HYDROGEOLOGY OF THE LAVERTON 1:250 000 SHEET

DEPARTMENT OF ENVIRONMENT
HYDROGEOLOGICAL MAP EXPLANATORY NOTES SERIES
HM 9
2004

Department of
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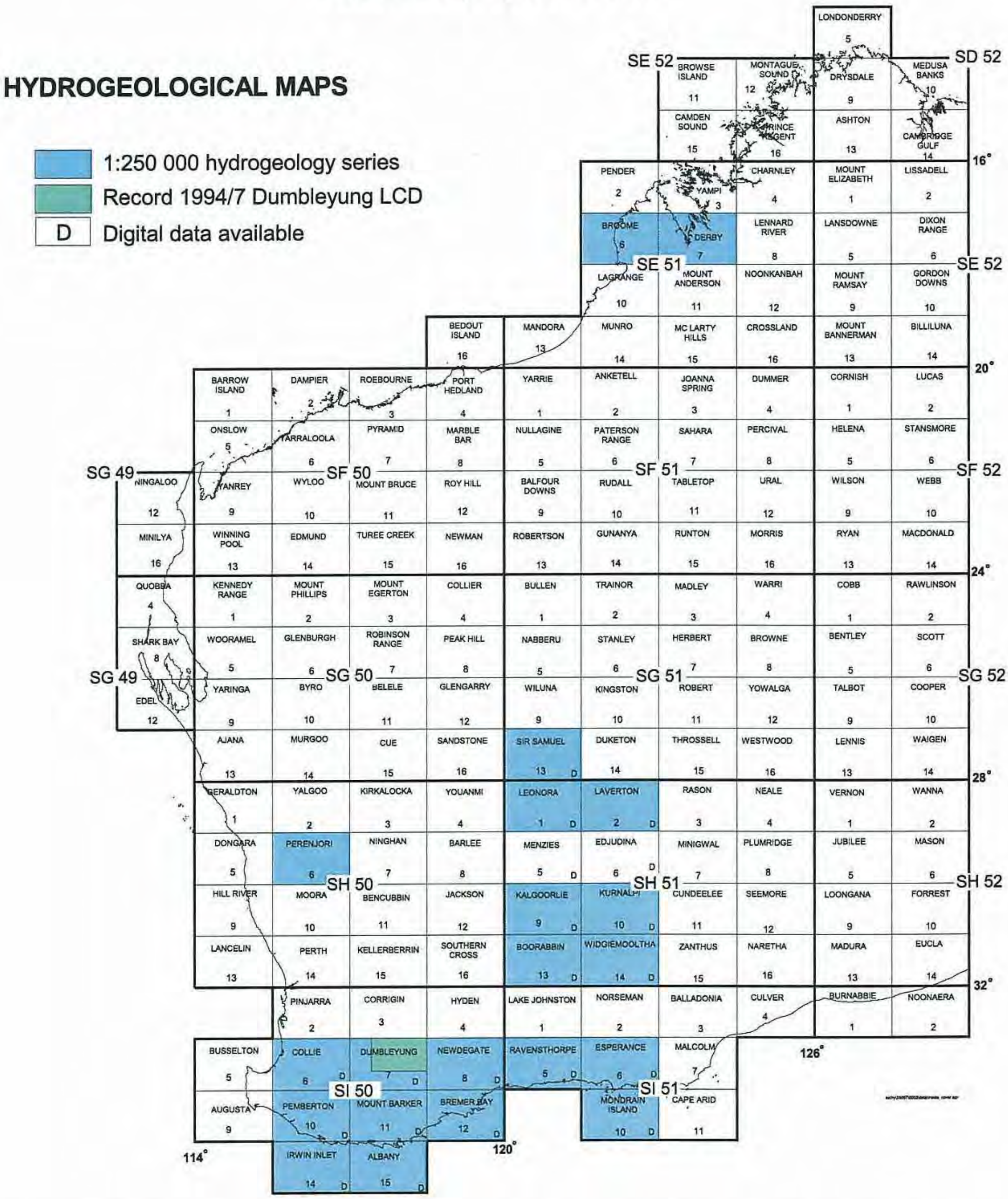

Cover Photograph: Flooded mine void at Lancefield. A production bore (LPB2) located to the right of the photograph is used for town water supply in Laverton.

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HYDROGEOLOGY OF THE LAVERTON 1:250 000 SHEET

BY

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Abstract

The LAVERTON 1:250 000 hydrogeological sheet covers a part of the Yilgarn Craton that is characterised by north-northwesterly trending belts of Archaean greenstones intruded by granitoid rocks. Cainozoic surficial deposits form an extensive cover over the Precambrian bedrock and conceal Tertiary sedimentary rocks preserved in palaeochannels.

Fractured-rock aquifers occupy the greater part of the LAVERTON area, but they generally contain only minor groundwater supplies, and these are difficult to locate. The palaeochannel sand and calcrete are considered to be the most prospective aquifers on LAVERTON. There are significant groundwater resources within the alluvium that are best utilised via downward leakage into either underlying palaeochannel sands or permeable structures in the basement.

Most of the groundwater on LAVERTON is brackish and is extensively used by the pastoral industry. Important brackish groundwater resources have also been identified in the palaeochannel tributaries throughout the sheet area. Saline to hypersaline groundwater occurs along the palaeodrainages and is currently used only for mining purposes.

The groundwater resources in the palaeochannels are being developed for use in ore processing; however, the brackish groundwater in the tributaries also has potential for potable water supply or horticultural development. A number of borefields have also been established in the alluvium, calcrete and fractured-rock aquifers throughout LAVERTON to provide water to the town of Laverton and the mining industry.

Keywords: hydrogeological maps, groundwater, aquifers, palaeochannels, Northern Goldfields.

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1 Introduction

1.1 Location

The LAVERTON[1] hydrogeological sheet (SH 51-2 of the International Series), which is bounded by latitudes 28°00' and 29°00' S and longitudes 121°30' and 123°00' E, lies within the northern part of the Eastern Goldfields Province of Western Australia. The map sheet takes its name from the mining town of Laverton, located towards the centre of the sheet.

Mining is the major activity of the region with most of the population concentrated in Laverton. The remainder of the sheet is sparsely populated, except for individual pastoral homesteads and scattered mining operations at Granny Smith, Mount Morgans and Murrin Murrin.

The sheet area is reached via the Leonora–Laverton Road, which links Laverton to the town of Leonora to the west, as well as connecting it with the towns of Wiluna in the north and Menzies and Kalgoorlie in the south. Good-quality, shire-maintained unsealed roads connect the major mining centres and pastoral properties. In addition, there is a network of fence-line tracks, suitable only for four-wheel drive vehicles, which provide access to more remote locations.

Pastoral properties carrying sheep occupy most of the sheet area, with mineral exploration and mining being restricted to the greenstone areas.

1.2 Climate

The climate is semi-arid to arid with hot, dry summers and cool to mild winters. January is the hottest month with an average maximum temperature of 36°C and an average minimum of 21°C at Laverton. July is the coolest month with an average maximum temperature of 18oC and an average minimum of 5°C. Frost occasionally occurs during the winter months.

The average annual rainfall is 226 mm at Laverton, but this is unreliable and the area is often subjected to both drought and localised short-term floods. Rainfall is evenly distributed between the summer and winter months, although heaviest in summer, when it is associated with thunderstorm activity or rain-bearing depressions formed from tropical cyclones.

Average annual potential evaporation increases from about 3400 mm in the south to 3700 mm in the northeast. Evaporation is greatest during the summer months of January and February and lowest during the winter months of June and July.

1.3 Physiography

Most of the area is gently undulating and of subdued relief, with elevations between 375 and 550 m AHD (Australian Height Datum). Throughout LAVERTON numerous granite monadnocks protrude slightly above the land surface, and greenstones and banded iron-formation form prominent hills and ridges such as Mount Redcliffe (553 m AHD), Mount Varden (535 m AHD) and Mount Zephyr (522 m AHD). The sheet area is characterised by broad alluviated valleys and playa lakes, which mark the courses of palaeorivers that ceased to flow when the climate became arid during the Tertiary. On LAVERTON, these palaeorivers form three distinct drainage systems, or palaeodrainages (Fig. 1).

[1] Sheet names are printed in capitals to distinguish them from identical place names

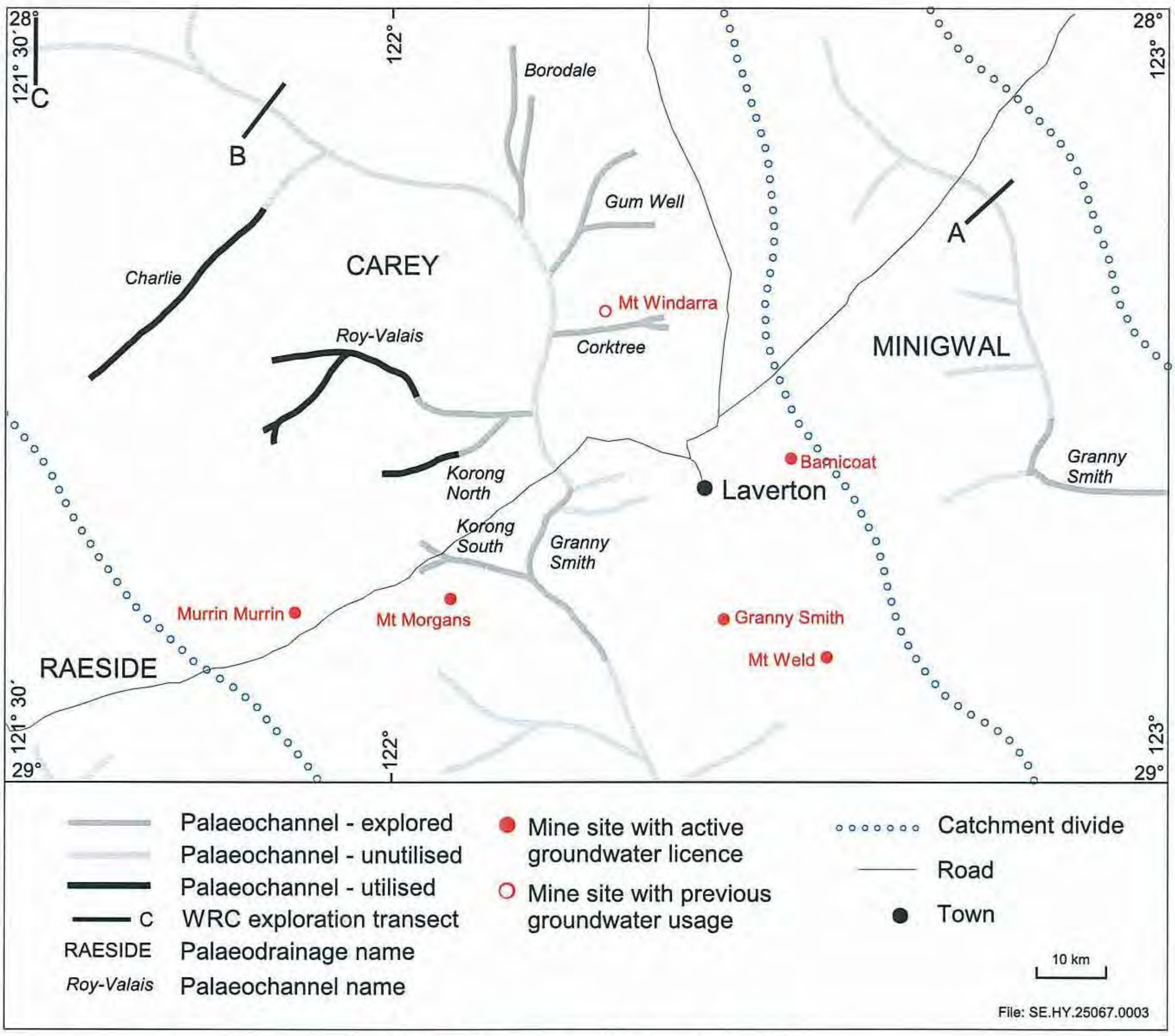

Figure 1. Location and palaeodrainages.

Two major surface-water divides cross LAVERTON separating the Carey, Minigwal and Raeside Palaeodrainages (Beard, 1973; Bunting *et al.*, 1974; van de Graaff *et al.*, 1977). These palaeodrainages once carried water east to the Eucla Basin but are now occupied by chains of playa lakes. The headwaters for these palaeodrainages are located to the west and north of the sheet area.

There are no permanent rivers; intermittent streamflow occurs only after major rainfall and the water runs into playa lakes. Runoff from bedrock outcrops may collect in gnamma holes or rock holes, and soaks and water holes commonly occur next to rocky outcrops.

1.4 Vegetation

The vegetation is quite diversified throughout LAVERTON and is controlled by soil type (Beard, 1981). Most of the area comprises low woodland dominated by mulga and mixed eucalypt scrub. Mulga and mallee shrubland thrive on elevated rocky features such as greenstone ridges. In the granite and sandplain areas, spinifex hummock grasslands with scattered mulga and eucalypt overstorey are prominent. The drainage lines are commonly occupied by thick woodland, with salt-tolerant halophytes such as samphire and saltbush surrounding the playa lakes.

Large areas of mulga and mallee trees around mining centres were cleared for firewood and timber during the initial mining activities, although this vegetation is regenerating. In the pastoral areas, overstocking and feral animals such as goats and rabbits have caused local erosion and land degradation.

1.5 Previous investigations

The earliest geological investigations detailed gold occurrence in the greenstone belts and descriptions of gold-mining centres at Burtville, Mount Morgans and within the Mount Margaret Goldfields. The discovery in 1969 of nickel at Mount Windarra resulted in numerous geological reports, which were summarised by Robinson *et al.* (1973). Willett e*t al.* (1986) reviewed the geological economic importance of the Mount Weld Carbonatite, which is located 35 km southeast of Laverton.

The first edition of the LAVERTON geological sheet was compiled in 1975 (Gower, 1976), and included a bibliography of previous publications. The Bureau of Mineral Resources (BMR, now Geoscience Australia) published the results of an aeromagnetic and radiometric survey (Tipper and Gerdes, 1971). Griffin (1990) outlined the regional geology of the Eastern Goldfields Province. The entire LAVERTON sheet was remapped at 1:100 000 scale between 1991 and 1996 by the Australian Geological Survey Organisation (now Geoscience Australia) (Duggan, 1993, 1995; Williams and Duggan, 1995, Wiliams *et al.*, 1995; Jagodzinski, 1996; Rattenburg and Duggan, 1996). In addition, the western half of LAVERTON was also remapped at 1:50 000 scale by Hallberg (1985).

The first description of the regional hydrogeology and the availability of groundwater was by Morgan (1966), who undertook bore siting for various pastoral leases. The calcrete aquifers on LAVERTON were evaluated by Sanders (1969) and Sanders and Harley (1971) to determine their potential for irrigation and mine water supplies. Forbes (1978) made an assessment of the groundwater resources of the Eastern Goldfields in response to concerns about the availability of groundwater for mining supplies. This was subsequently revised by Bestow (1992), who provided regional estimates of the renewable and stored groundwater resources for each 1:250 000 sheet area. Allen (1996) provided a description of the hydrogeology and groundwater availability, but did not assess the groundwater resources.

The Water and Rivers Commission (now Department of Environment) carried out a major study of the groundwater resources in the Northern Goldfields between 1996 and 1999 (Johnson *et al.*, 1999). This study included a drilling program and geophysical survey (Johnson et al., 1998; Tesla-10, 1997). The hydrogeology of the adjacent LAVERTON and SIR SAMUEL 1:250 000 sheets was compiled in 1999 (Johnson, 1999a,b).

Considerable groundwater exploration and development has been carried out on LAVERTON for the mining industry over the past thirty years. Borefields have been established for mining developments throughout the region, with a large amount of work having been carried out for the nickel operations at Mount Windarra and gold operations at Mount Morgans, Lancefield and Granny Smith. Recent groundwater exploration has concentrated on locating water supplies in palaeodrainages, particularly within the Roy-Valais, Korong and Charlie Well Palaeochannels for the Murrin Murrin nickel operation.

1.6 Map compilation

The hydrogeological map of LAVERTON depicts aquifer distribution, potentiometric levels in metres AHD (for the palaeochannel aquifers), groundwater salinity (isohalines), groundwater point-data distribution and cadastral data. Data used in the compilation of the map include: cadastral data from Department of Land Administration; geology from GSWA (Gower, 1976); pastoral bore data from the Water and Rivers Commission groundwater database (AQWABase); mining bore data from groundwater consultant and mining company reports (held by the Water and Rivers Commission); WAMEX mineral exploration drilling and MINEDEX mining operation locality data from the Department of Industry and Resources.

The LAVERTON hydrogeological map is, at the 1:250 000 scale, a generalisation of the data which have been entered into a digital database and stored as graphical layers of information. Interpretation of the data was conducted at 1:250 000 scale, which should be considered when working at larger scales. The hydrogeological boundaries, potentiometric contours and isohalines are interpretative and must be taken as approximate. The most accurate interpretation is associated with mine production borefields, whilst areas with limited pastoral bore distribution have only reliable salinity information.

2 Geology

2.1 Regional setting

The LAVERTON sheet lies within the Eastern Goldfields Province of the Yilgarn Craton (Griffin, 1990; Myers, 1997). It is characterised by linear, north-northwesterly trending greenstone belts of Archaean supracrustal rocks comprising metamorphosed volcanic and sedimentary rocks, with intervening areas of granitoid rocks. Proterozoic dykes cut both the greenstone and granitoid rocks.

Cainozoic surficial deposits form an extensive cover over the Precambrian rocks, and include Tertiary sedimentary rocks preserved in palaeochannels located in palaeodrainages that once carried water eastward to the Eucla Basin.

2.2 Archaean and Proterozoic

The greenstone belts contain metamorphosed and deformed sequences of mafic (*Ab*) and ultramafic (*Au*) volcanic rocks; felsic volcanic and volcaniclastic rocks (*Af*); sedimentary rocks (*As*); and minor chert and banded iron-formation (*Ac*). A variety of granitoid rocks (*Ag*), generally foliated, occupy about 60% of LAVERTON. The Archaean bedrock is poorly exposed on LAVERTON owing to widespread surficial cover and deep weathering.

Granitoid emplacement has extensively deformed the greenstone belts resulting in complex geological structures (Myers, 1997). The contacts are characterised by strong deformation, local high-grade metamorphism, and interleaving of granitoid and greenstone rocks. As a result of their deformation, the greenstones are highly sheared and fractured. In contrast, the granitoids are generally massive except for jointing and local fracturing developed adjacent to the greenstone contacts.

The Mount Weld Carbonatite (*Pm*) lies 35 km southeast of Laverton and intrudes the Archaean volcano-sedimentary rocks of the Yilgarn Craton. The carbonatite is approximately 4 km in diameter composed largely of sövite (a calcium carbonate-rich intrusive rock), and is concealed beneath alluvium and lacustrine sediments (Lewis, 1990). It is deeply weathered, in places to 60 m, and this has produced a vuggy, fissured and karstic weathered profile overlying fresh bedrock. (Dames And Moore, 1995). The residual carbonatite contains an important economic resource of phosphate and rare earth elements, which has yet to be mined.

Proterozoic mafic and ultramafic dykes (*Pd*) intrude the granite–greenstone terrane throughout LAVERTON. The dykes are widespread, less than 200 m across, with easterly and northeasterly trends, and can be traced as aeromagnetic lineaments.

Most rock types have been lateritised and deeply weathered over much of the area, resulting in deep sections that are completely weathered to clay, or partially weathered with the original texture preserved. The weathering profile is commonly 30–40 m thick, but exceeds 120 m in the Keringal deposit at Granny Smith (Dames And Moore, 1993). The weathered granitoid profile is principally characterised by large thicknesses of kaolin, which may extend a depth of 50 m. In places, a quartz-rich grit comprising partially decomposed basement directly overlies the fresh granitoid rock and is often misinterpreted as palaeochannel sand.

2.3 Cainozoic

2.3.1 Tertiary sedimentary rocks

Tertiary sedimentary rocks deposited in valleys cut by Cretaceous to early Tertiary rivers form palaeochannels that are now concealed by Cainozoic sediments. On the map, these sediments are shown in blue with solid lines where proven by drilling and geophysics, and dashed lines where they are inferred to be present. Their distribution is interpreted between drillholes.

Sediments in the Carey, Minigwal and Raeside Palaeodrainages on LAVERTON have been described in Johnson et al. (1999), and are similar to those in the Roe Palaeodrainage (Kern and Commander, 1993). They typically comprise basal fluvial sand (*Tw*) overlain by lacustrine clay (*Tp*). The palaeochannel sand, which reaches a thickness of 30 m in the Carey Palaeodrainage (AGC, 1989), consists of unconsolidated quartz sand with minor silt, clay and lignite. The unit is Eocene in age and is an equivalent of the Wollubar Sandstone (Kern and Commander, 1993). The palaeochannel clay is a multicoloured, plastic clay with minor sand and pisolitic beds, and in places reaches 60 m in thickness. The unit becomes more silty and sandy in the upper parts of the palaeochannels.

The palaeochannels and their tributaries, delineated by drilling, range in width from 100 m in the Roy-Valais Borefield (Rust PPK, 1996) to about 1000 m in the Carey Palaeodrainage, near Lake Carey (AGC, 1989). They reach to 120 m depth where bedrock is deeply incised.

2.3.2 Surficial deposits

A variety of Cainozoic surficial deposits (*Ql*, *Cza* and *Czk*) are encountered on LAVERTON, where they form a veneer over the Archaean and Tertiary rocks. Cainozoic surficial deposits in elevated areas are generally unsaturated and are not mapped. Only those units that are likely to contain groundwater are shown on the map.

High-level deposits of laterite, eluvium, and sandplain are widespread. The laterite occurs as plateaus of massive, ferruginous duricrust, bounded in part by breakaways, and as pisolitic soil in lower areas. The eluvium consists of quartzofeldspathic sand derived by weathering and erosion of granitoid rocks with scattered, small pebbles of granitoid rocks. Sandplain deposits, which are partly eolian in origin, comprise low dunes of red-brown sand forming extensive, gently undulating areas on LAVERTON.

Alluvial and colluvial deposits (*Cza*) are widespread throughout LAVERTON. The unit has a variable thickness of up to 30 m beneath Transect B (Johnson *et al.*, 1998). This variation in thickness is largely dependent on position in the drainage system, with the thickest sequences often coinciding with the axes of the Tertiary palaeochannels. The alluvium occurs as coalesced alluvial fans and broad sheetwash areas consisting of unconsolidated sand, silt and clay. In places, the alluvium has been cemented by silica, iron oxide or carbonate to form a hardpan, locally termed the 'Wiluna Hardpan' (Bettenay and Churchward, 1974).

Bodies of calcrete (*Czk*) exist at the margins of present-day salt lakes, and locally in some of the main tributaries in the palaeodrainages (Sanders, 1974). The calcrete rarely exceeds 10 m in thickness. Karstic features, including sinkholes and gilgai structures, are commonly developed due to the susceptibility of the calcrete to chemical dissolution via percolating surface water and groundwater movement.

Deposits associated with playa lakes (*Ql*) consist of saline and gypsiferous clay and silt that may be up to 10 m thick. They typically overlie highly weathered Archaean rocks, or alluvium within the trunk palaeodrainages. The lake margins consist of stabilised dunes of unconsolidated sand, silt and gypsum derived from the desiccated surface of the playa lakes.

3 Hydrogeology

3.1 Groundwater occurrence

The LAVERTON area is underlain by weathered and fractured Archaean bedrock, which forms the northern portion of the Yilgarn Goldfields fractured-rock groundwater province. The bedrock is overlain locally by palaeochannel deposits, and by widespread alluvium, colluvium, calcrete and lake deposits.

The fractured bedrock is characterised by secondary permeability resulting from chemical weathering of tectonic and decompression fracture systems. Fractured-rock aquifers are more commonly developed in mafic and granitoid rocks than in sedimentary or felsic volcanic rocks. The maximum depth to which open fractures penetrate is 250 m in the Lancefield underground operations, north of Laverton. Groundwater can be inferred to occur to a similar depth along major faults and shear zones. Vuggy weathering profiles developed in the Mount Weld Carbonatite also constitute an important local aquifer.

Minor mafic and ultramafic dykes occur in the western half of LAVERTON. They are undeformed, generally appear to lack open fractures, and are possibly hydraulic barriers to groundwater movement.

The palaeochannel sand is highly permeable and contains significant supplies of groundwater, which is brackish in the tributaries and saline to hypersaline in the main trunk drainages. The sand, however, has limited groundwater storage with most groundwater abstracted being the result of induced leakage from overlying sediments and surrounding fractured-rock aquifers.

Groundwater is contained within the primary porosity of the alluvium, whereas calcrete exhibits increased secondary permeability through chemical dissolution. Although, the alluvium aquifer has low permeability owing to its clayey nature, the calcrete is capable of large groundwater supplies from solution cavities.

Direction of groundwater flow and variation in salinity are closely related to topography, whereas bore yields depend largely on rock type.

Groundwater occurrence on LAVERTON is illustrated in Figure 2. Groundwater recharge is difficult to estimate as it constitutes a very small proportion of rainfall, most of which is either directly evaporated or utilised by the native vegetation, with a small component of runoff into claypans and playa lakes. Direct recharge principally takes place around bedrock outcrops, in the sandplains, and sinkholes within the calcrete. Most recharge is likely to occur during heavy rainfall, when it is augmented by recharge from surface runoff and local flooding.

There is a regional watertable on LAVERTON. Depth to groundwater is dependent on topography and ranges from less than 1 m in playa-lake environments to more than 40 m in elevated areas. The regional watertable may be absent in high areas where the weathered and fractured zone is unsaturated or where fractures are poorly developed.

Groundwater flow is towards the major palaeodrainages and modern playa lakes where the watertable is close to the surface. Hydraulic gradients along the palaeodrainages are generally very low with steeper gradients in the upper reaches of the catchments. Groundwater discharge is mainly by evaporation from playa lakes with a relatively small amount by throughflow within the palaeochannels.

The units on the accompanying map represent distinct hydrogeological units with lithological associations similar to those used on geological maps.

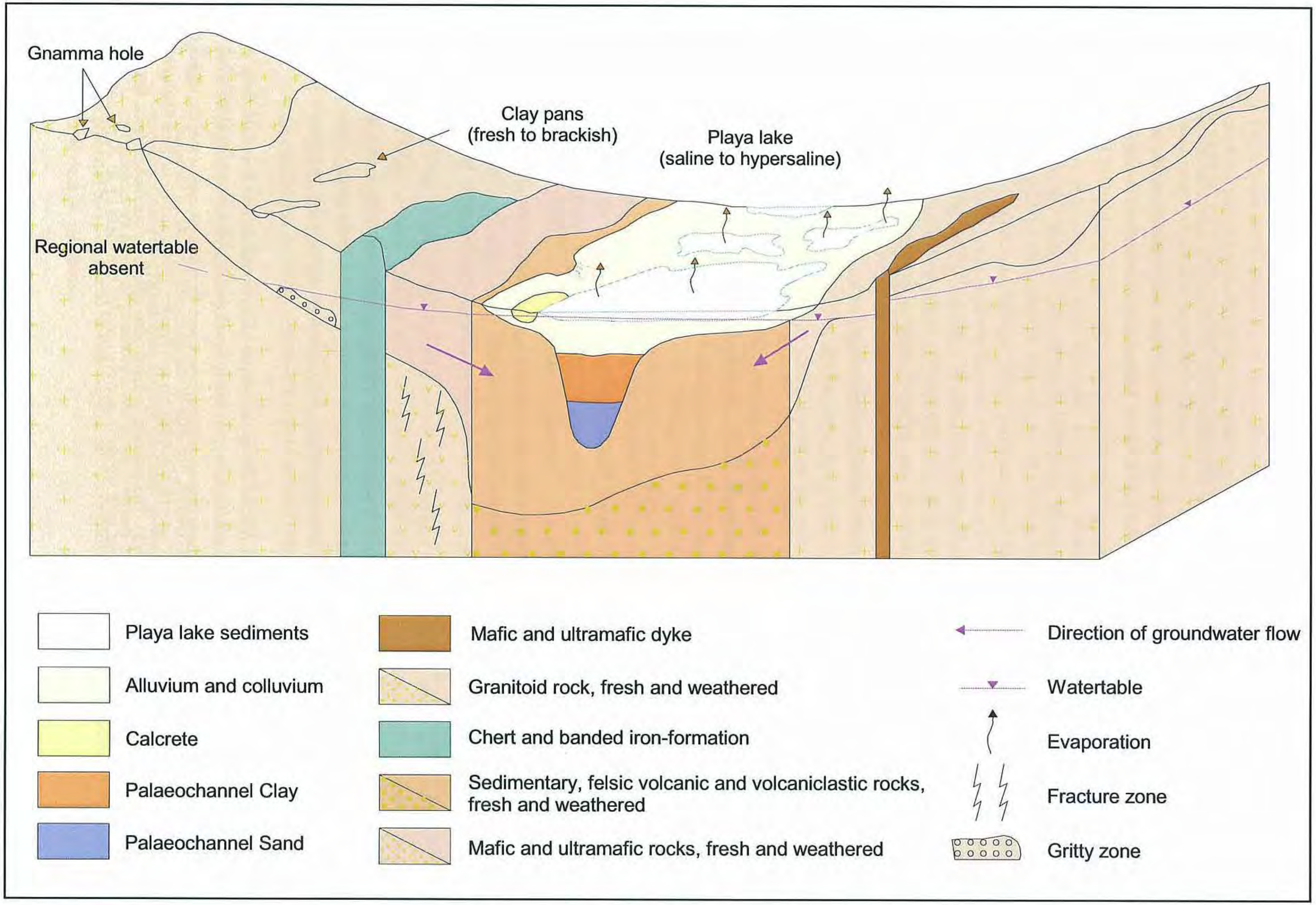

Figure 2. Schematic section showing groundwater occurrence.

3.2 Aquifers

3.2.1 Surficial deposits (*Ql*, *Cza* and *Czk*)

Lacustrine sediments (*Ql*) are intermittently saturated as the lakes are usually dry for most of the year and are replenished only after heavy rainfall. The regional watertable is close to the surface in playa lake environments. The sediments are generally fine-grained to clayey, with bore and well yields likely to be low. They are not utilised as aquifers on LAVERTON. Playa lakes commonly have marginal gypsiferous sand and clay deposits that are not mapped but may contain a perched watertable.

Alluvial and colluvial deposits (*Cza*) occur as channel fill associated with palaeodrainages, and comprises unconsolidated silty sand and minor gravel. Minor deposits of colluvium interfinger the alluvium, and have been mapped together owing to their possessing similar aquifer properties.

The poorly sorted sediments form an unconfined aquifer with a shallow watertable and an average saturated thickness of between 5 and 15 m. The permeability of the alluvium is generally low owing to its silty nature. The hydraulic conductivity can, however, increase significantly in permeable sand and gravel horizons, and in calcretised sections. In addition, the alluvial aquifer is commonly partly indurated by siliceous and ferruginous cementation, possibly representing previous watertable positions, which has secondary porosity and high permeability developed in bands.

Bore yields from the alluvium are variable ranging between 50 and 400 m^3/day, which reflects the variability in hydraulic conductivity. Short-term yields up to 1500 m^3/day have been recorded in the Roy-Valais Borefield during pumping tests (AGC, 1977). The largest yields are from unconsolidated, clayey, rounded basaltic gravels that form colluvial deposits at the base of greenstone ridges (Johnson *et al.*, 1999).

The aquifer is not currently utilised on LAVERTON; although the former WMC Valais Borefield (now referred as Roy-Valais Borefield) at Mount Windarra previously utilised the alluvial aquifer. The Valais Borefield was utilised between 1974 and 1986 with 11 production bores supplying 1.7×10^6 m^3/yr of process water to the Mount Windarra nickel operation (Golder and Assoc., 1988). Groundwater can also be obtained from the alluvium through leakage into underlying palaeochannel and fractured-rock aquifers, such as in the Laverton TWS borefields at Beasley Creek and Skull Creek. The alluvial aquifer has been explored in the Peter Well area, east of Barnicoat Gold Mine; however, it has never been developed.

Calcrete (*Czk*) is an important local aquifer in the Northern Goldfields capable of providing large supplies of brackish to saline groundwater. The aquifer occurs low in the drainage systems where the watertable is generally shallow (<5 m below ground level) and saturated thickness is mostly between 5 and 10 m. Bore yields are highly variable depending on the nature and extent of karstic development. Bore yields in the Jupiter borefield, south of Mount Morgan, ranged from less than 100 m^3/day in massive calcrete to 1500 m^3/day in highly karstic calcrete (Mackie Martin and Assoc., 1990).

The calcrete aquifer is utilised on LAVERTON in the Mount Morgan and Jupiter borefield, both part of the Mount Morgan Gold Operation, and has been previously developed by Ashton Mining in the Cork Tree Well borefield. All calcrete bodies have been extensively explored for mine-process water throughout the sheet area, primarily north of Lake Carey (Mackie Martin and Assoc., 1990), and Cork Tree Shallow, north of Mount Windarra (Rust PPK, 1996). The pastoral industry also utilises groundwater from the calcrete via shallow bores and wells equipped with windmill-powered pumps that yield up to 20 m^3/day.

3.2.2 Tertiary sedimentary rocks (*Tp* and *Tw*)

The palaeochannel sand (*Tw*) is the major aquifer in the Northern Goldfields region. The sand aquifer is confined throughout LAVERTON by relatively impermeable clay (*Tp*), although the confining clay layers in the tributaries are often silty and contain multiple sand horizons.

Groundwater flow in the sand aquifer is generally towards the southeast, in the direction of the original drainage. The potentiometric surface in the Carey Palaeodrainage falls from 460 m AHD in the Charlie Well Palaeochannel (Rust PPK, 1996) to about 395 m AHD beneath Lake Carey, south of Laverton. There are no potentiometric data available within the Minigwal Palaeodrainage, although it is likely that groundwater flow is towards the south, prior to discharging into the Carey Palaeodrainage farther downstream.

The hydraulic gradient in the Raeside Palaeodrainage is steepest (0.6 m/km) in the upper reaches of the tributaries reflecting narrowing of palaeochannel, thinner sand sections and lower hydraulic conductivity. In the vicinity of salt lakes, the hydraulic gradient is very low (about 0.2 m/km) suggesting groundwater discharge through evaporation at lake surfaces.

Bore yields from the sand aquifer are variable and range from about 200 to 1400 m^3/day (Table 1). Short-term yields in excess of 2000 m^3/day have been recorded during pumping tests in the Roy-Valais borefield (Rust PPK, 1996) with larger yields dependent on grain size, thickness and extent of sand.

The palaeochannel sand aquifer is utilised in the Roy-Valais and Korong North borefields to providing process water to the Murrin Murrin nickel operations. There has been extensive exploration in the tributaries of the Carey Palaeodrainage on LAVERTON, in relation to Murrin Murrin, particularly within the Charlie Well, Borodale, Gum Pool, Cork Tree and Korong South Palaeochannels. In addition, the Carey and Minigwal Palaeodrainages in the vicinity of the Granny Smith Gold Mine have been explored (AGC, 1989).

3.2.3 Mount Weld Carbonatite (*Pm*)

The Mount Weld Carbonatite is an important local aquifer comprising deeply weathered carbonatite. The weathering processes have formed an irregular regolith with granular, fissured and vuggy characteristics resting on unaltered, fresh bedrock (Dames And Moore, 1994). The weathered carbonatite is semi-confined within weathered and fractured Archaean greenstone rocks of low permeability, as well as lying beneath a thick sequence of alluvium and palaeochannel clay.

Bore yields from the carbonatite are dependent on the extent of weathering and hence are highly variable, ranging from 200 m^3/day in fresh bedrock to about 2000 m^3/day in karstic sections (Table 1). The aquifer is only utilised on LAVERTON within the Mount Weld Borefield for supplying process water to Granny Smith Gold Mine.

3.2.4 Granitoid rocks (*Ag*)

Granitoid rocks, which occupy about 60% of LAVERTON, consist of even-grained to porphyritic granite, monzogranite and granodiorite that are generally foliated and metamorphosed. They are poorly exposed with extensive areas of granitoid rocks being overlain by residual sandplains and colluvium. In outcrop, granitoid rocks appear to be massive with only minor foliations and joints, although widely spaced jointing is evident on air photos.

In places, the granitoid rocks are deeply weathered to more than 100 m, with the thicker profiles occurring along shear zones or beneath the palaeodrainages. Bore yields of up to 100 m^3/day are obtainable from both the quartz-rich grit at the base of the weathered profile, and fractures in the uppermost 10 to 20 m of fresh rock. Larger supplies, up to 500 m^3/day, are available from lineaments, probably faults or shear zones, within the granitoids and at the contact with greenstone rocks.

Table 1. Summary of data from major borefields.

Aquifer	*Borefield*	*Mining operation*	*Number of bores*	*Production bores (a)* Depth range (m)	Yield (m^3/day)	Salinity (mg/L TDS)
Alluvium	Peter Well	Barnicoat	6			
	Valais	Mount Windarra	11	36 – 96	300 – 1100	1200 – 3000
Calcrete	Cork Tree	Murrin Murrin	-	24 – 39	400 – 1200	4200 – 12000
	Cork Tree Well	Ashton Mining	2	31 – 36	1200 – 1500	8200 – 8600
	Jupiter	Mount Morgans	3	8 – 15	100 – 1500	14000 – 140000
	Mount Morgans	Mount Morgans	7	7 – 14	450 – 1200	2600 – 17000
Eocene sedimentary rocks	Roy – Valais	Murrin Murrin	62	39 – 91	400 – 1400	600 – 7500
	Korong North	Murrin Murrin	5	60 – 79	150 – 500	900 – 7200
	Borodale	Murrin Murrin	- (a)	50 – 126	n/a	1800 – 10000
	Charlie Well	Murrin Murrin	- (a)	53 – 102	300 – 500	650 – 2500
	Cork Tree (Deep)	Murrin Murrin	- (a)	85 – 110	250 – 350	1100 – 12000
	Gum Well	Murrin Murrin	- (a)	57 – 88	n/a	1800 – 3500
	Korong South	Murrin Murrin	- (a)	59 – 100	n/a	1000 – 13800
Mount Weld Carbonatite	Mount Weld	Granny Smith	9	61 – 133	500 – 2300	1800 – 6000
Chert and banded iron-formation	Beasley Creek	Laverton TWS	2	61 – 70	1500	1400 – 1620
	Southern	Mount Windarra	4	51 – 65	80 – 900	5700 – 8200
	Telegraph shaft	Laverton TWS	1	114 – 115	500	700 – 850
Felsic volcanic and metasedimentary rocks	Goanna pit	Granny Smith	9	82 – 123	80 – 1300	3500 – 68300
	Granny pit	Granny Smith	11	54 – 132	290 – 860	4700 – 150000
	Windich pit	Granny Smith	4	40 – 134	200 – 1040	52500 – 230000
Granitoid rock	Northern	Mount Windarra	4	55 – 77	180 – 220	1200 – 4600
Ultramafic and mafic rocks	Barnicoat	Barnicoat	4	60 – 85	250 – 350	15000 – 39600

(a) exploratory bore data where no production bores.
(b) dewatering production bore data.

Pegmatite dykes and quartz veins (not mapped) are a minor, but widespread, component of the granitoid rocks. These tend to be well fractured and may form small but locally important aquifers. They are also present in the greenstone belts. Proterozoic mafic dykes (*Pd*) commonly intrude the Archaean granitoid rocks and weather to massive, impermeable clay.

In general, the granitoids are poorly explored throughout LAVERTON owing to their low mineral prospectivity and poor groundwater prospects due to their homogeneity and sparse fracturing (Johnson *et al.*, 1999). Most production bores in the Northern Borefield at Mount Windarra were established in sandy horizons of a weathered granite. In addition, several dewatering bores for the Goanna, Granny and Windich pits at Granny Smith gold mine are positioned along lithological contacts between greenstone and granitoid rocks.

3.2.5 Chert and banded iron-information (*Ac*)

Chert and banded iron-formation are common within the Duketon Greenstone Belt through the centre of LAVERTON, where they are associated with mafic and ultramafic volcanic rocks and form prominent narrow ridges. These localised aquifers have well-developed joint systems as a result of brittle deformation, and are not deeply weathered. In places, they are recharged directly by infiltration of rainfall and from runoff along creek such as Beasley Creek, where fractured chert outcrops in the creek beds.

Three borefields have been developed in the chert and banded iron-formation. The Beasley Creek Borefield and the Telegraph shaft at Lancefield are developed within chertose bodies and are the prime source of town water supply for Laverton. An additional production bore (LPB2) has been established within the brecciated chert to supplement the Laverton town water supply during periods of peak demand. The abandoned Southern borefield at Mount Windarra had four production bores positioned within banded iron-formation with bore yields ranging from 80 to 900 m^3/day.

3.2.6 Sedimentary, felsic volcanic and volcaniclastic rocks (*As* and *Af*)

A complex succession of metamorphosed sedimentary rocks, and felsic volcanic and volcaniclastic rocks is widespread in the greenstone belts. The sedimentary rocks are well represented throughout LAVERTON, comprising quartz-rich siltstones, sandstones and conglomerates that are fine grained, strongly deformed and deeply weathered. In contrast, the felsic extrusive rocks are restricted largely to the southwestern corner of LAVERTON and consist of dacite, schists and felsic tuffs that tend to be foliated, relatively unjointed and form fine-grained weathering products.

Most of the dewatering bores in the Goanna, Granny and Windich pits at Granny Smith intersect fractures and lithological contacts between metasedimentary and granitoid rocks. Bore yields range between 80 and 1300 m^3/day depending on the extent of weathering and fracture development.

In general, bore yields from sedimentary and felsic volcanic rocks are small, less that 100 m^3/day, although higher yields can occur along structural features and lithological contacts. The felsic volcanic and volcaniclastic rocks are not developed on LAVERTON, and are likely to constitute poor sources of groundwater owing to their clay-rich weathering products.

3.2.7 Mafic and ultramafic rocks (*Ab* and *Au*)

Mafic and ultramafic rocks are the dominant rock types in the greenstone belts. The mafic rocks comprise extrusive basalt, amphibolite and high-Mg basalt that tend to be characterised by columnar jointing. However, in outcrop the mafic rocks are commonly highly weathered and the joints are filled with clay. Ultramafic rocks are restricted to the Duketon Greenstone Belt and include dunite, talc schists and talc–carbonate rocks that are typically thin, deeply weathered and poorly exposed.

The Barnicoat borefield, east of Laverton, is established in fractures and shear zones within mafic volcanic rocks. Bore yields are variable, ranging from 150 to 400 m^3/day depending on the extent of weathering of fracture development. However, the mafic and ultramafic aquifers are poorly explored and largely undeveloped throughout the sheet area.

4 Groundwater quality

4.1 Salinity

4.1.1 Regional variation

The distribution of groundwater salinity on LAVERTON in all aquifers is related to topography. Groundwater tends to increase in salinity towards and along the drainage lines, particularly the palaeodrainages, with the lowest salinity groundwater beneath catchment divides.

The mapped salinity pattern, displayed as a side panel on the hydrogeological map, is based on pastoral bore data held in AQWABase and represents the salinity of groundwater at the watertable. It is important to note that this dataset is non-synoptic and does not include unrecorded bores that may have been abandoned after drilling because of high salinity or low yields.

Groundwater salinity on LAVERTON is highly variable, ranging from less than 1000 mg/L total dissolved solids (TDS) in fractured-rock aquifers along catchment divides, to more than 200 000 mg/L TDS in brines in palaeochannels, adjacent playa lake sediments, and in fractured and weathered bedrock. The salinity range of groundwater from the major borefields is given in Table 1.

Potable groundwater (<1000 mg/L) occurs in elevated areas of enhanced recharge, primarily weathered and fractured bedrock aquifers along catchment divides. Alluvium and colluvium, adjacent to bedrock outcrops, contain small supplies of low-salinity groundwater.

Brackish groundwater (1000-3000 mg/L) is widely distributed throughout LAVERTON. The tributaries comprising alluvium, colluvium and palaeochannel sand commonly contain brackish groundwater that progressively increases in salinity downstream towards the main trunk drainages. The low-salinity groundwater in the upper parts of the palaeochannel tributaries is indicative of modern recharge. As calcrete is generally located in the lower reaches of the palaeodrainages, it commonly contains brackish groundwater of 2000 to 6000 mg/L (Sanders, 1969).

Saline groundwater (3000-35 000 mg/L) is associated with the lower reaches of the tributaries, and within alluvium and colluvium in the palaeodrainages. The weathered and fractured bedrock contains variable supplies of saline groundwater, with the higher salinity groundwater occurring in all rock types when low in the landscape.

Hypersaline groundwater (>35 000 mg/L) occurs mainly in palaeochannels and in bedrock adjacent to playa lakes. The high salinities of groundwater in playa lakes result from the concentration of salts as water evaporates from the lake surface. The salts in the hypersaline groundwater of the palaeochannels may have been accumulating for hundreds to thousands of years (Commander *et al.*, 1994).

4.1.2 Variation within aquifers

Groundwater salinity in the alluvial aquifer ranges from 1000 to 4000 mg/L on the flanks of the palaeodrainages and below alluvial fans, with higher salinity water encountered in the lower parts of the drainage system and towards salt lakes. Colluvium deposited on the flanks of greenstone ridges contains low-salinity groundwater, up to 3000 mg/L, owing to surface runoff from outcropping bedrock. Groundwater within the lake sediments is saline to hypersaline, with salinities exceeding 200 000 mg/L.

Groundwater in the calcrete is commonly brackish to saline, between 2000 and 6000 mg/L, because of its position in the lower reaches of drainages. Groundwater salinity in the calcrete can increase significantly with depth and during periods of high abstraction.

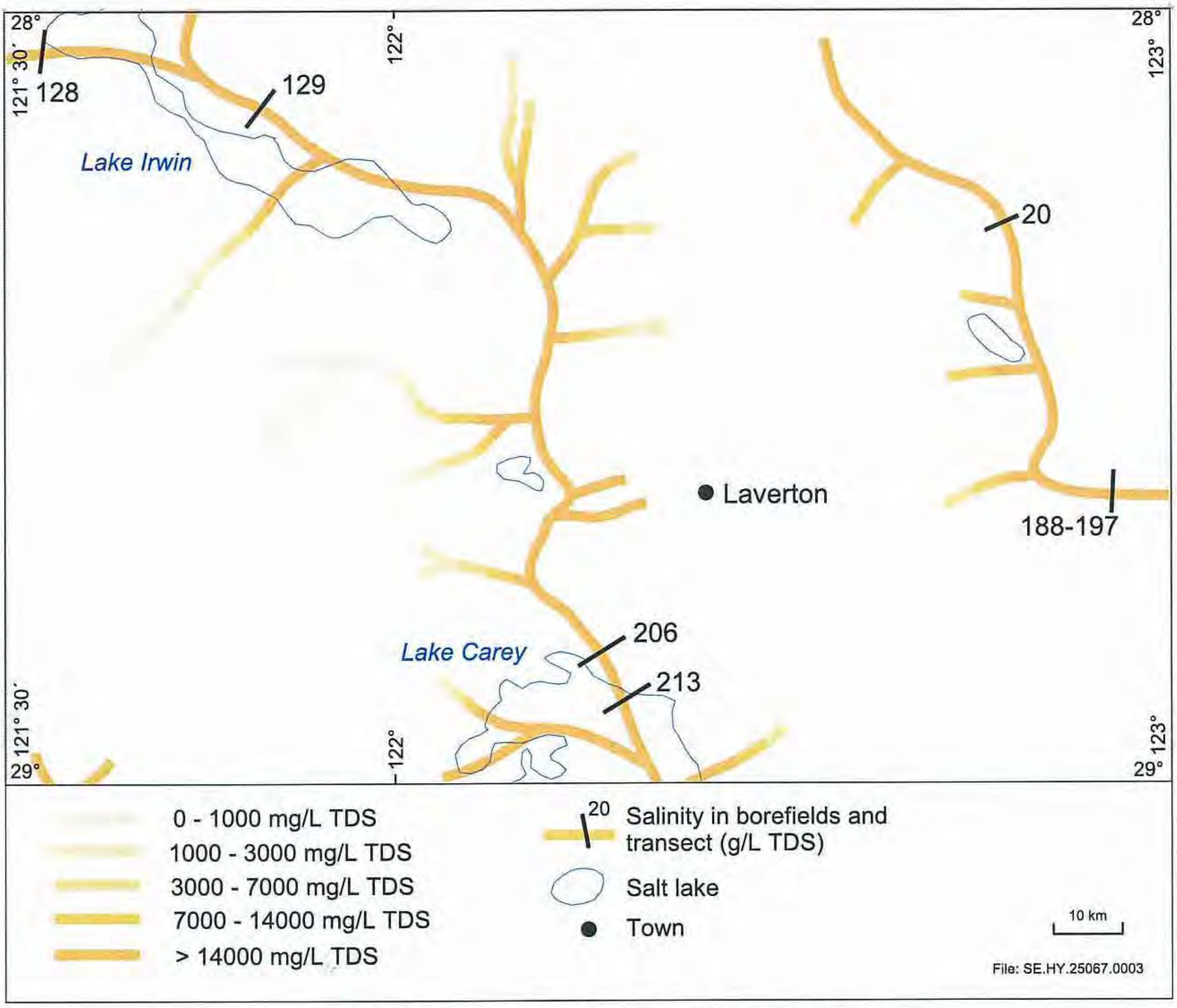

Figure 3. Groundwater salinity in the palaeochannels.

The groundwater salinity in the Tertiary sediments of the palaeochannels generally increases steadily downstream from about 1500 mg/L in the upper parts of the palaeodrainage systems to about 220 000 mg/L near playa lakes (Fig. 3). There are also variations in salinity along the palaeodrainages. Increases in salinity are related to groundwater discharge at salt lakes, whereas decreases in salinity are related to the accession of lower salinity groundwater from tributaries (Johnson e*t al.*, 1999).

Although salinity variation in the granitoids is poorly understood, the groundwater salinity in the granitoids will typically be lower in elevated areas.

The groundwater salinity in different types of greenstone aquifer tends to be highly variable, ranging from 1000 mg/L in the Beasley Creek Borefield to over 150 000 mg/L in dewatering bores at Granny pit. Local variations in groundwater salinity are common, such as in dewatering bores at Granny pit where the salinity ranges from 4500 to 150 600 mg/L (Dames And Moore, 1993). Mine dewatering of underground operations throughout LAVERTON shows that there is an appreciable increase in groundwater salinity with depth.

4.2 Hydrochemistry

The results of chemical analyses of groundwater from 25 sampling points are presented in Table 2, and the major ions from the chemical analyses are plotted on trilinear diagrams in Figure 4. Most waters are of sodium chloride type irrespective of the aquifer, reflecting their derivation (through precipitation) from cyclic salts. This is confirmed by the composition of the major ions of saline groundwater being close to that of seawater.

Table 2. Selected chemical analyses of groundwater.

Bore/well	*pH*	*EC (a) (mS/m at 25°C)*	*TDS (b)*	*Total hardness*	*Total alkalinity*	*Ca*	*Mg*	*Na*	*K*	*HCO_3*	*Cl*	*SO_4*	*NO_3*	*SiO_2*	*B*	*F*
			(mg/L)													
Alluvium																
PB126 (Peter Well – Barnicoat)																
PB7 (Valais – Mount Windarra)	7.8	-	1 550	-	-	80	50	325	34	280	470	280	62	75	-	-
NEA-6c	7.9	16 000	9 100	2 880	160	310	490	2 600	190	160	2 800	1 500	65	92	-	-
NEB-6c	7.5	112 000	73 600	8 400	120	380	1 800	28 000	730	120	36 000	6 500	44	41	-	-
Calcrete																
MMT16 (Cork Tree – Murrin Murrin)	7.6	14 720	9 520	-	260	215	255	2 900	96	260	4 540	1 020	25	76	-	0.5
PB2 (Mount Morgans)	7.6	7 300	4 400	1300	350	135	235	1 640	35	395	205	340	-	-	-	-
JP 60 (Jupiter – Mount Morgans)	7.5	19 200	13 660	-	-	200	370	4 440	120	420	6 660	1 600	66	-	-	-
Eocene sedimentary rocks (palaeochannel sand)																
MMT12 (Cork Tree Deep – Murrin Murrin)	7.2	6 450	4 180	-	225	220	245	820	49	225	1 670	700	16	47	-	0.5
MMT53 (Charlie Well – Murrin Murrin)	7.7	1 970	1 280	-	210	52	48	350	16	210	420	170	21	74	-	0.9
MMT55 (Roy-Valais – Murrin Murrin)	7.5	2 180	1 420	-	210	78	62	330	22	210	490	220	10	-	-	-
MMT139 (Roy-Valais – Murrin Murrin)	8.1	2 000	1 300	-	170	50	48	340	33	170	470	200	11	-	-	-
TPK2 (Korong South – Murrin Murrin)	7.5	1 200	780	-	215	49	42	180	5	215	180	80	23	70	-	0.4
TPK11 (Korong North – Murrin Murrin)	7.7	1 290	820	-	170	42	30	180	13	205	210	76	17	60	-	0.6
NEA-6b	8.0	35 000	19 600	5 080	320	360	1 000	5 600	590	320	8 400	3 300	110	49	-	-
NEB-6b	7.2	169 000	128 700	12 000	48	350	2 800	48 000	1 500	48	65 000	11 000	39	28	-	-
Mount Weld Carbonatite																
B2 (Mount Weld – Granny Smith)	7.4	3 330	2 110	-	-	105	95	555	18	295	750	330	80	24	-	-
Chert and banded iron-formation																
LPB2 (Lancefield – Laverton TWS)	7.5	-	1 010	-	-	47	32	240	10	190	280	120	20	-	-	-
1/90 (Beasley Creek – Laverton TWS)																
SB2 (Southern – Mt Windarra)	7.0	15 400	6 980	-	-	935	680	440	30	250	1 830	3 020	35	-	-	-
Telegraph Shaft																
Granitoid rocks																
NB1 (Northern – Mt Windarra)	7.0	10 800	4 600	-	-	560	280	505	40	210	1 240	1 570	56	-	-	-
Sedimentary, felsic volcanic and volcaniclastic rocks																
DW10 (Goanna Pit – Granny Smith)	7.3	26 000	13 000	-	-	140	210	5 000	80	380	6 300	1 300	5	22	-	1.6
DW16 (Granny Pit – Granny Smith)	7.8	10 000	6 520	-	-	85	110	1 950	54	355	2 900	550	5	20	-	-
DW21 (Windich Pit – Granny Smith)	7.2	81 500	52 500	-	-	385	1 000	15 850	260	275	25 000	2 720	55	-	-	-
Mafic and ultramafic rocks																
IDA H Bore (Barnicoat)	6.6	38 000	23 600	8300	-	570	1 670	11 200	170	510	16 700	7 760	67	-	-	-

Notes: (a) EC=Electrical conductivity; (b) TDS=Total dissolved solids.

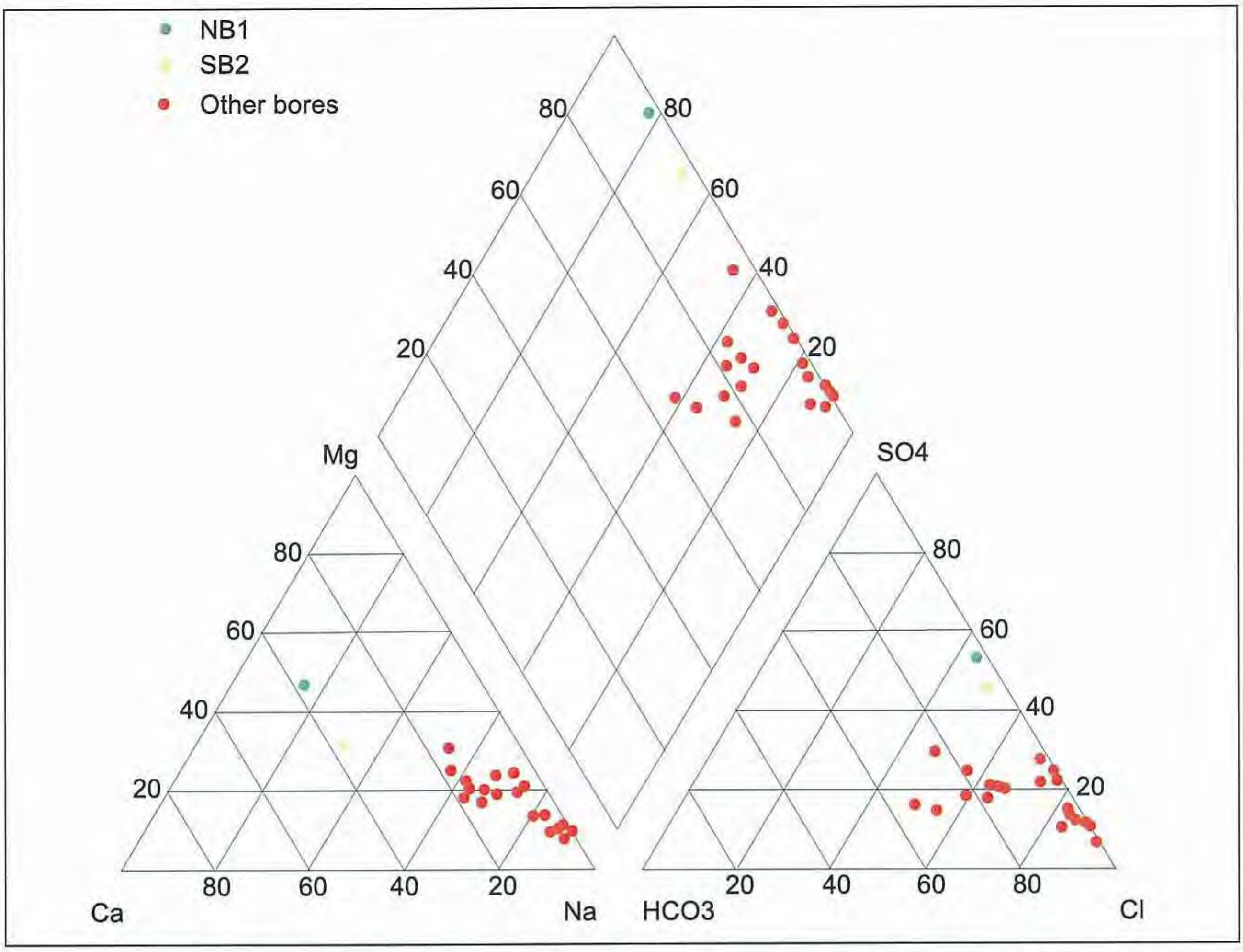

Figure 4. Piper trilinear diagram of selected chemical analyses of groundwaters.

Groundwater from the Mount Windarra area, primarily the Southern and Northern borefields, contains anomalously high proportions of magnesium and sulphate, which is the result of recharge through the highly weathered, sulphide-rich gossanous caprock. The remaining groundwaters show little hydrochemical variation other than an overall increase in the proportion of sodium and chloride along the direction of groundwater flow.

The pH ranges from slightly acidic to slightly alkaline with most groundwater sampled having a pH between 6.6 and 8.1. The preferred alkalinity for carbon-in-pulp and carbon-in-leach circuits for gold ore processing is between pH 9.0 and 9.5. Low groundwater pH, which causes severe metal corrosion, can be raised, usually by adding lime. Conversely, high concentrations of sulphate and magnesium in mine-process water cause scaling problems.

There are relatively high concentrations of nitrate throughout LAVERTON. The analyses listed in Table 2 show that nitrate commonly exceeds the 45 mg/L standard for drinking water, with a maximum concentration of 110 mg/L in the palaeochannel sand aquifer at Transect A. The likely sources of the nitrates may be related to nitrate-fixing bacteria associated with soil crusts and termite mounds (Jacobson, 1993) and to nitrate-fixing vegetation. Locally, around stock watering points, there may be nitrate contamination from animal faeces.

Bores in the alluvium and calcrete aquifers contain high levels of silica, up to 92 mg/L at Transect A, although these are not considered harmful. Fluoride is generally very low, although there are elevated levels in the metasedimentary rocks at Granny Smith gold mine with up to 1.5 mg/L in the Goanna pit.

5 Groundwater development

5.1 Groundwater exploration

Geophysical techniques have been used with varying success to locate palaeochannels on LAVERTON. Seismic and resistivity methods used in the 1970s to determine depth to bedrock and salinity variations in the calcrete aquifers produced satisfactory results. Since the 1980s, gravity and transient electromagnetic methods have proved successful in identifying prospective exploration targets in palaeochannels.

The air-core drilling technique is used extensively in the Northern Goldfields to explore and delineate the palaeochannels; however, many of these drill holes have been abandoned due to running sands. Most production bores are installed using mud-rotary drilling, as this method enables the hydrostatic pressure in the palaeochannel sands to be balanced by the column of mud.

Preliminary exploratory drilling to locate useful water supplies in bedrock areas is usually carried out using rotary air-blast (RAB) and reverse circulation (RC) technologies. The bedrock aquifers normally contain localised groundwater supplies within fractures that are difficult to locate, and therefore require a large number of exploratory bores. The hydrogeology is likely to be complex, reflecting the variety of bedrock types, structure, degree of weathering, and wide range of salinities. Bore yields reflect the degree of fracturing and type of weathering (Table 1).

5.2 Mining

A large number of bores on LAVERTON have been drilled by mining companies to obtain water for mineral processing. The borefields are therefore located close to mining centres and obtain groundwater from alluvium, calcrete, palaeochannel sediments or highly weathered and fractured Archaean bedrock.

The alluvial aquifer is not currently utilised by the mining industry on LAVERTON. The Mount Morgans borefield (Plutonic) has an annual groundwater allocation of 1.15 x 10^6 m^3 and is the only borefield on LAVERTON established in the calcrete aquifer.

The Roy-Valais, Korong North and Charlie borefields at Murrin Murrin are the major borefields developed in the palaeochannels on LAVERTON with a groundwater allocation of about 13.5 x 10^6 m^3/yr. The Roy-Valais and Charlie borefields consist of 62 production bores that provide process water to the laterite nickel operation and have an combined annual allocation of 12.8 x 10^6 m^3. While, the Korong North borefield comprises six production bores that were utilised primarily during the initial stages of mine development.

There has been extensive groundwater exploration in the Korong South and Cork Tree Palaeochannels as part of the Murrin Murrin process water supply. However, at the time of writing, there had been no development of these resources.

The largest groundwater supplies are found in Tertiary palaeochannel aquifers. The groundwater in storage in the palaeochannels is very large when compared with the estimated recharge. Johnson *et al.* (1999) noted that drawdown in these borefields throughout the Northern Goldfields has been lower than predicted from short-term pumping tests, indicating that there is significant inflow from tributaries, weathered and fractured bedrock, and by leakage from the overlying sediments. In most pumping tests, the aquifer responses indicate confined conditions that are likely to remain after several years of pumping.

Groundwater allocation from fractured and weathered bedrock, including mine dewatering, was estimated to be about 10 x 10^6 m^3 in 1997. The Mount Weld borefield, and dewatering of mining operations at Granny Smith and Barnicoat, are the most prominent areas of groundwater development in the highly weathered and fractured bedrock.

Groundwater obtained from mine dewatering is also used for ore processing and mining requirements. Detailed information on groundwater abstraction related to mine dewatering on LAVERTON is limited. In 1997, the major mine dewatering activities on LAVERTON were at Granny pit (Granny Smith) abstracting about 0.9 x 10^6 m^3 (Dames And Moore, 1997a) and Keringal pit (Granny Smith) abstracting 0.4 x 10^6 m^3 (Dames And Moore, 1997b) from combinations of dewatering bores and in-pit sumps. Dewatering will result in major changes to the groundwater regime where pits are being excavated below the watertable. On cessation of mining and dewatering, these pits will eventually fill with water to the level of the regional watertable.

Seepage of highly concentrated saline water may occur from unlined dams associated with the disposal of tailings. Current practice is to line the tailings ponds to minimise leakage, and keep the salts stored within the tailings. Other potential contaminants include cyanide and metal-cyanide complexes.

5.3 Potable

The water supply for Laverton is obtained from two production bores in the Beasley Creek borefield and Telegraph Shaft at the abandoned WMC Lancefield Operations. Both bores, and the shaft, draw groundwater from a fractured chert aquifer. The borefield and shaft are operated and maintained by the Water Corporation, with groundwater abstraction in 1991/92 having been 0.31 x 10^6 m^3. Salinity of the scheme ranges between 800 and 1300 mg/L TDS, with elevated levels during periods of high demand.

In 1992, declining water levels were observed in the Beasley Creek borefield and Telegraph Shaft, suggesting that groundwater abstraction was exceeding recharge (WAWA, 1992). In order to reduce demand on these groundwater sources, a production bore (LPB2) was established in the chert aquifer to the north of Telegraph Shaft. The addition of this production bore at Lancefield has ensured the long-term groundwater supply to Laverton.

In 1983/84, the Water Corporation conducted groundwater exploration in the Skull Creek area, about 5 km east of Laverton. There were six production bores installed in the shallow alluvial aquifer, although they have not been equipped because of high salinity and low bore yields.

Sufficient supplies of potable to marginal groundwater are available acceptably close to mine sites throughout LAVERTON, with the majority of domestic water supplies on mine sites being abstracted from fractured-rock aquifers. In localities where there are poor prospects for locating potable water, small-scale desalination of groundwater can also be used for some domestic supplies.

5.4 Pastoral

The pastoral industry, with about 200 bores and wells, is an important groundwater user on LAVERTON. The distribution of stock-watering points has been dictated more by the foraging range and by paddock system on the pastoral properties than by the availability of groundwater (Allen, 1996). In general, groundwater supplies are easily obtained, but many exploratory sites have been abandoned due to poor drilling conditions, inadequate supplies, or unacceptable salinity (Morgan, 1966).

Most bores and wells used by the pastoral industry are less than 30 m deep, and are typically equipped with windmill-powered pumps that yield up to 20 m^3/day. The alluvium and calcrete deposits are the most extensively utilised aquifers on account of their shallow watertables (<10 m below surface) and low groundwater salinity. Groundwater suitable for stock-watering, up to 5000 mg/L TDS, is readily obtainable throughout the area except in the centres of the palaeodrainages, where water of salinity of 8000 mg/L TDS is used.

5.5 Further development

The palaeochannel sand aquifer is considered to be the most prospective aquifer for further development on LAVERTON. It is readily located, exploited and managed, and sustainable yields are much more likely than from weathered and fractured bedrock. The groundwater resources in the Raeside and Carey Palaeodrainages are sufficient for current and planned mining developments, although many of the tributaries are being increasingly exploited for laterite-nickel ore processing.

The calcrete aquifer has potential for further development on LAVERTON. There are significant stored groundwater resources in the thick calcrete deposits at Mount Morgans and north of Mount Windarra. The remaining calcrete bodies are poorly saturated with the only development potential being for the pastoral industry.

There is only localised potential for further development in the alluvium owing to its silty nature and low permeability. In addition to direct utilisation, groundwater can also be obtained from the alluvium through leakage into underlying palaeochannel and fractured-rock aquifers during aquifer depressurisation. Colluvial deposits, adjacent to bedrock outcrops, may be suitable for a small-scale groundwater supply.

There appears to be little potential for further large-scale development in the current borefields established within the weathered and fractured bedrock. Low-salinity groundwater can be found in elevated areas of the greenstone belts. The best prospects for locating large supplies of groundwater are in highly weathered profiles developed on ultramafic rocks, and along the contact zones between granitoid and greenstone rocks.

6 Groundwater resources

The groundwater resources of the Northern Goldfields, including those on LAVERTON, are detailed in Johnson et al. (1999). Because the annual recharge from rainfall is very small, groundwater resources on LAVERTON are considered in terms of groundwater held in storage. However, only a proportion of this groundwater is economically recoverable.

The alluvial and colluvial deposits contain by far the largest groundwater resources in the Northern Goldfields. Based on a specific yield of 0.05 and a saturated thickness of 10 m, groundwater storage in the alluvium on LAVERTON is estimated at about 2400 x 10^6 m^3 (Johnson *et al.*, 1999). On a regional scale, groundwater resources in the alluvium probably represent about 65% of the total groundwater resources on LAVERTON.

Groundwater storage in the calcrete aquifer was estimated using a specific yield of 0.1 and a saturated thickness of 5 m. This amounts to a total of groundwater in storage of about 100 x 10^6 m^3 within the calcrete on LAVERTON. Groundwater in the calcrete probably represents about 3% of the total groundwater resources of the area.

The palaeochannels on LAVERTON contain significant groundwater resources held in storage. Based on a specific yield of 0.2, this groundwater storage is estimated at 960 x 10^6 m^3 for 631 km of palaeochannel length (Johnson *et al.*, 1999). The groundwater storage of 1.5 x 10^6 m^3 per kilometre of palaeochannel is comparable with estimates by Commander *et al.* (1992) for the Roe Palaeodrainage. The estimated volume of groundwater in storage is conservative because it does not include groundwater made available by pumping-induced inflow from the surrounding weathered and fractured bedrock, or by leakage from the overlying alluvium and calcrete. Hence, groundwater in the palaeochannels probably represents about 25% of the total groundwater resources on LAVERTON.

The potential resources in weathered and fractured bedrock are difficult to estimate reliably on a regional scale because of their localised and discontinuous nature. Hence, Johnson *et al.* (1999) estimated stored groundwater resources within regional fracture systems using a number of assumptions for specific yield and aquifer dimensions. From this they calculated the total groundwater storage in the weathered and fractured bedrock on LAVERTON to be about 200 x 10^6 m^3. It is likely that groundwater in the bedrock represents about 5% of the total groundwater resources of the area.

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Appendix 1

LAVERTON 1:250 000 hydrogeological series digital data reference files and documentation

Design file	Level	Description	Scale of capture (where applicable)
Lavtopo.*dgn*	L1	Roads, highway	
	L2	Tracks	
	L5	Cross section transects	
	L6	Airport, landing grounds	
	L11	Dams, tanks	
	L17	Pools, waterholes, rock holes, gnamma holes	
	L20	Intermittent lakes (simplified) and names	
	L21	Creeks, rivers and names	
	L22	Permanent lakes	
	L30	Mine names	
	L31	Mining symbols	
	L32	Mining centre names	
	L41	Localities	
	L42	Road and highway names	
	L43	Mountains, hills, ranges, trig points, rock names	
	L44	Control points; major and minor	
	L45	AMG grid	
	L60	Neatline, latitude and longitude lines	
	L62*	Documentation	
	L63*	Alignment for text around map edge	
Lavhydro.*dgn*	L1*	Geological boundaries	1:500 000
	L2*	Outcrop boundary	1:500 000
	L3	Hydrogeological linework	
	L4	Hydrogeological labels	
	L5	Faults	1:500 000
	L6	Linework and labels for outcrop	
	L7*	End of palaeochannels	
	L11*	Palaeochannels	
	L16*	Remaining linear geology	1:500 000
	L17	Chert and banded iron-formation	1:500 000
	L18	Dolerite dykes	1:500 000
	L45	AMG grid – map and side panels	
	L60	Legend, latitude and longitude text	
	L62	Documentation	
Lavsal.*dgn*	L1	Salinity linework	1:250 000
	L2*	Salinity labels	
	L10	<1000 mg/L colour fill	
	L11	1000–3000 mg/L colour fill	
	L12	3000–7000 mg/L colour fill	

LAVERTON 1:250 000 hydrogeological series digital data reference files and documentation (cont...)

Design file	Level	Description	Scale of capture (where applicable)
	L13	7000–14 000 mg/L colour fill	
	L14	>14 000 mg/L colour fill	
	L20	Salt lakes	
	L45	AMG grid	
	L60	Scale bar	
	L62*	Documentation	
Lavwc.*dgn*	L45	AMG grid	
	L50	Catchment divide	
	L53	Direction of groundwater flow	
	L54	Isopotential lines	
	L55	Isopotential labels	
Lavbores.*dgn*	L1*	Wells from Geonoma	
	L2*	Bores from Geonoma	
	L3*	AQWABase wells	
	L4*	AQWABase bores	
	L5*	Exploration bores — no borefield	
	L6*	Exploration bores — borefield	
	L7*	Old exploration bores — replaced	
	L8*	Monitoring bores	
	L9*	Old production bores — replaced	
	L10*	Production bores >50 m^3/day	
	L11*	Abandoned production bores>50 m^3/day	
	L12*	Production bores — potable	
	L13*	WRC bores	
	L14*	Unknown data point source	
	L15*	Position uncertain	
	L16*	Mine shaft	
	L17*	Main Roads bores	
	L18*	Dewatering bores	
	L19*	Wells – not stored in Geonoma	
	L20*	Bores – not stored in Geonoma	
	L25	Bore names	
	L30	Wells (data from L1)	
	L31	Bores <50 m^3/day (data from L2,5,6,7,17)	
	L32	Production bores >50 m^3/day (data from L10, 12)	
	L33	Abandoned production bores (data from L9, 11)	
	L35	WRC and mining company transects	
	L36	Water pipelines	
	L37	Borefield names	
	L45*	AMG grid	
	L62*	Documentation	

*Note: information not shown on printed map.

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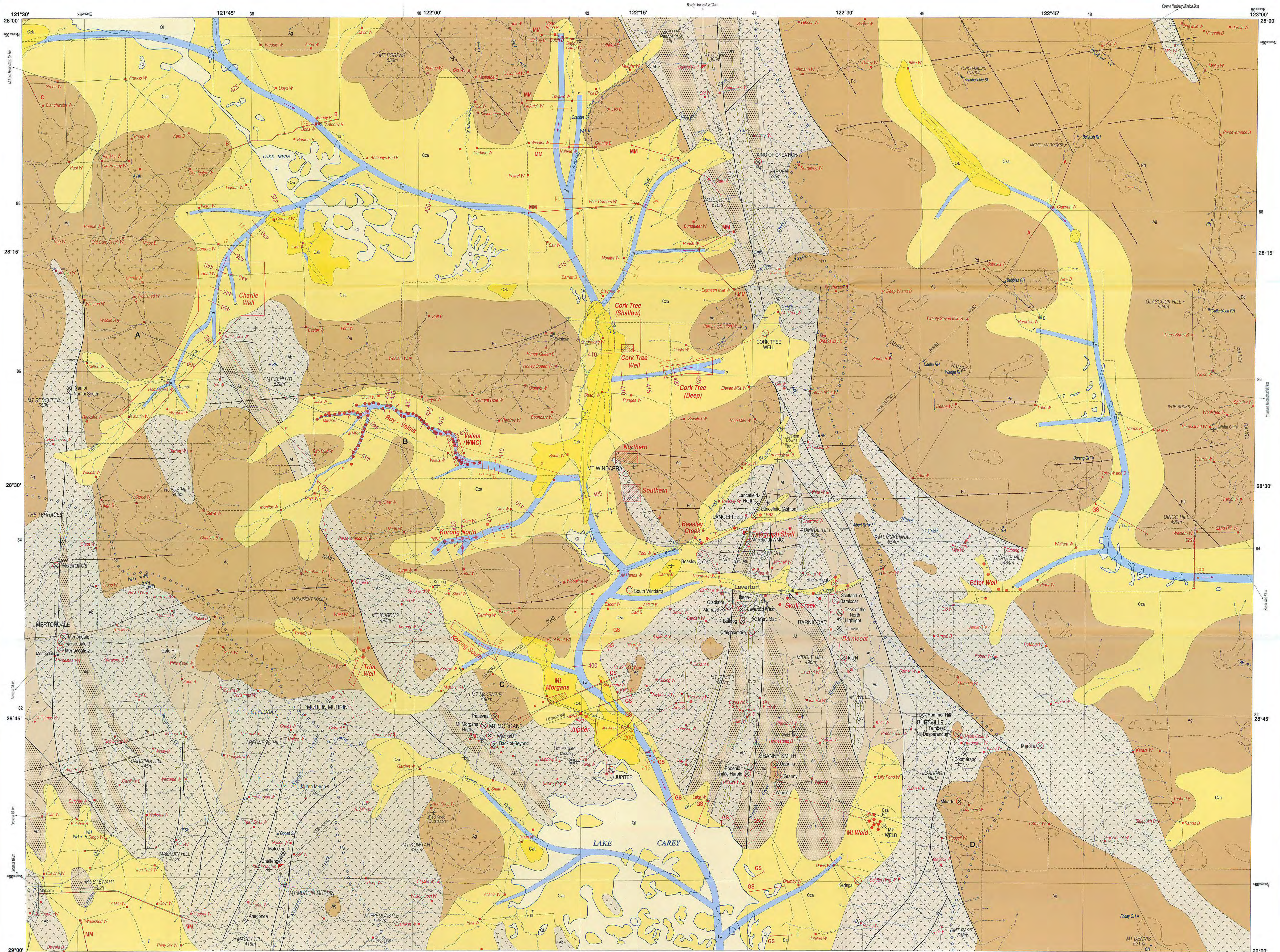
1 : 250 000 HYDROGEOLOGICAL SERIES

LAVERTON

WATER AND RIVERS COMMISSION

SHEET SH 51-2



REFERENCE

AQUIFER TYPES

	Surficial deposits — local aquifers, minor to major groundwater resources
	Sedimentary aquifer in palaeochannels — major aquifer, major groundwater resources
	Sedimentary aquitard in palaeochannels — no groundwater resources (section only)
	Fractured and deeply weathered rocks — local aquifers, minor groundwater resources, locally large supplies from fracture zones and permeable horizons in weathering profile

HYDROGEOLOGY

Era	Period	Symbol	Description	Aquifer
PHANEROZOIC / CAINOZOIC	QUATERNARY	Ql	Playa lake sediments — mostly clay	Minor shallow aquifer, possible small supplies in sands; hypersaline
		Cza	Alluvium and colluvium — clay, silt and sand, minor gravel; conceals palaeochannels	Major shallow aquifer; fresh to hypersaline
		Czk	Calcrete — often with extensive karst development	Significant local aquifer; fresh to saline
	EARLY TERTIARY	Tp	Clay — minor sands; restricted to palaeochannels (section only); equivalent to PERKOLILLI SHALE	Aquitard
		Tw	Sand — restricted to palaeochannels; concealed by palaeochannel clay; equivalent to WOLLUBAR SANDSTONE	Major aquifer; fresh to hypersaline
PROTEROZOIC		Pm	MT WELD CARBONATITE — concealed by alluvium (section only)	Major local aquifer; brackish to saline
		Pd	Mafic and ultramafic dykes: interpreted	Very minor local aquifer; brackish to saline
ARCHAEAN		Ag	Granitoid rock; outcrop (indicated by overprint); generally weathered to sandy clay	Local aquifer; fresh to saline
		Ac	Chert and banded iron-formation	Major local aquifer; fresh to saline
		As	Metasedimentary rocks	Minor local aquifer; brackish to saline
		Af	Felsic volcanic and volcaniclastic rocks	Minor local aquifer; brackish to saline
		Ab	Mafic rocks	Minor local aquifer; fresh to saline
		Au	Ultramafic rocks and weathered equivalents	Major local aquifer; fresh to saline

YILGARN CRATON

SYMBOLS

GEOLOGY

hydrogeological boundary
inferred hydrogeological boundary
extent of weathering (section only)
fault or shear zone

SURFACE WATER FEATURES

intermittent drainage
surface water divide
playa lake
RH GH WH — rockhole, gnamma hole, waterhole
Sp Sk — spring, soak
D T — dam, tank
P — water pipeline

GROUNDWATER FEATURES

450 — isopotential (m AHD)
direction of groundwater flow
watertable (section only)
3 — isohaline in palaeochannel (TDS g/L)
206 — salinity in palaeochannel (TDS g/L)

MINING INFORMATION

underground mine, opencut
MT MORGANS — mining locality
Westralia — mine name

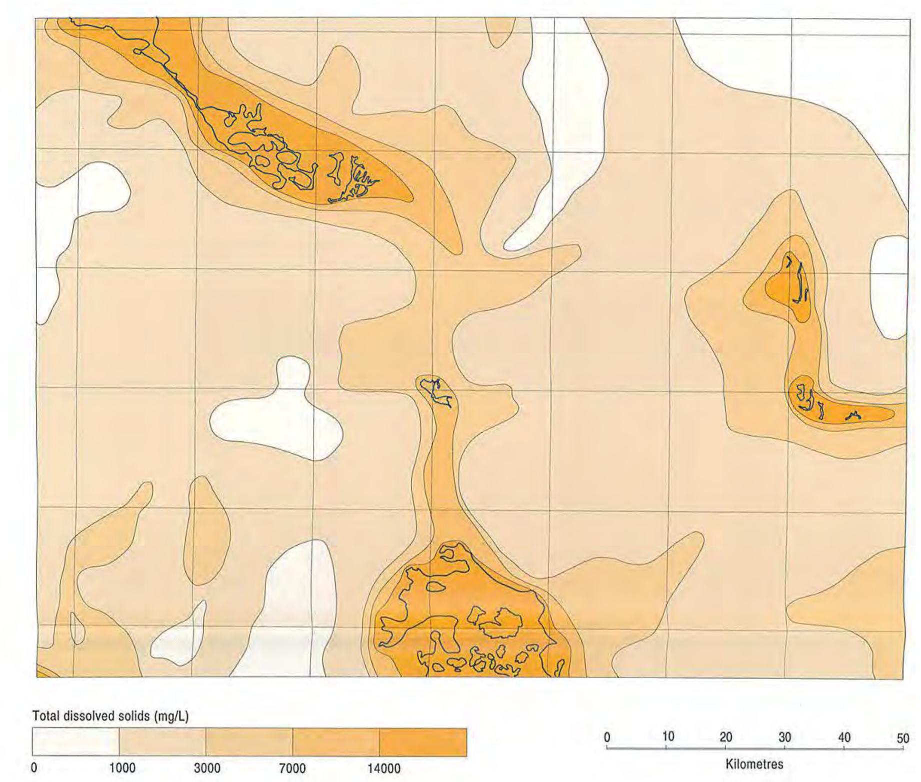
ARTIFICIAL FEATURES

MMP3 — production bore; yield >50 m³/day
abandoned bore; yield >50 m³/day
bore
well, shaft
area of detailed groundwater investigation
borefield (currently in use)
borefield (disused)
Mt Weld — borefield name, cluster of bores
A — WRC exploratory line
MM — Murrin Murrin exploratory line
GS — Granny Smith exploratory line
storage reservoir
P — groundwater pipeline, disused
mine dewatering

TOPOCADASTRAL INFORMATION

sealed road
graded road
track
airfield, landing ground
Laverton — townsite, population less than 10 000
Mt Morgans — homestead

GROUNDWATER SALINITY



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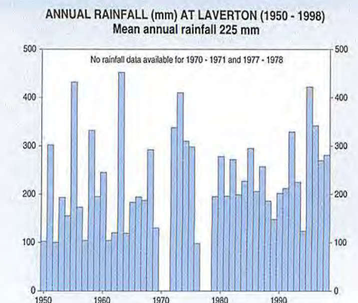
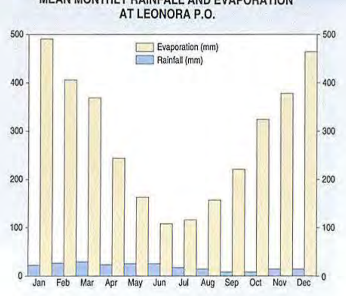
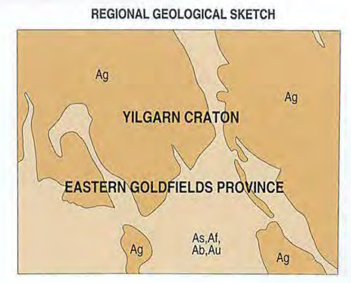
ANNUAL RAINFALL (mm) AT LAVERTON (1950 - 1998)
Mean annual rainfall 225 mm



MEAN MONTHLY RAINFALL AND EVAPORATION AT LEONORA P.O.



REGIONAL GEOLOGICAL SKETCH



Hydrogeology by S.L. Johnson, 1999
Geology by C.F. Gower, 1976

Edited by R. Duberal

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Topography from the Department of Land Administration Sheet SH 51-2 with modifications from geological field survey

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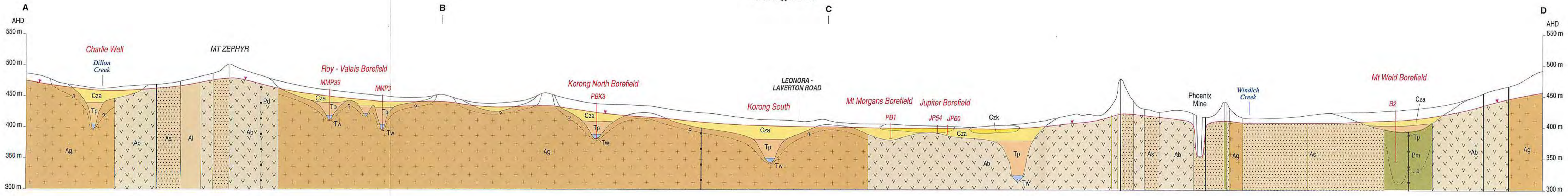
DIAGRAMMATIC SECTION

Vertical exaggeration x 50



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MINISTER FOR WATER RESOURCES

WATER AND RIVERS COMMISSION
R. PAYNE
CHIEF EXECUTIVE OFFICER

SCALE 1: 250 000

5000 Metres 0 5 10 15 20 25 30 Kilometres

TRANSVERSE MERCATOR PROJECTION

Grid lines indicate 20 000 metre interval of the Australian Map Grid Zone 51

1:250 000 HYDROGEOLOGICAL SERIES

LAVERTON

SHEET SH 51-2

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