chlorite, plagioclase, iron oxides, and sphene. The rock is interpreted to be a metapyroxenite on the basis of its amphibole-rich composition and relict igneous texture, which is still recognizable due to the pseudomorphous replacement of pyroxene by finer grained amphibole or the ghosting of primary textures by fine-grained iron oxides. In areas of strong deformation, the original textures are destroyed and a very fine grained tremolite schist (*Aur*) is formed. The metapyroxenite was originally a fine- to medium-grained, equigranular rock composed mainly of pyroxene with minor amounts of plagioclase. This lithology does not occur in mappable units and its relationship with the associated metabasalt is uncertain, but it may have formed in the inner parts of thick high-Mg basalt flows.

Talc–chlorite schist (*Aut*) is less abundant than serpentinized ultramafic rock, and is usually not well exposed. The schist is a soft, fine-grained, well-foliated rock, containing varying proportions of talc and chlorite, as well as minor amounts of carbonate and opaque minerals (probably magnetite). The foliation is defined by the alignment of carbonate-rich zones, differentiation into chlorite-rich and talc-rich bands, and by the preferred orientation of chlorite and talc.

The best exposure of talc–chlorite schist (*Aut*) is in the Murphy Hills on the east side of a prominent ridge of metachert (AMG 230058). Another exposure occurs below 0.1–0.2 m of hardpan in a costean about 3 km southeast of Mason Hill (AMG 241429). At this location, the schist is slightly weathered, well foliated, and talc-rich, with a speckled brown and greenish appearance.

Metamorphosed fine-grained mafic rocks (*Ab, Aba, Abm, Abp, Abt, Aby*)

Subdivision of the mafic rocks is based on variations in mineralogy and textural characteristics. Very fine grained and/or deeply weathered mafic rocks have been mapped as undivided mafic rocks (*Ab*). This category includes metabasalt, as well as some minor amounts of intimately associated fine-grained metagabbro. Metabasalt has relict intergranular or granular textures, is commonly sparsely plagioclase-phyric (*Abp*), and more rarely may contain oikocrysts of amphibole after igneous pyroxene. Drillhole chips of fresh metabasalt that are considered to have a tholeiitic composition are shown as tholeiitic basalt (*Abt*).

The dominant mafic rock type in areas of higher grade within the greenstone sequence, adjacent to the granitoids, is a well-foliated and lineated amphibolite (*Aba*) composed mainly of acicular hornblende and plagioclase. The rock probably formed by amphibolite-facies metamorphism of a basalt or gabbro protolith. The protolith is inferred to be a gabbro if the amphibolite contains abundant, coarse-grained, strained hornblende grains enclosed by the foliation.

Good exposures of amphibolite occur near Christmas Well and in the Murphy Hills area close to the granite–greenstone contact (e.g. AMG 229047). The only exposure of amphibolite observed in the northern part of DUKETON is 2.5 km northeast of German Well (AMG 451361), where there are fresh exposures of well-foliated, medium-grained amphibolite with a grain size of 2 mm or less. The pleochroic green to light brownish green amphibole is set in a foliated matrix of recrystallized quartz and plagioclase of around 0.1–0.2 mm grain size.

Metamorphosed high-Mg basalt (*Abm*) occurs at several locations in the southern part of DUKETON. This metabasalt is commonly inequigranular to porphyritic, and contains large, randomly oriented, acicular amphibole pseudomorphs after igneous pyroxene up to 9 mm in length (Fig. 5). The relict pyroxene needles are set in a finer grained, spinifex-textured matrix that was originally composed mainly of pyroxene and plagioclase. Relict varioles up to 4 mm in diameter are present in a few exposures.

Excellent exposures of metamorphosed high-Mg basalt (*Abm*) are present about 2 km south of Christmas Well Pit (AMG 291177), where spinifex-textured metabasalt occurs in association with variolitic metabasalt, metagabbro, metaleucogabbro, and metaperidotite. The spinifex-textured rocks contain relict medium- to coarse-grained pyroxene needles and fascicular pyroxene aggregates, both of which have been replaced by chlorite and tremolite–actinolite. The matrix is fine-grained and spinifex-textured, and consists of tremolite–actinolite, chlorite, epidote, albite, and opaque minerals. The associated variolitic metabasalt is a very fine grained, well-foliated rock with abundant, irregularly distributed, pale-coloured relict varioles between 1 and 4 mm in diameter.

Metamorphosed amygdaloidal basalt (*Aby*), with irregularly shaped patches rich in tremolite–actinolite and epidote (≤ 6 mm in diameter), is a minor variant in some areas. In some lower grade rocks, the amygdales are zoned from an epidote-rich core to a margin containing tremolite–actinolite, albite, and epidote.

Metamorphosed medium- and coarse-grained mafic rocks (*Ao, Aog*)

Undivided medium- to coarse-grained mafic rocks (*Ao*) include weathered metagabbro and coarser intervals within metabasalt units.

Metagabbro (*Aog*) is common in the greenstone sequences, and shows considerable variation in mineralogy, primary texture, grain size, and degree of deformation. The metagabbro is principally composed of amphibole after pyroxene with subordinate amounts of plagioclase, as well as accessory magnetite. Metaleucogabbro, containing more than 65% leucocratic minerals, and metamorphosed quartz gabbro are minor variants.

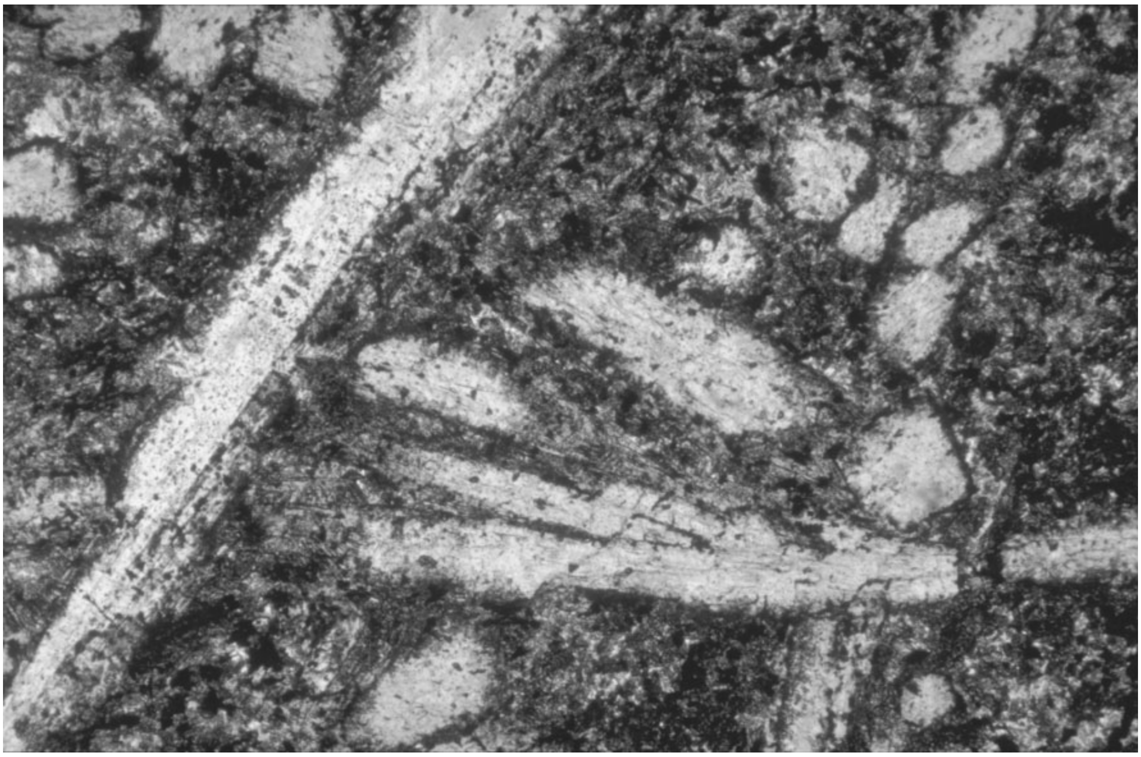

Figure 5. Metamorphosed, porphyritic high-Mg basalt with relict pyroxene-spinifex texture. The former pyroxene needles are replace by tremolite–actinolite, chlorite and small amounts of epidote. Plane polarized light. Field of view 2.0 mm. GSWA 121504 (AMG 290177)

In weakly deformed metagabbros, the pseudomorphous replacement of igneous minerals by the metamorphic assemblage has resulted in the preservation of many of the primary textures (Fig. 6). These rocks typically contain relict subophitic and intergranular textures, and may be markedly inequigranular. In some instances they contain large relict oikocrysts of amphibole after pyroxene, up to 16 mm in diameter (Fig. 7). By contrast, strongly deformed metagabbros characteristically contain highly strained, relict individual grains or aggregates of pyroxene and plagioclase enclosed by a finer grained, foliated and completely recrystallized matrix.

There are excellent exposures of metagabbro, as corestones up to 0.5 m across, about 1.5 km northeast of Corner Well (AMG 206360). The rock is a dark greenish-grey, medium-grained gabbro, which in thin section has a subophitic texture comprising pyroxene, and chlorite after plagioclase. The grain size is typically 1–3 mm and the texture is equigranular, with no obvious foliation.

Metamorphosed felsic volcanic and volcaniclastic rocks (*Af, Afd, Afi, Afp, Afr, Afs, Aft, Afv*)

Metamorphosed felsic rocks are widely distributed throughout DUKETON, and are particularly abundant in a 15 km long belt located to the south and east of Duketon. Many of the metamorphosed felsic rocks are fine grained and strongly deformed, thus precluding a positive identification of the original rock type. However, in these cases a tentative identification has been made on the basis of phenocryst mineralogy and abundance (depending on the degree of deformation and metamorphism).

Metamorphosed felsic rocks rich in relict quartz and/or plagioclase crystals were probably felsic volcaniclastic rocks and have been mapped as undivided metamorphosed felsic rocks (*Af*). In areas where the deformation is not extreme, the felsic rocks have been further subdivided, and metamorphosed felsic volcanic rocks (*Afv*), metadacite (*Afd*) and metamorphosed felsic tuff (*Aft*) and rhyolite–dacite lava (*Afr*) have been recognized. Strongly deformed and recrystallized felsic rocks composed of white mica, quartz and plagioclase, with relict, partly recrystallized quartz grains enclosed by the foliation, have been mapped as felsic schist (*Afs*), as the original rock type is unclear and they are predominantly metamorphic in character (Fig. 8). A foliated and metamorphosed felsic rock with phenocrysts of quartz and feldspar up to 3 mm across (*Afp*) has been identified in mineral-exploration drillholes in the central part of DUKETON.

An exposure of metadacite (*Afd*) can be seen in the southern part of DUKETON close to North Pinnacle (AMG 308045). The rock is relatively fresh, containing phenocrysts of quartz and plagioclase up to 3 mm in size, in a very fine grained matrix of quartz, white mica and plagioclase (Fig. 9). The quartz phenocrysts are generally embayed and rounded, although rare bipyramidal crystals are present. The plagioclase crystals are subhedral to euhedral and occur as small glomeroporphyritic aggregates.

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Figure 6. Metagabbro showing pseudomorphous replacement of former pyroxene grains by amphibole, and interstitial plagioclase by fine-grained epidote, chlorite and plagioclase. Plane polarized light. Field of view 2.0 mm. GSWA 121473 (AMG 469230)

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Figure 7. Inequigranular, mottled metagabbro. Contains former pyroxene grains, now replaced by amphibole, subophitically enclosing finer grained plagioclase. AMG 289170

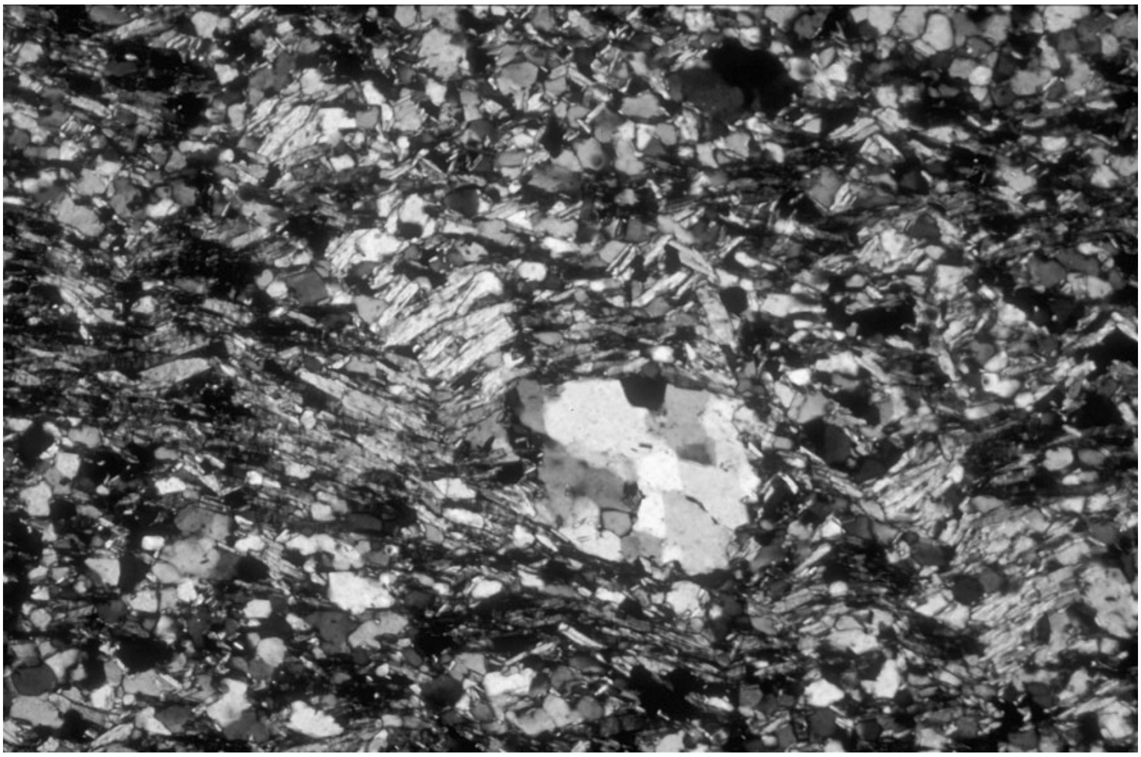

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Figure 8. Well-foliated felsic schist with a recrystallized, relict quartz grain. Crossed polars. Field of view 2.0 mm. GSWA 121446 (AMG 238031)

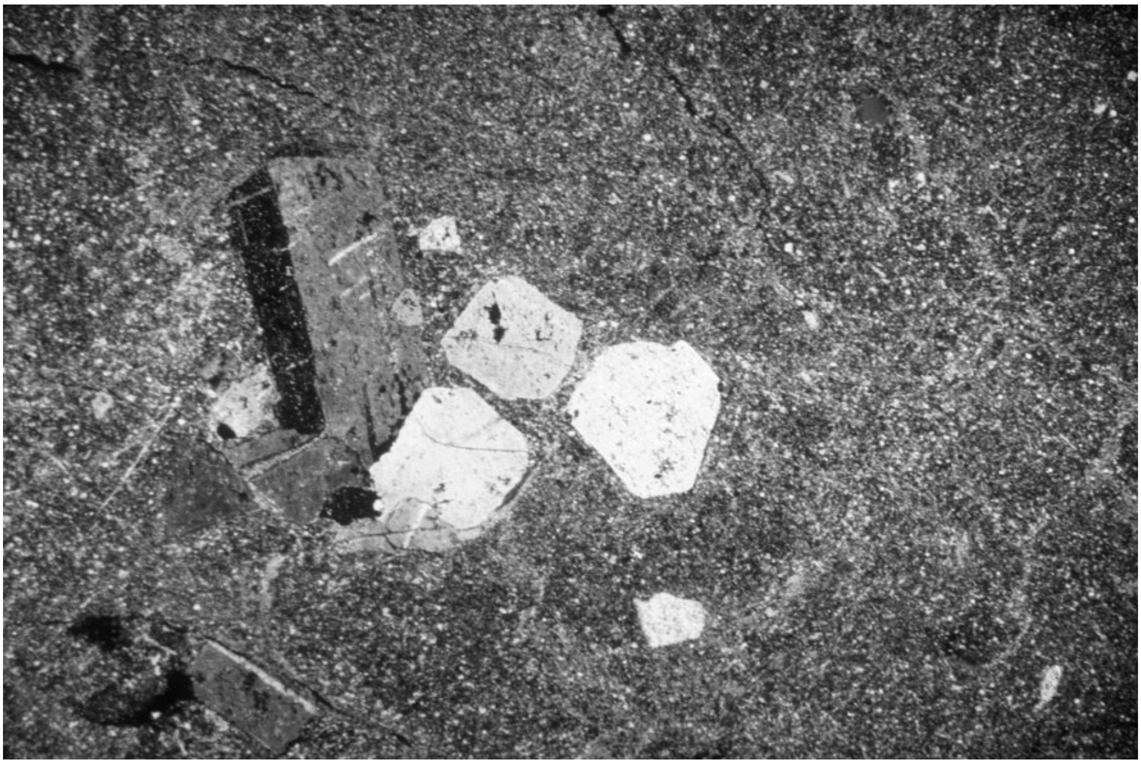

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Figure 9. Glomeroporphyritic metadacite from north of North Pinnacle. Crossed polars. Field of view 6.5 mm. GSWA 121427 (AMG 308047)

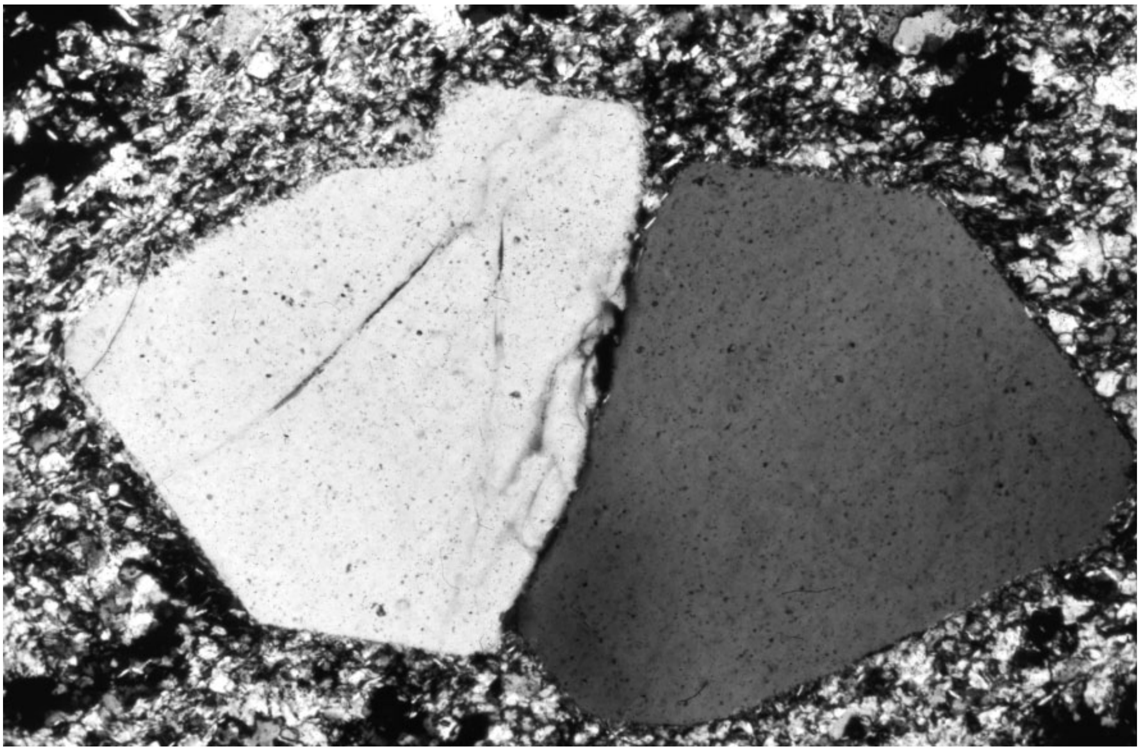

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Figure 10. Bipyramidal quartz crystals in metamorphosed felsic lava from Mason Hill. Crossed polars. Field of view 1.0 mm. GSWA 120907, AMG 224454

Metamorphosed porphyritic rhyolite–dacite lava (*Afr*) at Mason Hill retains well-preserved primary volcanic features, including both relict spherulites and phenocrysts, that confirm the effusive nature of the protolith (Langford, 1995). There is a complete absence of broken or shardic crystals, and the population of phenocrysts is uniform in distribution and morphology. The sequence comprises several thin flows, each up to 3 m thick, and overlies a metasiltstone unit that is at least 2 m thick, indicating a relatively quiescent and intermittent phase of extrusive volcanism.

In thin section, the metalava at Mason Hill contains small relict quartz crystals as phenocrysts, glomeroporphyritic aggregates and bipyramidal pairs up to 2 mm across (Fig. 10). Some of the small bipyramidal pairs have reaction haloes (Fig. 11). The phenocrysts are typically less than 1 mm across, and have subhedral and embayed forms. The proportions of plagioclase and alkali feldspar, and hence the composition of the protolith, cannot be determined precisely.

Felsic metalava of probable rhyolitic composition (*Afr*) is well exposed along about 50 m of the Urarey–Warren Bore Road northeast of The Patch (AMG 257408). The rock is weathered and finely foliated, but contains well-preserved quartz phenocrysts up to 3 mm across. In thin section, these include glomeroporphyritic aggregates set in a very fine grained quartz–sericite matrix. Exposures of metalava closely associated with mafic rocks occur about 7 km east of Bandya Homestead (AMG 215367). The presumed metarhyolite outcrops as a unit about 15 m wide between finely foliated mafic rocks, and in thin section includes phenocrysts of quartz including glomeroporphyritic aggregates and bipyramidal pairs from 0.5 to 1 mm across.

Metamorphosed intermediate rocks (*Afi*) are exposed southeast of Swanson Hill (e.g. AMG 310220). They characteristically contain plagioclase phenocrysts in a fine-grained, recrystallized and well-foliated matrix of quartz, plagioclase, and chlorite, with or without tremolite–actinolite, epidote, and biotite. In many cases they contain irregularly shaped aggregates of fine-grained chlorite and/or tremolite–actinolite that may be former mafic phenocrysts that have now been completely replaced by metamorphic minerals. These rocks are interpreted to be intermediate in composition based on the absence of relict quartz phenocrysts, the presence of plagioclase phenocrysts, and the abundance of biotite and/or chlorite in the matrix, as opposed to white mica, which is the dominant phyllosilicate in the felsic rocks. Additionally, the more mafic varieties have epidote and/or tremolite–actinolite as a matrix constituent.

Metasedimentary rocks (*As, Asc, Ascf, Ascb, Ash, Ashg, Asq, Ass, Ac, Aci*)

Metasedimentary rocks are a major component of the DUKETON greenstone sequence. They occur in major units from 1 to 6 km wide in outcrop, and in numerous thin and probably discontinuous layers within mafic, felsic, and ultramafic units. The protoliths ranged from mudstone through to cobble conglomerate. However, most of the metasedimentary rocks are fine grained, strongly

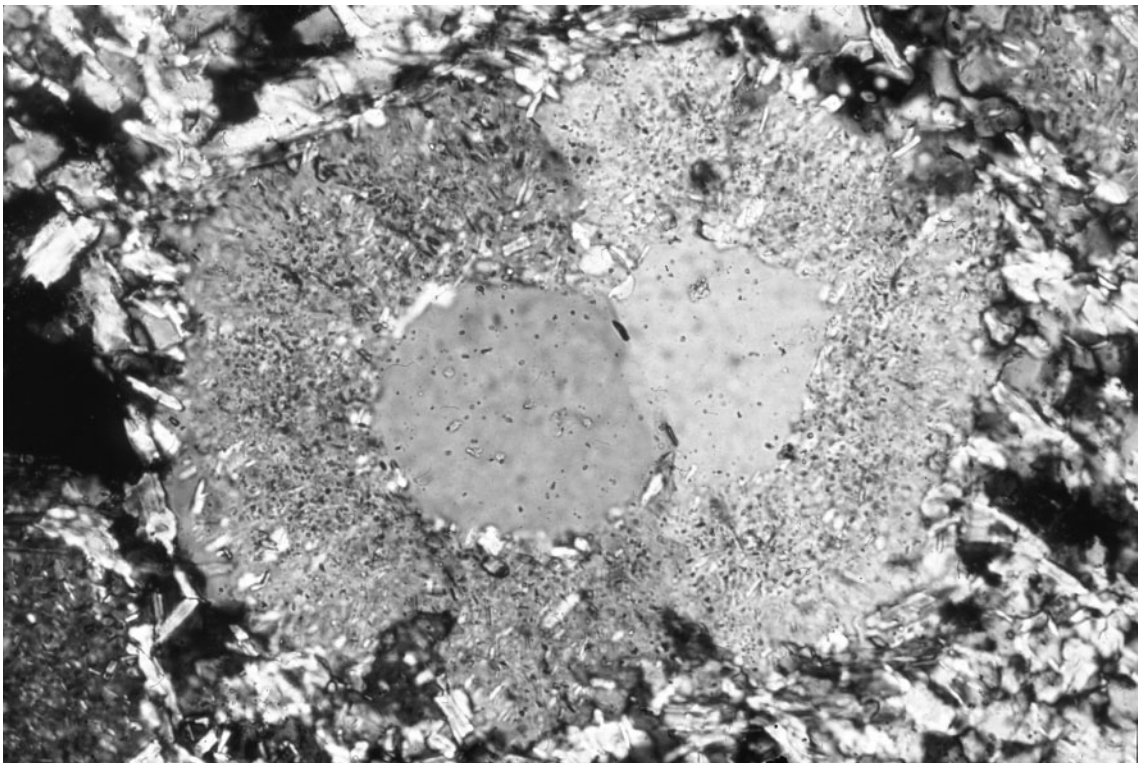

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Figure 11. Reaction halo around bipyramidal quartz in metamorphosed felsic lava from Mason Hill. Crossed polars. Field of view 1.0 mm. GSWA 120906, AMG 222452

TJF16 12.10.98

Figure 12. Strongly deformed, metamorphosed mafic conglomerate in the Murphy Hills. Contains clasts of metagabbro and metabasalt in a well-foliated matrix. AMG 239047

deformed and deeply weathered, and are generally shown on the map as undivided metasedimentary rocks (*As*). The most distinctive metasedimentary rock types are banded metachert and metaconglomerate.

Metaconglomerate occurs in several areas close to the southwestern boundary of the greenstone belt. Metamorphosed oligomictic conglomerate (*Asc*) occurs with metamorphosed pebbly sandstone, siltstone and carbonaceous mudstone in a thick unit that extends from Steer Creek Well to north of Bandya Hill. In the area to the east and north of Bandya Hill, the metaconglomerate contains rounded clasts, up to 17 cm in length, of siliceous metasedimentary rock, metachert and, less commonly, metabasalt, in a fine-grained metasandstone–siltstone matrix. The metaconglomerate occurs in association with metamorphosed pebbly sandstone and metamorphosed pebbly siltstone, both containing clasts of metachert, massive ironstone and, rarely, metamorphosed felsic volcanic rocks up to 5.5 cm wide and 15 cm long.

Two very distinctive metaconglomerate units are present in the Murphy Hills area. There is a western unit of metamorphosed felsic conglomerate (*Ascf*) that contains well-rounded felsic volcanic and granitoid pebbles and cobbles in a felsic, quartz-bearing, deformed matrix (e.g. AMG 232057). An associated metamorphosed mafic conglomerate (*Ascb*) contains large flattened clasts of metagabbro and metabasalt, up to 15 cm long, in a foliated mafic matrix (Fig. 12). Both metaconglomerates are intensely deformed and contain flattened clasts that are enclosed by the foliation.

Fine-grained metasedimentary rocks (*Ash*) are typically poorly exposed and deeply weathered. They are largely recrystallized and consist of fine-grained quartz, plagioclase and white mica, with or without chlorite and opaque minerals. Graphite-rich varieties (*Ashg*) occur locally. Some fine-grained metasedimentary rocks contain scattered relict sedimentary quartz and plagioclase grains up to 1.2 mm in diameter, and quartz-rich siltstone (*Asq*) is a minor variant. Primary bedding features are generally not recognizable, and the protoliths may have been thickly bedded mudstones or siltstones with some sandy sections.

Coarser grained metasedimentary rocks, including sandstone (*Ass*) and minor pebbly sandstone, occur in several areas, most notably between Butcher Well (AMG 361291) and Moolart Well (AMG 412260). In this area, the sequence comprises fine- to medium-grained metasandstone with minor, locally graphitic metasiltstone, and abundant, thin discontinuous metachert bands. The metasandstone contains a range of clast types, but is dominantly felsic in composition.

Banded metachert (*Ac*) forms conspicuous, laterally extensive strike ridges throughout the greenstone sequence, commonly along the contacts between different rock types. The metachert is typically ferruginous with a well-developed layering, 1 to 30 mm thick, defined mainly by variations in iron-oxide and silica content. In a typical exposure, the layering varies in thickness and thin layers tend to be discontinuous. Iron oxide-rich layers are red-brown, dark brown or grey-black, whereas the silica-rich layers range from creamy white through to light brown or light grey, depending on iron-oxide content. In some areas, for example in the northern Murphy Hills, there is a gradation from very iron-rich metachert to relatively iron-poor, banded siliceous metasiltstone over a distance of 1–2 km. This suggests that in some cases the metacherts may be metamorphosed silicified shales that were locally iron-rich.

The metachert units commonly have well-developed tight to isoclinal folds. In addition, some of units are brecciated and crosscut by numerous late-stage fractures, possibly due to a contrast in competency with the surrounding rocks.

Metamorphosed banded iron-formation (*Aci*) is exposed at only one location on DUKETON (AMG 370118). The rock is distinctive, fine grained, and very siliceous with well-developed alternating black and dark red to red-brown layers rich in iron oxides. The relationship of the banded iron-formation to the banded metachert units is uncertain, but it seems likely that it is a facies equivalent.

Granitoid and gneiss (*Ag, Agg, Agm, Agn, Agzq*)

The DUKETON greenstone belt is flanked by large areas of Archaean granitoid, gneiss and migmatite in the west, and granitoid in the east. These rocks are typically deeply weathered and partly covered by extensive sand sheets, or siliceous duricrust on the tops of breakaways (e.g. Neckersgat Range). There are very good exposures of fresh rock at Lizzar Soak (AMG 028145) in the southwest.

The granitoids on the western side of DUKETON are complexly intermingled with gneisses and migmatites on a range of scales, and they are deformed to varying degrees. However, the extreme weathering and poor exposure make it difficult to determine the proportions of each rock type, and so these rocks have been mapped collectively as gneissic granitoid and quartzofeldspathic gneiss (*Agn*). Elsewhere on DUKETON, deeply weathered granitoids have been mapped as undivided granitoid rocks (*Ag*) where the primary mineralogy of the rocks cannot be ascertained.

The granitoids in the western part of DUKETON commonly contain diffuse structures, such as a poorly defined layering and thin biotite schlieren, that may be contiguous with structures in the gneisses. Biotite monzogranite is the dominant granitoid type, and although some exposures of granodiorite and syenogranite also occur, they are of minor importance. The monzogranite is typically fine to medium grained and moderately well foliated. The rock is composed of strained and partly recrystallized quartz, plagioclase, K–feldspar and biotite, with ubiquitous accessory clinozoisite, sphene, apatite and ilmenite.

The quartzfeldspathic gneiss at Lizzar Soak is a multiply deformed, heterogeneous, commonly migmatitic rock that has complex relationships with the associated granitoids. The gneiss contains different generations of migmatite leucosomes that have been recognized on the basis of overprinting relationships and contrasts in mineralogy. The

Figure 13. Tightly folded S_1 leucosome in a quartzofeldspathic gneiss at Lizzar Soak (AMG 028145). Note that the monzogranite bodies in the upper and lower parts of the photograph cut S_1. The monzogranites are moderately deformed and contain a fabric (S_2) that is parallel to the axial plane fabric in the folds

host rock is a multiply deformed, biotite-bearing quartzofeldspathic gneiss containing an early foliation (S_1) that is refolded and cut by a second fabric (S_2, for more detail *see* **Structure and metamorphism**). Early leucosomes are thin (<10 mm thick), rich in quartz and plagioclase, and lie parallel to S_1. They have been deformed in subsequent deformation events, and in high-strain zones they are largely transposed into S_2. The early leucosomes are cut by a second generation of thicker monzogranite leucosomes (>50 mm thick) that are characteristically, but not always, parallel to S_2. They are strongly deformed and, in some cases, tightly folded about F_2 (Fig. 13). The host gneiss and the early leucosomes are in turn cut by a range of less strongly deformed, medium-grained monzogranite leucosomes that generally lie parallel to S_2. The very last generation of leucosomes is represented by large, relatively massive, fine- to medium-grained biotite monzogranite bodies that cut across all previous leucosomes.

A mineral-exploration drillhole located about 2 km south of Mulga Queen (AMG 049486) intersected weathered, foliated, fine-grained granodiorite (*Agg*). The rock is greenish to brownish grey, and in thin section consists of equigranular quartz and plagioclase from 0.2 to 0.5 mm in grain size, together with chloritized ?biotite aggregates.

An elongate body of deeply weathered biotite–quartz monzonite (*Agzq*) lies in the central part of the greenstone belt between McKenzie Well (AMG 338127) and Fisher Well (AMG 290304). The monzonite is a fine- to medium-grained, inequigranular to porphyritic rock containing varying amounts of quartz (5–25%), and approximately equal proportions of plagioclase and K–feldspar, now both completely altered to clays. Igneous textures are generally well preserved and the rock is weakly deformed, but the exposures are poor and the relationships with the surrounding greenstones are unclear.

The granitoids along the eastern side of the greenstone belt are deeply weathered and largely covered by Cainozoic deposits. In the few areas of fresh exposure, the predominant rock type is a fine- to medium-grained biotite monzogranite (*Agm*). In contrast to the granitoids along the western margin of DUKETON, the eastern granitoids are generally more homogeneous, less strongly deformed, and lack accessory sphene and epidote. Moreover, they are not associated with gneisses or migmatites.

Quartz veins (*q*)

Quartz veins are a ubiquitous feature of both the greenstone sequence and the granitoids, although they are more abundant in the greenstones. Broadly, there are two types of quartz vein. The more common variety is composed of massive milky quartz, typically extensively fractured. These veins may occur in a wide range of orientations, but are most commonly subparallel to the regional foliation. They probably formed at various stages during the ductile deformation of the area, and hence, have undergone differing degrees of deformation.

The second type of quartz vein is largely undeformed and is composed of interlocking milky quartz crystals up to 12 cm in length. These veins usually lie at a high angle to the regional foliation and they probably formed by open-space crystallization in late-stage extensional fractures. A prominent vein of this type occurs in the Murphy Hills close to the southern margin of DUKETON (AMG 230028).

Stratigraphy

A well-constrained stratigraphy has not been determined for DUKETON, largely because of uncertainties in correlation, the lack of detailed structural control, and poor exposure in critical areas. There is no evidence for a pre-greenstone basement, and in the absence of reliable younging indicators, it is unclear which are the lowest stratigraphic units in the greenstone sequence. Locally coherent sequences are mappable in isolated sections of the greenstone belt, but their stratigraphic context is uncertain.

Structure and metamorphism

The Duketon greenstone belt is a structurally complex assemblage of sheared, elongate fault slices and dismembered folds (Fig. 3). The dominant stratigraphic and structural trend is north-northwesterly, parallel to the length of the belt. Four major discontinuities or shear zones, lying parallel to the overall trend of the belt, have been interpreted from field evidence and aeromagnetic data.

The flanks of the greenstone belt are intensely deformed. The western margin (Hootanui Fault, Fig. 3) is a complex zone of heterogeneously deformed and interleaved granitoid and greenstone. However, in the southeast corner and on the northern border of the belt, the granitoids and greenstones have been coaxially folded and have locally discordant contacts, suggesting that the granitoids were intruded prior to the last major folding event. Most of the larger folds are upright and shallow-plunging with axial surfaces trending north-northwesterly (e.g. Christmas Well Anticline, Fig. 3) and, on aeromagnetic images (Fig. 14), the limbs appear to be sheared off along the major shear zones.

There are a number of smaller scale, asymmetric folds in metachert marker units and on aeromagnetic images (Fig. 14), but it is difficult to integrate these folds into a structural model for the greenstone belt due to uncertainty over the amount of displacement on the major shear zones, and the lack of detailed structural control in critical areas. Locally coherent sequences are present in some parts of the area, but these are probably discrete, structurally bound stratigraphic packages, and their correlation with other parts of the greenstone belt is uncertain.

Deformation sequence

Four phases of deformation (D_1–D_4) have been recognized on the basis of the overprinting of foliations, lineations and small-scale folds. The first two deformation events occurred close to the metamorphic peak and produced compressional structures, whereas the third deformation involved shortening with a component of simple shear, and was followed by late-stage crenulation and kinking of existing structures. These deformation events have been numbered sequentially and may not correlate with sequentially numbered events recognized elsewhere in the Eastern Goldfields (e.g. Hammond and Nisbet, 1992; Williams and Whitaker, 1993; Passchier, 1994; Swager et al., 1995).

D_1 structures

First generation (D_1) structures have largely been overprinted during subsequent deformation events, but relict D_1 fabrics are still preserved in gneisses, and possibly in parts of the greenstone sequence. No large-scale D_1 features are recognizable, probably due to the effects of later deformation and the lack of good exposure. The dominant D_1 structure is a well-developed, steeply dipping, east- to northeast-trending schistosity (S_1). In quartzofeldspathic gneisses at Lizzar Soak (AMG 028145), S_1 is tightly to isoclinally folded (Fig. 13) and largely transposed into S_2, which is a composite fabric comprising newly crystallized folia and reoriented S_1 surfaces. S_1 is best preserved in F_2 fold hinges, particularly in low-strain zones where the F_2 folds are more open. The S_1 fabric is defined by the alignment of biotite, quartz and quartzofeldspathic aggregates, and by thin, discontinuous leucosomes generally less than 4 cm thick.

A possible S_1 fabric is also preserved in silicified ultramafic cumulates near Baneygo in the southern part of the area (e.g. AMG 319074). In these rocks there is an early, steeply dipping fabric defined by the alignment of flattened olivine grains (now replaced by silica and secondary iron oxides) that is cut by the regional S_2 foliation (Fig. 15). Similar overprinting relationships are also present in some exposures of talc–carbonate schist, which have an early foliation defined by the alignment of flattened carbonate aggregates. In both rock types, the intersection of S_1 and S_2 results in the formation of a steeply plunging intersection lineation that is parallel to F_2 fold axes.

D_2 structures

The second deformation (D_2) was associated with peak metamorphism and the formation of the granites. The effects of D_2 are recognizable throughout the area, but are most pronounced in amphibolite-facies rocks adjacent to areas of granitoid rock. The identification of large-scale D_2 features is uncertain, but some of the folds on aeromagnetic images may have been formed during D_2. The characteristic D_2 structure is a pervasive, regionally extensive, north- to northwest-trending axial-plane foliation (S_2) that occurs in most rock types.

Second generation structures (D_2) are best developed in high-grade rocks, which typically show the greatest strain, and they are generally not well developed in low-grade metabasalt and metagabbro. In amphibolite-facies zones, S_2 is a continuous, pervasive schistosity defined by the preferred orientation of hornblende and plagioclase in

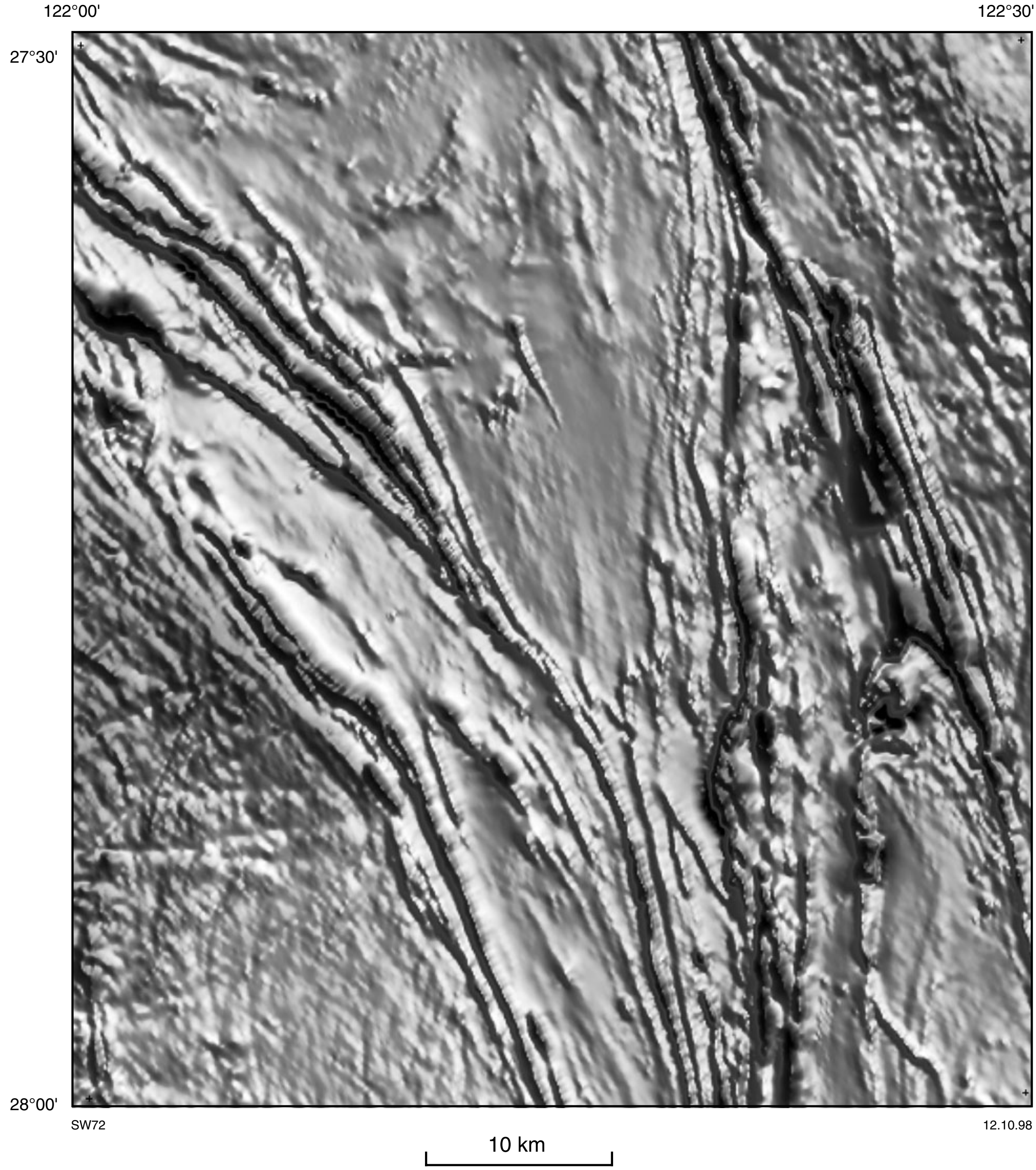

Figure 14. Grey-scale aeromagnetic map of total magnetic intensity for DUKETON (400 m line spacing, AGSO/GSWA, 1994)

amphibolite, and by the alignment of white mica and quartz in felsic rocks. By contrast, in low-grade metabasalt, S_2 is a weak to moderately well-defined discontinuous, anastomosing cleavage defined by the preferred alignment of chlorite and/or tremolite–actinolite

The F_2 folds are typically open to isoclinal, and moderate to steeply plunging with a similar geometry. The fold axes are parallel to a prominent, combined intersection–mineral lineation (L_2) that is particularly well developed in high-strain zones. The original orientation of the F_2 folds is uncertain as it is likely that they have been reoriented during subsequent deformation, particularly in areas that have been strongly affected by the D_3 deformation.

D_3 structures

The third deformation episode (D_3) resulted in east- to northeast-directed shortening, and the formation of north-

Figure 15. Silicified ultramafic rock containing two overprinting foliations. The earliest fabric, which runs from top to bottom in the photograph, is overprinted by a spaced cleavage, running from left to right, that is parallel to the regional foliation. Plan view. AMG 319074

to northwest-trending ductile shear zones parallel to the main faults (Fig. 3). These are broad zones of variable strain, within which D_2 structures are reoriented and partly overprinted by D_3 fabrics. In the areas of greatest strain, D_2 structures are overprinted by a planar fabric (S_3) containing a shallow-plunging mineral-elongation lineation (L_3). Some granitoid rocks from within the shear zone parallel to the Hootanui Fault (Fig. 3) contain S–C fabrics (Lister and Snoke, 1984), suggesting that D_3 involved a component of simple shear. Dextral strike-slip movement is indicated by the shallow plunge of the lineation and the asymmetry of S–C fabrics and σ-porphyroclasts (Passchier and Simpson, 1986). However, S–C fabrics are not commonly developed, and where they are present, the S-folia contain markedly elongate quartz grains and are much better developed than the C-folia. This suggests that D_3 involved a large component of flattening, and that the amount of lateral displacement may not have been large. The sense of movement on the other shear zones is not known, but the asymmetry of the large-scale structures on aeromagnetic images along the eastern side of the greenstone belt points to sinistral movement on the Turnback and Lulu Faults (Fig. 3).

Although the rocks are strongly deformed in the D_3 shear zones, earlier structures are still recognizable. For example, in strongly sheared gneisses close to the granite–greenstone contact in the Murphy Hills (Fig. 2, AMG 223058), the presence of a steeply plunging, coarse-grained, intersection lineation on S_3 surfaces is evidence for the presence of an earlier fabric (Fig. 16). This lineation is overprinted by L_3 and appears to be due to the intersection of S_3 with an S_1–S_2 gneissic layering that has been transposed into S_3.

Outcrop-scale F_3 folds are typically upright and open to tight, with flattened concentric profiles and shallow-plunging axes (Fig. 17). Moreover, the fold axes are subparallel to the L_3 mineral lineation, suggesting that they formed initially by buckling and layer shortening. On Mason Hill (AMG 223453), primary igneous layering in felsic metalavas, and bedding in metasedimentary rocks, are folded into an open F_3 anticline, with bedding–cleavage intersections indicating an axis plunging 28° to the northwest. Similarly, the Christmas Well Anticline is an F_3 fold that plunges about 20° to the north-northwest. This anticline is poorly exposed, but is partly delineated by individual rock units and the swing in orientation of S_2.

D_4 structures

The last recognizable deformation event (D_4) involved kinking and crenulation of all earlier structures. The kinks and crenulations are commonly associated with small-scale faults, fractures and quartz veins, and they occur in all rock types in the area.

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Figure 16. Multiply deformed quartzofeldspathic gneiss close to the granite–greenstone contact in the Murphy Hills area (AMG 223058). Side view looking west onto an S_3 surface. The rock has a well-defined, planar S_3 foliation containing two lineations. A crude, steeply plunging, coarse lineation, which runs from top to bottom in the photograph, is overprinted by a fine shallow-plunging mineral lineation (L_3), running from left to right

SW60 28.07.98

Figure 17. Profile view of a tight, concentric F_3 fold in a layered metachert in the Murphy Hills area (AMG 242228). The fold plunges moderately to the north (~20°). View looking north

Timing of granitoid emplacement

A number of structural features have been used to constrain the age of the granitoids. Firstly, the gneisses in the Lizzar Soak area, on the western side of DUKETON, contain folded S_1 fabrics that are cut by granitoid veins and pods, and larger bodies up to tens of metres in diameter. These crosscutting relationships indicate that granite emplacement must have occurred after D_1.

Secondly, the granitoids on the western side of DUKETON are complexly intermingled with gneisses and show varying degrees of deformation. Some exposures of granitoid rock contain a foliation that is parallel and contiguous with S_2 in the gneisses, and this is therefore interpreted to be a D_2 fabric. Many of the granitoid veins in the gneisses are folded to varying degrees about F_2 axes, and some of these veins are very tightly folded and crosscut by more gently deformed granitoids (Fig. 18). Away from D_3 shear zones, most of the larger granitoid bodies are only weakly deformed (e.g. southwest of Lizzar Soak, AMG 020130). These relationships suggest that granitoid emplacement occurred progressively during D_2, and may have peaked after the deformation ceased.

Thirdly, in a number of areas (e.g. AMG 17033), granitoid rocks contain strong D_3 fabrics, implying that the main phase of granitoid emplacement occurred prior to solid-state deformation in D_3.

Finally, the presence of granitoid clasts in sheared (D_3) felsic conglomerates in the Murphy Hills (AMG 233057) is also consistent with granitoid emplacement prior to D_3. These conglomerates lie close to the western margin of the greenstone belt, and if the clasts have been derived from the graintoids to the west, as seems likely, then there must also have been uplift, erosion, and depositon of granitoid detritus prior to D_3.

Aeromagnetic images suggest that there may be some minor, late-stage granitoids (Fig. 14). An even-textured, weakly magnetic body that cuts both the Lulu Fault and the prominent north-northwesterly trending structures to the west (Figs 3, 4), is interpreted to be a post-D_3 granitoid.

Granite–greenstone relationships

The nature of the contact between the granites and the greenstones is of considerable interest as it is one of the keys to understanding the tectonic development of the Yilgarn Craton. Williams (1993) has suggested that the granites and gneisses may be basement to the greenstone sequences. However, not much is known in detail about granitoid, gneiss and greenstone relationships because of the poor exposure in critical areas.

There are a number of locations in the Murphy Hills area in the southern part of DUKETON where granite–greenstone contacts can be examined. Rocks on both sides of the contact are typically strongly deformed and well foliated (combined S_2–S_3 fabric), but at one location (AMG 220074) the contact is deformed into a tight to open fold. Here, the greenstones are also intruded by narrow granitoid dykes that emanate from the main granitoid body, suggesting that it is a deformed intrusive contact. The dominant fabric on both sides of the contact (S_2–S_3) is also axial planar to the fold, indicating that intrusion probably took place prior to D_3. This is also consistent with the timing of granitoid emplacement inferred by structural relationships in the gneisses at Lizzar Soak (AMG 028145). These observations suggest that the granites on DUKETON are younger than both the greenstones and the quartzofeldspathic gneisses and therefore cannot be basement to the greenstones.

The relationships between the gneisses and the greenstones cannot be directly determined as there are no exposures of a contact between them. However, gneissic rocks to the west of the greenstone belt contain evidence of a similar structural history to that of the greenstones, and so it is probable that they have undergone the same sequence of deformation events. The origin of the quartzofeldspathic gneisses is obscured by the high-grade metamorphism and deformation, but it is possible that they are simply a greenstone-like sequence that has undergone higher grade metamorphism and partial melting, as suggested by Bunting and Chin (1979). This is supported by the fact that the gneisses contain remnants of banded iron-formation (Bunting and Chin, 1979), layers or lenses of amphibolite and metapelitic rocks, and have a diffuse decimetre- to metre-scale compositional layering.

Metamorphism

The Duketon greenstone belt can be broadly divided into two metamorphic zones: an extensive greenschist facies zone, and a restricted area of amphibolite-facies metamorphism (Fig. 19). This subdivision is based on an assessment of the peak metamorphic mineral assemblages, which are interpreted to be those defining the D_2 fabrics. Thus in weakly deformed rocks that have not undergone shearing (D_3), minerals of the peak assemblage occur as coarse-grained pseudomorphs of igneous minerals, whereas in the more strongly deformed rocks, they define the S_2 schistosity. In sheared rocks, coarse-grained relics of S_2 are commonly enclosed by S_3 folia. The metamorphic conditions in D_2 and D_3 were probably very similar, as the mineralogy of the respective fabrics is essentially the same.

Amphibolite-facies rocks occur in narrow zones adjacent to the granitoids. The rocks in these zones are almost completely recrystallized, although igneous textures are pseudomorphously preserved in some cases, particularly in the metagabbros. The characteristic assemblage in the amphibolites and metagabbros is hornblende–Ca-plagioclase–(epidote–sphene–quartz). Felsic schists dominantly comprise quartz–Ca-plagioclase–white mica, and are typically well foliated.

In areas of lower metamorphic grade, the characteristic assemblage in metamorphosed mafic rocks is epidote–albite(–chlorite– tremolite–actinolite –quartz–sphene). The strain is generally lower than in the amphibolite-facies zone and igneous textures are commonly preserved. Pyroxene is typically pseudomorphed by tremolite–actinolite and/or chlorite, and plagioclase grains by aggregates of albite and epidote(–sphene).

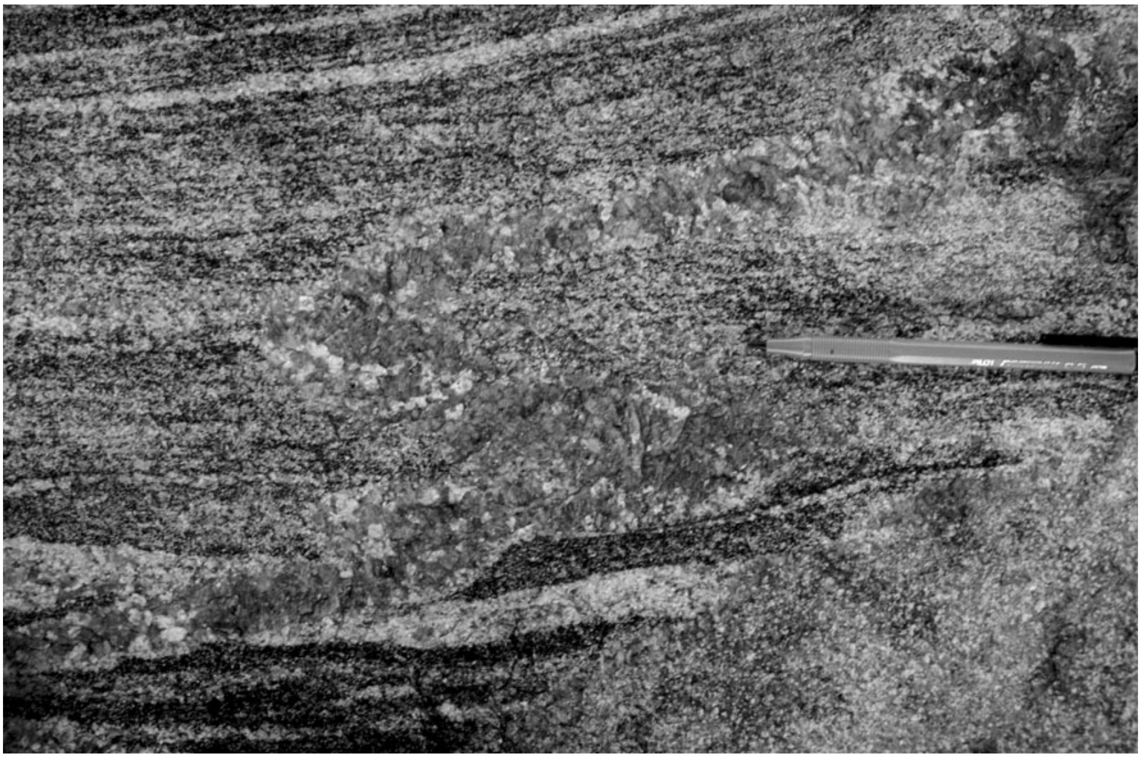

Figure 18. Quartzofeldspathic gneiss at Lizzar Soak (AMG 028145) with a tightly F_2-folded monzogranite leucosome. The folded leucosome cuts earlier, plagioclase-rich S_1 leucosomes that lie parallel to a composite S_1–S_2 fabric. A larger, fine-grained monzogranite body in the lower right cuts all earlier structures and leucosomes and is only weakly deformed

In quartzofeldspathic gneisses, the assemblages are not diagnostic but the presence of Ca-plagioclase is indicative of amphibolite-facies conditions (or higher). Additionally, the presence of clinopyroxene-bearing amphibolite lenses in the gneisses suggest that the metamorphic temperature was approximately 700°C. The peak temperature in the amphibolite-facies zone was probably less than about 650°C, based on the stable coexistence of quartz and white mica. The temperature in the lower grade areas was probably 350–400°C, based on the absence of biotite and the presence of chlorite–white mica–albite. The metamorphic pressure is not well constrained but was most likely to have been less than 8 kb, considering the absence of blueschist-facies assemblages in the metabasalt (Liou et al., 1985).

In amphibolite-facies areas, the pseudomorphous replacement of coarse-grained igneous textures is suggestive of static recrystallization. These textures have been partially overprinted by finer grained, mylonitic fabrics during D_3, suggesting that the metamorphic peak was probably reached prior to D_3.

Proterozoic dykes (*Ꝑdy*)

There are several north- to northwest-trending, highly magnetic, linear features that cut across the greenstone stratigraphy on aeromagnetic images (Fig. 14). These features are interpreted as non-outcropping, Proterozoic mafic dykes (*Ꝑdy*) by analogy with similar features elsewhere in the Eastern Goldfields.

Palaeozoic geology

Permian sedimentary rocks (*Ps*)

Two minor outliers of presumed Permian sedimentary rocks (*Ps*) are exposed on DUKETON (Fig. 3). These outliers outcrop on Mount Maiden (AMG 095517) in the north, and about 8 km southwest of Bandya Hill, in the southwest. They typically consist of weakly cemented, flat-lying arkosic sandstone and conglomerate. Bunting and Chin (1979) considered them to be equivalent to the sandstone facies of the Paterson Formation in the Officer Basin (Lowry, 1971).

The outcrop to the southwest of Bandya Hill is the larger of the two known outliers of possible Permian sedimentary rocks on DUKETON. Here they unconformably overlie quartzofeldspathic gneiss and granitoid and consist of poorly consolidated, flat-lying beds of medium- to coarse-grained sandstone and pebbly sandstone, with subordinate siltstone and lag conglomerate. Graded bedding, cross-bedding and basal scour structures are present in sandstone layers. The conglomerate contains subangular to subrounded clasts of quartz and chert, up

Figure 19. Simplified geological map of DUKETON showing the variations in metamorphic grade

to 28 cm in diameter, in a poorly sorted, silty to sandy matrix. A good exposure of the unconformable contact between the sedimentary rocks and the underlying gneiss and granitoid occurs 7 km southwest of Bandya Hill (AMG 118205).

Cainozoic regolith

A large proportion of the land surface on DUKETON is mantled by regolith. This surficial cover consists both of residual, indurated deposits exposed by recent erosion, and a variety of younger clastic and chemical deposits. Individual regolith units have been delineated by interpretation of aerial photographs and Landsat images, supported by field observations. The regolith has been broadly separated into undivided Cainozoic deposits, and Quaternary deposits associated with currently active drainage systems.

Cainozoic duricrust and chemical deposits (*Czk, Czl, Czli, Czu, Czz*)

The oldest regolith units, consisting of duricrust and related chemical deposits, lie primarily on low hills and breakaways. These are divided into lateritic duricrust (*Czl*), massive ironstone (*Czli*), silcrete (*Czz*), silica caprock over ultramafic rock (*Czu*), and pedogenic calcrete (*Czk*). Pedogenic calcrete forms as a broad duricrust in arid areas (Hocking and Cockbain, 1990). All other Cainozoic units are formed by the transport and deposition of material derived from the weathering and erosion of duricrust and exposed rock.

In the southern part of DUKETON, there are numerous breakaways in the central greenstone belt where weathered bedrock and lateritic duricrust (*Czl*) have been exposed by recent erosion. Bands of massive ironstone (*Czli*) and siliceous duricrust over ultramafic rocks (*Czu*) are also common. By contrast, the northern part of DUKETON is dominated by low, rounded hills of ferruginous saprolite and ironstone debris, and only rarely are breakaways and duricrusts well developed. Silcrete (*Czz*) is typically developed over weathered granitoids; for example, east of German Well (AMG 490340) and 6 km northwest of Lout Claypan (AMG 020290).

Cainozoic mass-wasting deposits (*Czc, Czcq, Czf, Czg*)

Proximal slope deposits comprising angular rock debris, gravel and sand in a silty matrix have been mapped as colluvium (*Czc*). They typically form extensive aprons surrounding upstanding areas of exposed rock, and may form a thin veneer over duricrust. These deposits also include patches of quartz vein rubble and debris (*Czcq*), the largest of which are northeast of Garden Well (AMG 220350) and in the Mulga Queen–Famous Blue area. Areas overlying or adjacent to granitoids are commonly covered by deposits of coarse-grained quartz–feldspar sand with varying proportions of granitoid fragments (*Czg*).

On low, rounded hills in the northern part of DUKETON, the lateritic duricrust is commonly degraded to lateritic rubble, with ironstone and ferruginous saprolite (*Czf*). These deposits are generally coarse, containing clasts up to 10 cm across, but determination of the related bedrock lithology is not possible.

Cainozoic fluvial and eolian sediments (*Cza, Czs*)

Extensive sheetwash deposits (*Cza*) consisting of silt, clay and sand dominate the more distal or alluvial parts of the regolith, with scattered granules and pebbles of weathered rock. These may be very thin, as exposures of weathered bedrock can be seen along tracks that have eroded only tens of centimetres into the deposits. Upslope they grade into the proximal slope deposits (colluvium).

Large parts of DUKETON, particularly areas underlain by granitoid rocks, are covered by extensive sand plains (*Czs*) composed of unconsolidated, light brown, iron-stained quartz sand. Sand ridges are found only in the far northeast of DUKETON, and the east-southeasterly trend dominant over much of the remainder of the DUKETON 1:250 000 sheet (Bunting and Chin, 1979) is not clearly developed.

Quaternary fluvial and chemical sediments (*Qa, Qac, Qak*)

Unconsolidated to semi-consolidated, dominantly sandy alluvium (*Qa*) of probable Quaternary age lies along intermittently active fluvial channels and on floodplains. These deposits grade laterally into older sheetwash and colluvial deposits. They are considered to be Quaternary in age because the fluvial systems are currently active and cut into older regolith deposits.

The flood plains may also have small claypans (*Qac*) as part of the active system, and in the larger valleys there may be deposits of groundwater calcrete (*Qak*). Groundwater calcrete forms by precipitation below the watertable, and is probably still actively forming (Hocking and Cockbain, 1990), unlike the calcrete associated with the breakdown of calcium-rich primary minerals in underlying bedrock. Large outcrops of groundwater calcrete are present about 10 km north of Red Well (AMG 370560), and along Borodale Creek southeast of Bandya Homestead (AMG 180330).

Economic geology

Mineral production from DUKETON is restricted to gold and accessory silver. Despite extensive exploration, no economic base-metal sulfide deposits have been discovered. The mining activity in this region during the first half of the twentieth century is described fully in Hobson and Miles (1950), and much information on the subsurface geology of individual gold-mining leases can be found in

Table 1. Gold production from larger workings on DUKETON to 1990

Mining centre / *Mine/project*	*Ore treated (t)*	*Gold production (kg)*	*Period*
Duketon Centre [a]	35 645	881.685	1901–1989
Famous Blue	11 080	164.809	1904–1940
	124	0.448	1981–1983
Mulga Queen	12 818	313.876	1903–1943
Riccaboni	1 431	29.524	1905–1910
Golden Spinifex	2 694	59.793	1901–1915
Lauriston	1 037	32.039	1901–1907
Erlistoun Centre			
Baneygo	3 601	123.294	1898–1927
Duketon–Baneygo	86 103	372.394	1989–1990
Mistake	3 830	88.700	1899–1935
	1 102	4.495	1980–1984

NOTE: (a) Mostly on DUKETON

Gibson (1906), Honman (1917), and Miles (1940). Data from more recent exploration activity in the region can be obtained from the GSWA WAMEX library of open-file company reports and in a review of mineral occurrences in the northern Eastern Goldfields by Ferguson (1998).

Gold

DUKETON covers part of the Mount Margaret district of the Mount Margaret Mineral Field, and includes two gold-mining centres: Erlistoun and Duketon–Hootanui. These centres were active mainly during the first decade of the twentieth century, after which production dropped dramatically, although some mines were worked sporadically up to 1945. There was renewed gold-mining activity between 1988 and 1993, and openpits were worked at Baneygo, Russell Find, and Christmas Well. Recorded production figures for DUKETON are shown in Table 1. More recent exploration work at Rosemont (Christmas Well), since publication of the geological map, has led to the discovery of further gold mineralization at greater depth and along strike to the north and south.

Most gold production has been from deposits within or adjacent to quartz veins, or lodes (Miles, 1940). The gold occurs principally as liberated grains (Miles, 1940). Gold-bearing quartz veins may either cut across or lie parallel to the regional foliation, and they commonly occur along fault or fracture zones at the contact between different rock types. Most of the gold-bearing quartz veins are probably related to D_4 structures as they generally post-date the regional foliation.

A significant deposit of alluvial gold was worked at The Patch (Fields Find) in 1912–13 (Honman, 1917). Later mining in the area focused on gold-bearing quartz veins associated with a small fault zone along the contact between a mafic intrusion and foliated greenstone sequences (Honman, 1917; Miles, 1940).

Nickel

Exploration of greenstones and ultramafic units in the Duketon area by Cominco, Kathleen Investments, Kennecott, and Shell Minerals in the late 1960s to early 1970s failed to locate significant nickel mineralization.

Copper–lead–zinc

Exploration for copper–zinc deposits, of volcanic massive-sulfide type, has been carried out in the northern central Duketon greenstone belt in an extensive area of felsic metavolcanic and metasedimentary rocks. Subeconomic concentrations of sphalerite–galena–chalcopyrite–pyrite ore occur at Mason Hill (AMG 223453) but no significant mineralization has been discovered.

Exploration for copper–zinc has been carried out in felsic metavolcanic and metasedimentary rocks that form a north-northwesterly trending wedge between Swanson Hill and Mason Hill. A comprehensive program carried out between 1973 and 1988 located lead–zinc anomalies in faulted metamorphosed rhyolite–andesite flows, tuffaceous rocks and breccia, with minor chert, and mafic and sedimentary rocks. Gossans were also enriched in cobalt, bismuth, and gold (Bell, 1980).

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Appendix 1

Gazetteer of localities on DUKETON

Locality	*AMG coordinates*	
	Easting	*Northing*
Ballantraye mine	406400	6947700
Bandya Homestead	414600	6936100
Bandya Hill	416400	6925700
Baneygo mine	432200	6906600
Butcher Well	436100	6929100
Christmas Well (Erlistoun)	446300	6920100
Corner Well (Bandya)	419300	6935000
Duketon	429100	6942200
Famous mine	407800	6953600
Famous Blue mine	408500	6950600
Fisher Well	428900	6930400
Garden Well	418700	6932000
German Well	443300	6934300
Golden Spinifex mine	429200	6942300
Ingi-jingi Hill	421900	6946000
Lauriston mine	429100	6942500
Lizzar Soak	403100	6914300
Lout Claypan	407300	6925600
Mason Hill	422200	6945400
McKenzie Well	433800	6912700
Mistake mine	435600	6905200
Moolart Well	441100	6926000
Morialta mine	428000	6946100
Mount Maiden	409300	6951500
Mourillian mine	413000	6952200
Mulga Queen	405300	6951400
Mulga Queen mine	405100	6951600
Mulga Queen South mine	405400	6951100
North Pinnacle	430300	6903100
Parramatta mine	414900	6950700
Pinjanie Hill	428900	6937700
Pinje-Eda Hill	428400	6937900
Red Well	434200	6949000
Riccaboni mine	411600	6953600
Russell Find	438500	6905500
Steer Creek Well	426700	6907300
Swanson Hill	429600	6922800
The Patch	425000	6940200
Wallaroo mine	428500	6944700
Watermelon mine	428200	6945700

Appendix 2

Summary of historical data on underground gold mines

The following summary of published geological information is based principally on underground observations by Gibson (1906), together with later observations by Honman (1917) and Miles (1940).

Erlistoun Mining Centre

The Erlistoun Mining Centre in the south of DUKETON has three mine groups: Baneygo, Mistake, and Midas. Gibson (1906) noted northerly trending hematite-bearing quartz veins and narrow quartz reefs.

At Baneygo, the main reef dips steeply east and is up to 2 m wide. To the south there are two thin parallel reefs, with the westernmost reef apparently lying on the contact between granite to the west and the main greenstone belt to the east.

Between Baneygo in the west and Mistake in the east, there are recorded exposures of barren quartz veins up to 10 m wide trending north. At Mistake, a large, well-defined quartz reef trends slightly east of north for about 1.2 km. The vein is up to 2 m wide, dipping 45° west in its northern part and steeper in the southern part. As well as pinching and swelling along its length, the reef also splits into smaller veins and stringers parallel to the main vein.

Duketon–Hootanui Mining Centre

The Duketon mining area includes the following leases: Crescent, Ruby, Rose of Persia, Golden Spinifex, Lauriston, At Last, Wallaroo, Watermelon, and Morialta.

At Rose of Persia, the reef consists of a quartz vein that ranges from an average of 0.6 m to nearly 2 m in thickness and dips 75–80° east.

Golden Spinifex and Lauriston shared a shaft extending to at least 43 m, and were the site of the Duketon township and a small battery. The reef at depth was on average only 0.5 m wide, but could be up to 2.7 m across. However, the wider veins tended to have poor gold values. For the first ten metres down from the surface, the reef dips east, and then turns to the west. The reef is not exposed, and there is no quartz vein lag; the regolith of slopewash deposits is up to 5 m thick. The reef runs parallel to the foliation in the felsic county rock.

At the Wallaroo mine, the reef averages 0.6 m in width. Sulfide mineralization was encountered at depth in the mine.

The reef at Morialta and Watermelon, north of Wallaroo, is about 1 m thick, varies from 0.3 to 2.0 m, and trends north-northwest.

The Mulga Queen mine (Gibson, 1906) is in a reef trending 325°, dipping 30° to the southwest in the main shaft, and steeper to both the north and south. The reef averages 0.6 m in thickness, but ranges from 0.3 to 1.2 m. There is some sulfide present in the northern end of the vein. The quartz reef cutting the greenstone is over 1 km long and 0.6–1.2 m wide.

At the Mulga Queen South mine, the reef consists of quartz vein that trends 320° and dips 45° to the southwest.

The Famous Blue mine contains several quartz veins, the largest trending north-northwest with a shallow dip to the east. The reef averages 1.2 m in thickness and apparently lies on the contact with a belt of felsic rocks to the east. Structures in the greenstones strike 310–330°, with a steep easterly dip. There are numerous quartz veins, with the best gold values on the north-northwesterly trending set.

The Famous mine lies on an irregular quartz reef about 1 m thick that trends 340° with a dip to the west of about 30°.

At the Riccaboni mine, structures in the greenstones strike 300–310°. A quartz reef cuts across the schistosity, between 045 and 060°, and dips 75° northwest. The reef averages 1 m in thickness, but the underground workings were inaccessible when Miles (1940) visited.

At the Mourillian mine, the greenstone foliation strikes 300–310° and includes a thin, cross-cutting quartz vein that trends 250°, dips 75° northwest, and is about 0.75 m wide.

At the Parramatta mine, there are two quartz veins only 15 cm wide which trend between 015 and 020°, and dip 62° east. There may be other thin cross-cutting veins in the area, but gold values throughout are low.

Originally called Field's Find, the deposit at the Patch was discovered in 1913–14 and initially proved a rich source of alluvial gold (Honman, 1917). Shafts sunk along the original line of the alluvial patches revealed 30 to 40 disconnected patches rich in gold along a faultline; hence the revised name of The Patch. Honman (1917) recorded dips of 40–50° west in foliated greenstones adjacent to a mafic intrusion (now mapped as talc–chlorite schist) dipping 75° to the west-southwest. The eastern contact between the cross-cutting dyke and country rock was thought to be faulted, and is the locus of gold mineralization.

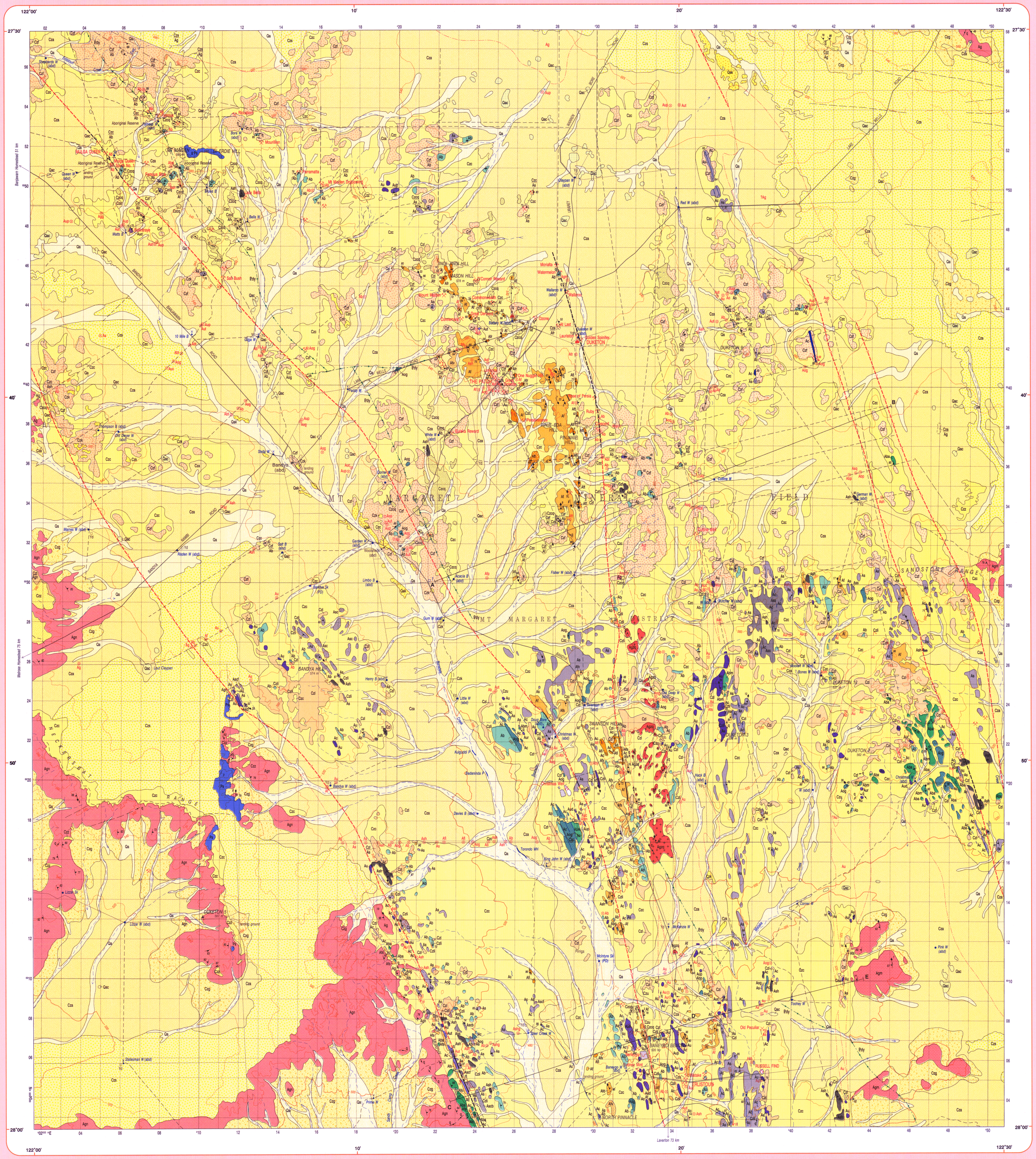
The geology of The Patch was reviewed by Miles (1940), who recorded the northward extension of the dyke through the Connemara goup of leases. The dyke, here averaging 400–420 m wide and trending northwest to west-northwest, is much wider than at The Patch. Quartz veins in this area occur within the supposed meta-sedimentary country rock and on the dyke contact.

AUSTRALIA 1:100 000 GEOLOGICAL SERIES

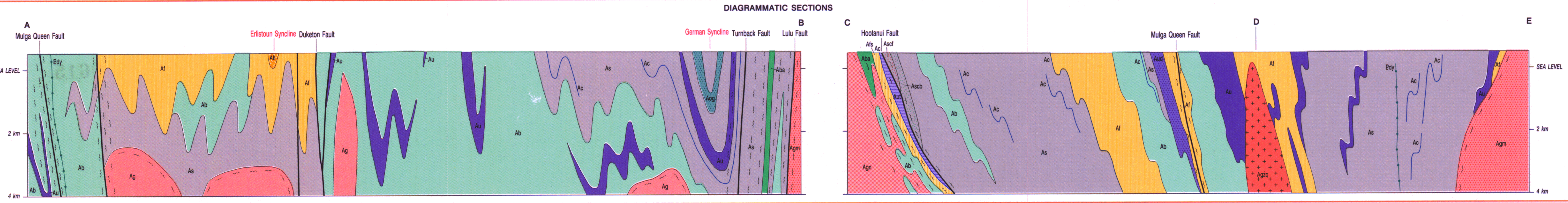
DUKETON

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET 3342



DIAGRAMMATIC SECTIONS



Legend

PHANEROZOIC — CAINOZOIC — QUATERNARY

- Qa — Alluvium — clay, sand, and gravel in channels and floodplains
- Qac — Clay and silt in claypans
- Qak — Calcrete in active fluvial channels

CAINOZOIC

- Cza — Sheetwash deposits — silt, clay, and sand as extensive fans
- Czs — Sandplain deposits — unconsolidated sand; includes stabilized dunes
- Czc — Colluvium — silt, sand, and rock debris as proximal sheetwash and scree
- Czcq — Quartz vein debris
- Czf — Ferruginous rubble and colluvium — ferruginous rock and ironstone rubble
- Czg — Sand over granitoid rock — quartz-rich and quartzo-feldspathic sand

- Czk — Calcrete
- Czl — Lateritic deposits — lateritic duricrust; massive and rubbly
- Czli — Massive ironstone
- Czu — Silica caprock over ultramafic rock
- Czz — Silcrete

PALAEOZOIC — PERMIAN

- Ps — Conglomerate, sandstone, and siltstone

PROTEROZOIC

- Ɍdy — Mafic dyke, interpreted from aeromagnetic data

ARCHAEAN

- q — Quartz vein

- Ag — Granitoid rock, undivided
- Agg — Biotite granodiorite to tonalite (subsurface only)
- Agm — Biotite monzogranite
- Agn — Gneissic granitoid and quartzo-feldspathic gneiss; includes minor amphibolite lenses
- Agzq — Quartz monzonite; commonly porphyritic

- As — Metasedimentary rock, undivided
- Asc — Conglomerate, pebbly sandstone, and minor siltstone; metamorphosed
- Ascf — Conglomerate and pebbly sandstone with granitoid and felsic volcanic clasts; metamorphosed
- Ascb — Conglomerate and pebbly sandstone with gabbro and basalt clasts; metamorphosed
- Ash — Siltstone; metamorphosed
- Ashg — Graphitic metasiltstone (subsurface only)
- Asq — Quartz-rich siltstone; metamorphosed (subsurface only)
- Ass — Sandstone; minor siltstone and conglomerate; metamorphosed
- Ac — Banded chert
- Aci — Banded iron-formation

- Af — Metamorphosed felsic igneous and clastic rocks, undivided
- Afd — Dacite lava; metamorphosed
- Afi — Fine-grained intermediate rock; metamorphosed
- Afp — Porphyritic felsic rock; metamorphosed (subsurface only)
- Afr — Porphyritic rhyolite-dacite lava; rarely spherulitic; metamorphosed
- Afs — Felsic schist; derived from volcanic or volcaniclastic rocks
- Aft — Felsic tuff; metamorphosed
- Afv — Felsic volcanic rock; metamorphosed

- Ao — Metamorphosed fine- to medium-grained mafic rock, undivided; includes some amphibolite
- Aog — Gabbro; fine- to medium-grained; includes minor leucogabbro and quartz gabbro; metamorphosed

- Ab — Metamorphosed fine- to very fine-grained mafic rock, undivided; locally gabbroic-textured
- Aba — Amphibolite; fine- to medium-grained
- Abm — High-Mg basalt; commonly with pyroxene spinifex texture; locally variolitic; metamorphosed
- Abp — Porphyritic basalt; metamorphosed
- Abt — Tholeiitic basalt; metamorphosed (subsurface only)
- Aby — Amygdaloidal basalt; metamorphosed (subsurface only)

- Au — Metamorphosed ultramafic rock, undivided
- Auc — Talc-carbonate rock
- Aud — Serpentinized dunite, with relict adcumulate texture
- Aup — Serpentinized peridotite; commonly with relict cumulate texture
- Aur — Tremolite schist; probably after pyroxenite or high-Mg basalt
- Aut — Talc-chlorite schist

Symbols

Geological boundary
- exposed
- approximate
- concealed, interpreted from aeromagnetic data

Fault or shear
- exposed
- concealed
- concealed, partly interpreted from aeromagnetic data

Minor folds, showing trend and plunge direction
- antiform
- minor fold
- asymmetric, showing sense of vergence

Bedding, showing strike and dip
- inclined
- overturned

Igneous layering, showing strike and dip
- inclined

Way-up indicator
- cross-bedding

Metamorphic foliation, showing strike and dip
- inclined
- vertical
- strongly foliated rock

Mineral lineation, showing trend and plunge direction
- horizontal
- inclined
- on foliation plane
- axis of crenulation

Joint, showing strike and dip
- inclined

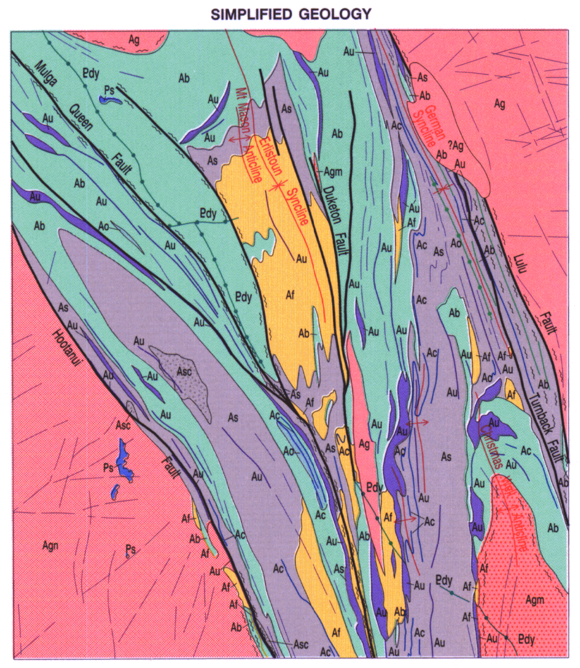
Airphoto or satellite image lineament
- structural trend

- Formed road
- Track
- Fence, generally with track
- Homestead — Bandya (abd)
- Building
- Yard — Yd
- Aboriginal reserve boundary
- Microwave repeater station
- Horizontal control, minor
- Breakaway
- Sand dune
- Contour line, 20 metre interval — 560

- Watercourse, ephemeral
- Bore, well — B W
- Windpump
- Tank — T
- Waterhole, soak, pool — WH Sk P
- Abandoned — (abd)
- Position doubtful — (PD)

- Mining centre — DUKETON
- Mining locality — RUSSELL FIND
- Mine (gold) — Famous Blue
- Opencut
- Alluvial workings, showing limits
- Battery, abandoned
- Mining area
  - opencut
  - tailings or stockpile
- Mineral exploration drillhole or costean, showing subsurface data — Ab

SIMPLIFIED GEOLOGY



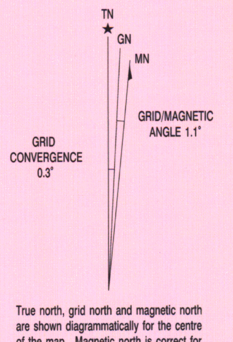
- Ps — Permian sedimentary rock
- Ɍdy — Mafic dyke

YILGARN CRATON

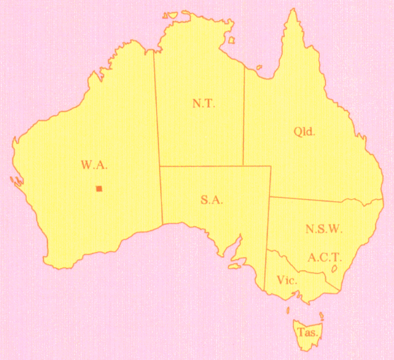
- Ag — Granitoid rock, mainly monzogranite
- Agm — Monzogranite
- Agn — Gneissic granitoid
- Asc — Metaconglomerate
- As — Metasedimentary rock dominant
- Ac — Banded chert and banded iron-formation
- Af — Metamorphosed felsic tuff and lava dominant
- Ao — Metagabbro
- Ab — Metabasalt dominant
- Au — Metamorphosed ultramafic rock

- Anticline
- Syncline
- Aeromagnetic or airphoto lineament

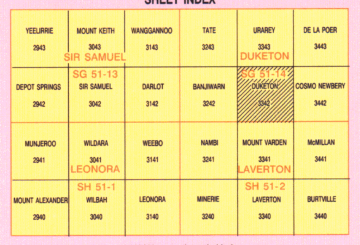
SCALE 1:500 000 — 0, 5, 10, 15, 20 Kilometres



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 five years



SHEET INDEX



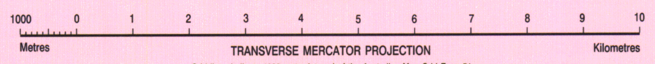
1:100 000 maps shown in black
1:250 000 maps shown in brown

DEPARTMENT OF MINERALS AND ENERGY
HON. GEORGE CASH, J.P., M.L.C.
MINISTER FOR MINES
K. R. PERRY, DIRECTOR GENERAL

NGMA
PRODUCT OF THE NATIONAL GEOSCIENCE MAPPING ACCORD

PIETRO GUJ
DIRECTOR, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SCALE 1:100 000



TRANSVERSE MERCATOR PROJECTION

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

Geology by T.R. Farrell and R.L. Langford 1994

Edited by C. Strong and G. Loan

Cartography by C. Bartlett, B. Williams, and P. Taylor

Topography from the Department of Land Administration Sheet SG 51-14, 3342, with modifications from geological field survey

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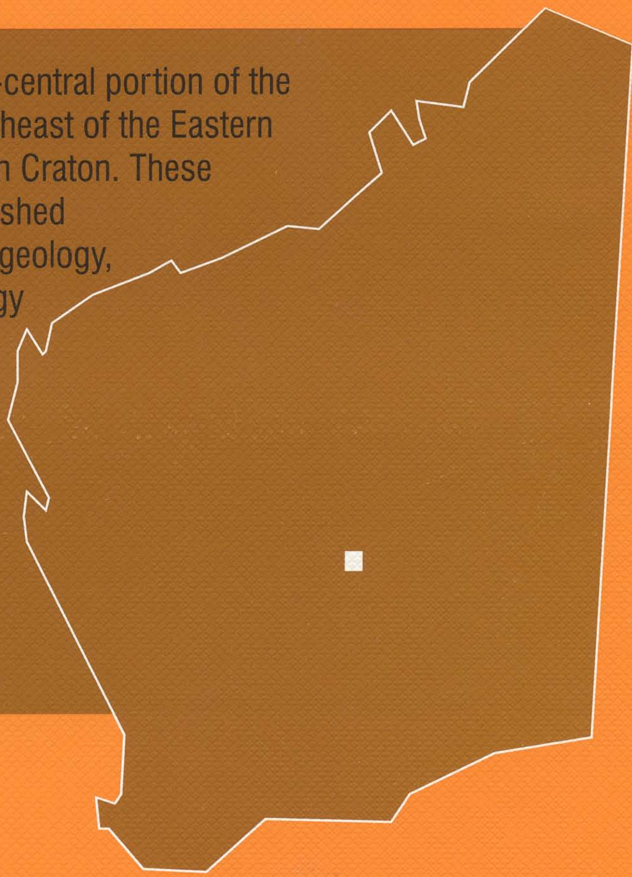
DUKETON

SHEET 3342 FIRST EDITION 1996

The Duketon 1:100 000 sheet covers the south-central portion of the Duketon 1:250 000 sheet, which lies in the northeast of the Eastern Goldfields Province, part of the Archaean Yilgarn Craton. These Explanatory Notes, which complement the published 1:100 000 map, describe the solid and regolith geology, structure, metamorphism, and economic geology of the granite–greenstone terrain. Cainozoic regolith cover dominates the area, and the geology of these deposits is fully described. The deformation history, including granitoid emplacement and granite–greenstone relationships, is discussed in detail. Metamorphic zones within the north-northwesterly trending belt are also discussed.



Further details of geological publications and maps produced by the Geological Survey of Western Australia can be obtained by contacting:

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LANGFORD, FARRELL

Geology of the Duketon 1:100 000 sheet

EXPLANATORY NOTES