HYDROGEOLOGY OF THE LEONORA 1:250 000 SHEET

DEPARTMENT OF ENVIRONMENT
HYDROGEOLOGICAL MAP EXPLANATORY NOTES SERIES
HM 10
2004

Department of
Environment

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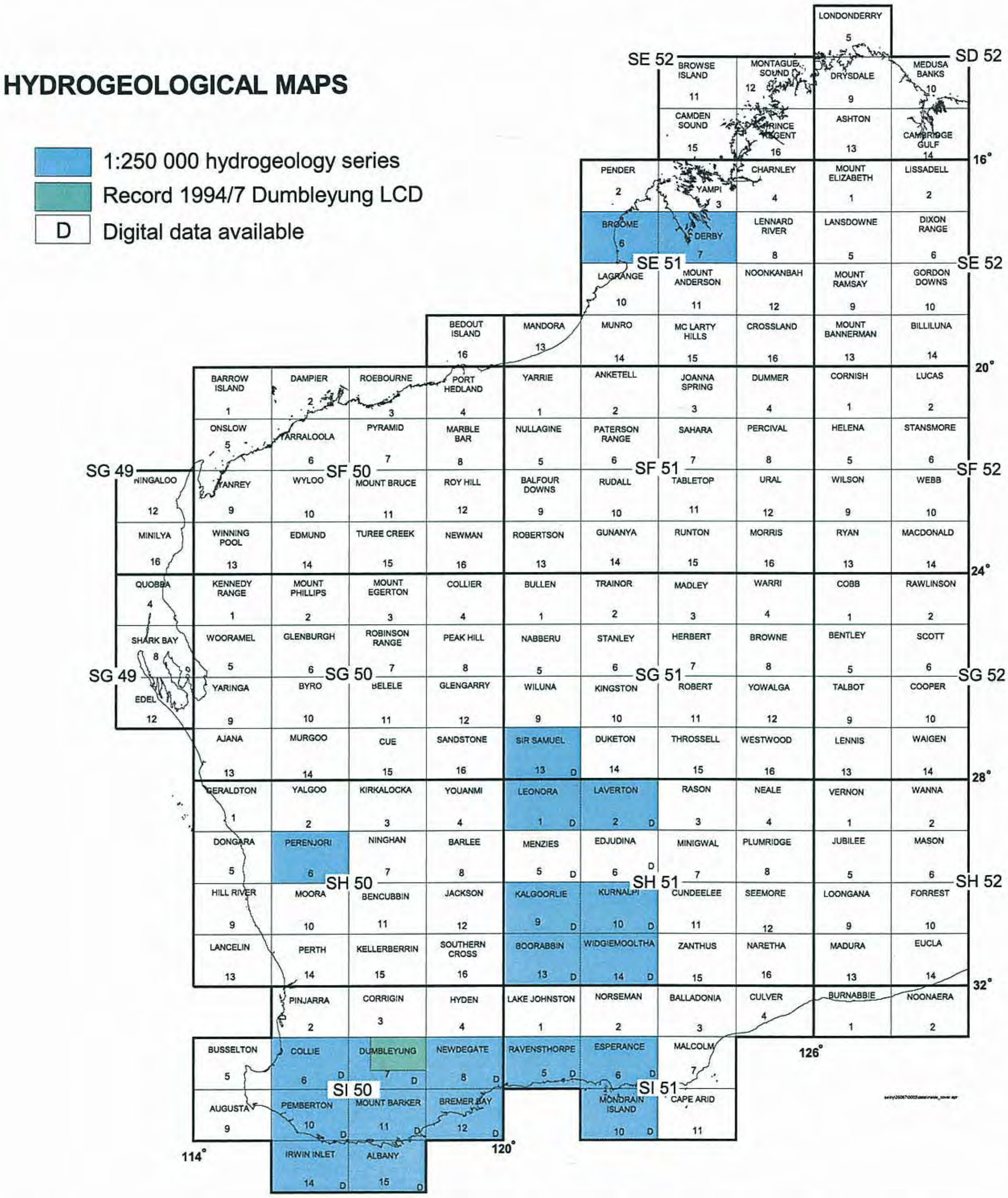

Cover Photograph: Abandoned cable tool drilling rig at Mulga Well in northwest portion on LEONORA.

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LEONORA 1:250 000 hydrogeological sheet ....(back pocket)

HYDROGEOLOGY OF THE LEONORA 1:250 000 SHEET

by

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Abstract

The LEONORA 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 LEONORA 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 LEONORA. 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 LEONORA is fresh to 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 fresh to brackish groundwater in the tributaries 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 LEONORA to provide water to the town of Leonora and the mining industry.

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

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1 Introduction

1.1 Location

The LEONORA[1] hydrogeological sheet (SH 51-1 of the International Series), which is bounded by latitudes 28°00' and 29°00' S and longitudes 120°00' and 121°30' E, lies within the northern part of the Eastern Goldfields Province of Western Australia. The map sheet takes its name from the mining town, Leonora, located in the southeastern corner of the sheet.

Mining is the major activity of the region with most of the population concentrated in Leonora. The remainder of the sheet is sparsely populated, except for individual pastoral homesteads and scattered mining operations at Agnew, Lawlers and Tarmoola.

The sheet area is reached via the Goldfields Highway linking Wiluna in the north to 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 37°C and an average minimum of 22°C at Leonora. July is the coolest month with an average maximum temperature of 18°C and an average minimum of 6°C. Frost occasionally occurs during the winter months.

The average annual rainfall is 229 mm at Leonora, 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 3600 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 350 and 550 m AHD (Australian Height Datum). Throughout LEONORA numerous granite monadnocks protrude slightly above the land surface, and greenstones and banded iron-formation form prominent hills and ridges such as Mount Clifton (554 m AHD) and Junior Hill (519 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 LEONORA, these palaeorivers form two distinct drainage systems, or palaeodrainages (Fig. 1).

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

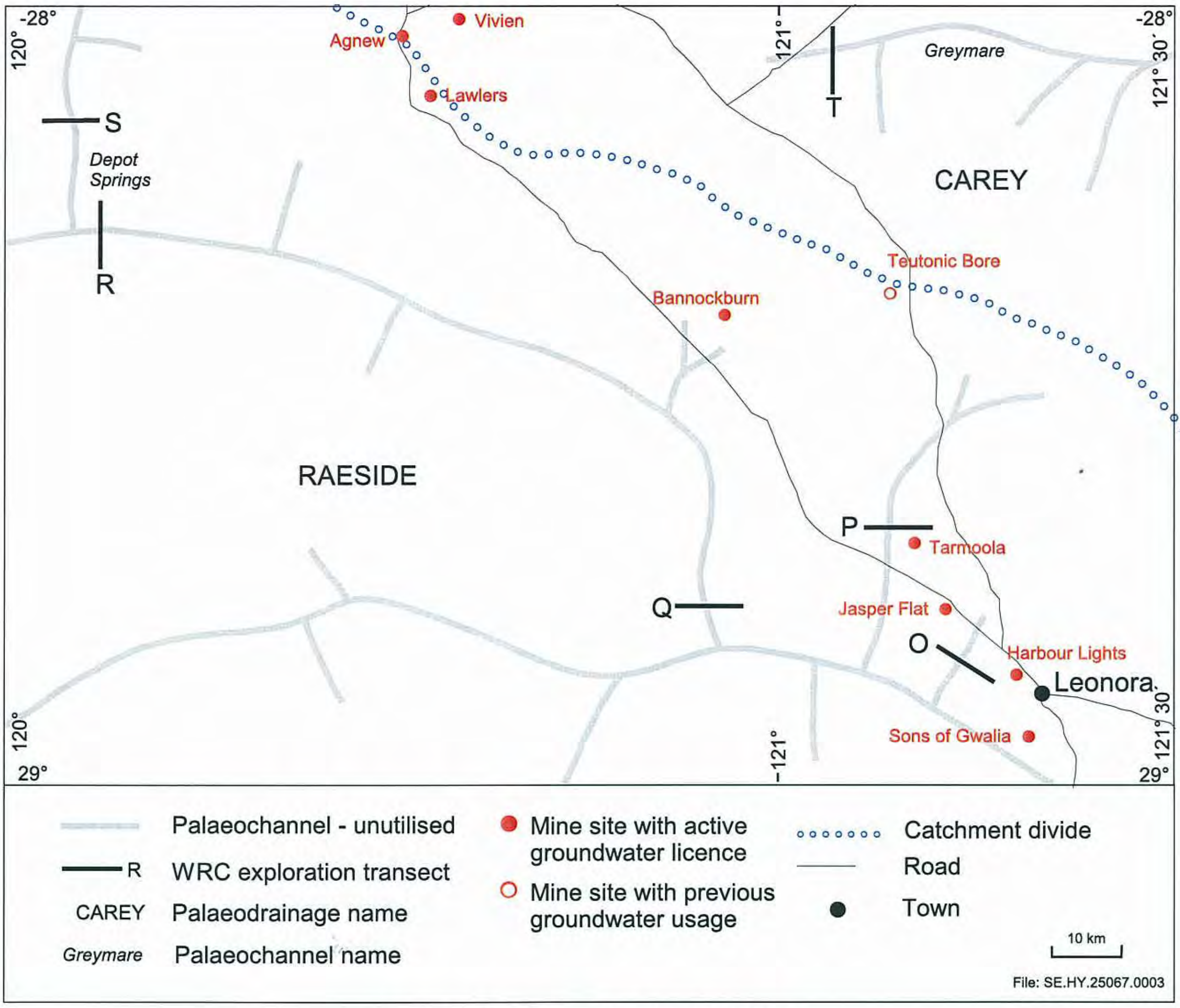

Figure 1. Location and palaeodrainages.

A major surface-water divide crossing LEONORA separates the Carey 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 both the Carey and Raeside 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 LEONORA 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 contribution to understanding the regional geology on LEONORA was by E. de C. Clarke (1925), who mapped the eastern portion of the sheet area. There are also numerous reports by Geological Survey of Western Australia (GSWA) staff that described the geology of gold-mining areas at Sons of Gwalia mine (south of Leonora), Lawlers, Agnew and Teutonic Bore. The first edition of the LEONORA geological sheet was compiled in 1975 (Thom and Barnes, 1977) 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 Young, 1966). Griffin (1990) outlined the regional geology of the Eastern Goldfields Province. The entire LEONORA sheet was remapped at 1:100 000 scale between 1991 and 1996 by the Australian Geological Survey Organisation (now Geoscience Australia) (Williams, 1993; Duggan, 1996a,b; Duggan *et al.*, 1996, Oversby, 1996; Oversby *et al.*, 1996). In addition, the southeastern 1:100 000 sheet area (Leonora) was also remapped at 1:50 000 scale by Hallberg (1985).

The first description of the regional hydrogeology and the availability of groundwater was detailed by Morgan (1966), who undertook bore siting for various pastoral leases. The calcrete aquifers on LEONORA 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).

In the early 1900s, the first groundwater exploration was conducted in the Station Creek area, 12 km north of Leonora, by the Mines Water Supply Branch (Department of Mines – now Department of Industry and Resources) to meet the potable water requirements of prospectors and pastoralists. The existing town water supply (TWS) for Leonora is located in this alluvial aquifer at Station Creek and has been extensively explored and developed by the Water Corporation (formerly Water Authority of Western Australia).

Considerable groundwater exploration and development has been carried out on LEONORA for the mining industry over the past thirty years. Geotechnics (1972) conducted a large groundwater exploration program to evaluate the groundwater resources of the Agnew area for WMC and the Public Works Department (PWD). This study focused on the Depot Springs area, in the northeast corner of LEONORA, and employed resistivity surveys prior to drilling (Cowan and Omnes, 1975).

Borefields have been established for mining developments throughout the region, with a large amount of work having been carried out for the gold operations at Agnew, Lawlers and Sons of Gwalia mines. Recent groundwater exploration has concentrated on locating water supplies in palaeodrainages, particularly within the Grey Mare, Station and Sullivan Palaeochannels for the Murrin Murrin nickel operation on LAVERTON.

1.6 Map compilation

The hydrogeological map of LEONORA 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 (Thom and Barnes, 1977); 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 LEONORA 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 within mine production borefields, whilst areas with limited pastoral bore distribution have only reliable salinity information.

2 Geology

2.1 Regional setting

The LEONORA 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 LEONORA. The Archaean bedrock is poorly exposed on LEONORA 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.

Proterozoic mafic and ultramafic dykes (*P̲d*) intrude the granite–greenstone terrane throughout LEONORA. 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, which is commonly 30–40 m thick, reaches about 120 m in the Fairyland Gold Mine (Rockwater, 1997). 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 and Raeside Palaeodrainages on LEONORA 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 40 m beneath Transect R, 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 reaches a thickness of 70 m thick beneath Transect Q. 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 on LEONORA from 100 m in Transect T and to over 1000 m in Transect Q, and are up to 125 m deep where bedrock is deeply incised.

2.3.2 Surficial deposits

A variety of Cainozoic surficial deposits (*Ql*, *Cza* and *Czk*) are encountered on LEONORA, where they form a veneer over the Archaean and Tertiary rocks. Cainozoic surficial deposits that occur 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 LEONORA.

Alluvial and colluvial deposits (*Cza*) are widespread throughout LEONORA. The unit has a variable thickness of up to 60 m beneath Transect R (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). Thin deposits of colluvium, less than 20 m at Transects O and P, form along the flanks of greenstone ridges and comprise subrounded, iron-stained gravels and angular rock fragments within a clay matrix (Johnson *et al.*, 1998).

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, except in the Depot Springs Palaeochannel, where up to 40 m of calcretised alluvium has been identified (Geotechnics, 1972). 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 LEONORA 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, ultramafic and granitoid rocks than in sedimentary or felsic volcanic and volcaniclastic rocks. The maximum depth to which open fractures penetrate is 200 m in the Sons of Gwalia underground operations, south of Leonora. Groundwater can be inferred to occur to a similar depth along major faults and shear zones. Vuggy weathering profiles developed in ultramafic volcanic rocks also constitute an important local aquifer.

Minor mafic and ultramafic dykes occur in the western half of LEONORA. 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 alluvial aquifer has low permeability owing to its clayey nature, the calcrete can often provide large local supplies of fresh to brackish groundwater 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 LEONORA 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 LEONORA. 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, and 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.

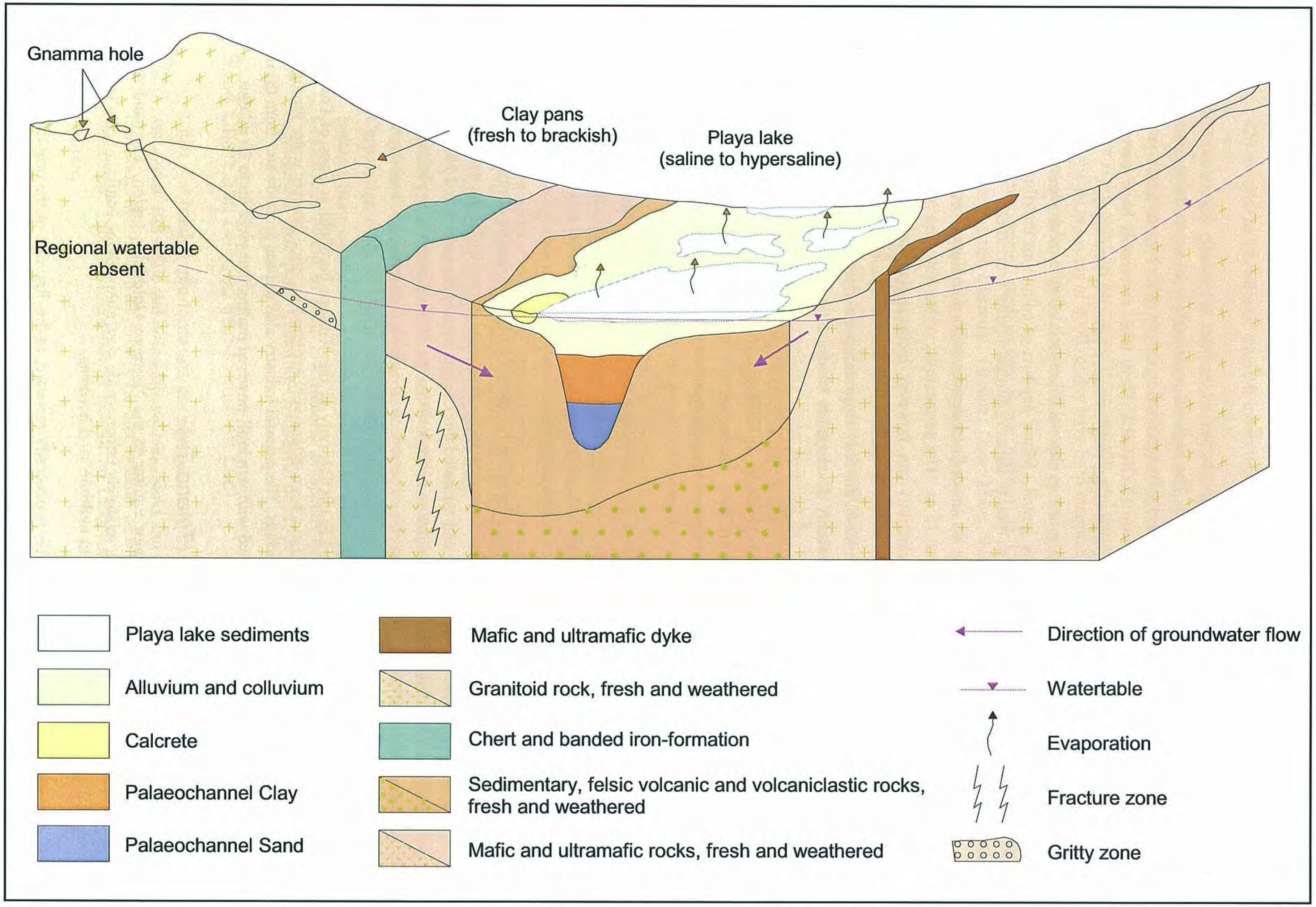

Figure 2. Schematic section showing groundwater occurrence.

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 LEONORA. 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 600 m^3/day, reflecting the variability in hydraulic conductivity. Short-term yields up to 1200 m^3/day have been recorded during pumping tests on LEONORA. The largest yields are from unconsolidated, clayey, rounded basaltic gravels that form colluvial deposits at the base of greenstone ridges, such as those intersected on Transects O and P (Johnson *et al.*, 1998).

The aquifer has been directly utilised on LEONORA in the Snowys Well borefield at Tarmoola, old Harbour Lights borefield in Station Creek and Marshall borefield at Bannockburn. Groundwater can also be obtained from the alluvium through leakage into underlying palaeochannel and fractured-rock aquifers, such as in the Leonora TWS borefield at Station Creek.

Calcrete (*Czk*) is an important local aquifer in the Northern Goldfields capable of providing large supplies of brackish 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 at Depot Springs (Geotechnics, 1972) ranged from less than 100 m^3/day in massive calcrete to 4400 m^3/day in highly karstic calcrete.

The calcrete aquifer is utilised on LEONORA only in the Western borefield at Sons of Gwalia mine, although numerous calcrete bodies have been extensively explored for mine-process water throughout the sheet area, primarily near Depot Springs. 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 is the major aquifer in the Northern Goldfields region. The sand aquifer is confined throughout LEONORA by relatively impermeable clay, although the confining clay layers in the tributaries are often silty and contain multiple sand horizons.

Groundwater flow in the sand aquifer is generally eastward, in the direction of the original drainage. The potentiometric surface in the Raeside Palaeodrainage falls from 395 m AHD at Transect R to about 350 m

AHD beneath Lake Raeside near Leonora. Also, the potentiometric surface in the Grey Mare Palaeochannel, a tributary of Carey Palaeodrainage, falls from about 470 m AHD at Transect T to about 420 m AHD at Transect C, where it meets the main trunk of the Carey Palaeodrainage.

The hydraulic gradient in the Raeside Palaeodrainage is steepest (0.4 m/km) in the upper reaches of the tributaries, where the palaeochannel narrows. 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 1000 m^3/day (Table 1). Short-term yields in excess of 2000 m^3/day have been recorded during pumping tests on LEONORA with larger yields dependent on grain size, thickness and extent of sand.

The palaeochannel sand aquifer is not utilised on LEONORA; however, there has been extensive exploration in the Charcoal, Granite, Grey Mare, Sullivan and Station Palaeochannels to meet the groundwater requirements of the Murrin Murrin nickel operation.

3.2.3 Granitoid rocks (*Ag*)

Granitoid rocks, which occupy about 60% of LEONORA, 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 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 1500 m^3/day, are available from lineaments, probably faults or shear zones, within the granitoids and at the contact with greenstone rocks.

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.

The Daisy Queen borefield at Lawlers Gold mine is located along a lithological contact between greenstone and granitoid rocks. Most bores in the Station Creek borefield operated by the Water Corporation are developed in sandy and permeable horizons of a weathered granite that receive downward leakage from overlying saturated alluvium. In general, the granitoids are poorly explored throughout LEONORA owing to their low mineral prospectivity and poor groundwater prospects due to their homogeneity and sparse fracturing (Johnson *et al.*, 1999).

3.2.4 Chert and banded iron-formation (*Ac*)

Chert and banded iron-formation are common only in the eastern half of LEONORA, where they are associated with mafic and ultramafic volcanic rocks and form prominent narrow ridges. Chert and banded iron-formation have well-developed joint systems as a result of brittle deformation, and are not deeply weathered. They have not been explored on LEONORA, but may have local potential as fractured aquifers.

3.2.5 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 felsic extrusive rocks are well represented in the Teutonic Bore area and include dacite, schists and felsic tuffs that tend to be foliated, relatively unjointed and form fine-grained weathering products. The metasedimentary rocks lie primarily to the northeast of Leonora and comprise quartz-rich siltstones, sandstones and conglomerates that are fine grained, strongly deformed and deeply weathered.

All the dewatering bores at Teutonic Bore intersect fractures and lithological contacts between felsic volcanic and metasedimentary rocks. Most bores in the Sons of Gwalia Eastern borefield are positioned in fractures and quartz veins within the highly schistose, felsic volcanic rocks. 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.

3.2.6 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 concentrated mainly in the Agnew area and include dunite, talc schists and talc-carbonate rocks that are typically thin, deeply weathered and poorly exposed. In places, a porous siliceous caprock has developed by weathering of the underlying ultramafic (dunite) rock (Whincup and Domahidy, 1982).

The watertable is deep in the upper reaches of the catchments and reaches a depth of 35 m in the Emu borefield (Puretech, 1998). Groundwater levels in mine shafts sunk in mafic and ultramafic rocks can also be deep, as the mines are sometimes located in elevated areas.

The Emu borefield at Agnew is developed in weathered and fractured basalt with a small number of bores in the siliceous caprock aquifer. The Fairyland borefield at Lawlers gold mine is established in the vuggy siliceous caprock aquifer, which is capable of bore yields up to 1500 m^3/day. In general, the mafic and ultramafic aquifers are poorly explored and developed throughout the sheet area.

4 Groundwater quality

4.1 Salinity

4.1.1 Regional variation

The distribution of groundwater salinity on LEONORA 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 data set 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 LEONORA 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.

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	Marshall Creek	Bannockburn	6	30 – 43	200 – 500	805 – 1465
	Snowys Well	Tarmoola	10	33 – 42	200 – 500	560 – 2200
	Station Creek	Harbour Lights	9	34 – 43	200 – 800	1120 – 2240
Calcrete	Western	Sons of Gwalia	4	17 – 34	100 – 700	29000 – 86100
	Depot Springs	–	–	26 – 47	600 – 4400	710 – 28800
Eocene sedimentary rocks	Charcoal	Murrin Murrin	–	58 – 87	250 – 1000	1190 – 4400
	Granite	Murrin Murrin	–	72 – 81	60 – 670	1000 – 3950
	Grey Mare	Murrin Murrin	–	41 – 82	140 – 1000	940 – 2700
	Station	Murrin Murrin	–	70 – 98	105 – 850	1700 – 33000
	Sullivan	Murrin Murrin	–	76 – 103	250 – 1050	1930 – 30000
Felsic volcanic and metasedimentary rocks	Eastern	Sons of Gwalia	8	81 – 99	250 – 600	3200 – 118600
Granitoid rock	Daisy Queen	Lawlers	3	62 – 86	600 – 1400	2160 – 2780
	Leonora TWS	–	12	40 – 60	190 - 500	1210 – 1350
Ultramafic and mafic rocks	Emu	Agnew	8	55 – 72	190 – 1250	460 – 1040
	Fairyland	Lawlers	3	80 – 88	> 1200	520 – 600
	Lawlers	Lawlers	2	80 – 88	> 1200	520 – 600
	New Woman	Agnew	1	66	480	750

(a) exploratory bore data where no production bores.

Potable groundwater (<1000 mg/L) occurs in elevated areas of enhanced recharge, primarily weathered and fractured bedrock aquifers beneath 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 LEONORA. The tributaries comprising alluvium, colluvium and palaeochannel sand commonly contain brackish groundwater, such as in Transects O and P, 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.

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 *et al.*, 1999).

Although salinity variation in the granitoids is poorly understood, the groundwater salinity in the granitoids will typically be lower in elevated areas. In the Leonora TWS borefield at Station Creek, the salinity in the weathered granite aquifer is variable, ranging from about 750 mg/L to 1300 mg/L (WAWA, 1992).

The groundwater salinity in different types of greenstone aquifer tends to be highly variable, ranging from less than 1000 mg/L at the Emu borefield to over 100 000 mg/L in the Eastern borefield. Local variations in groundwater salinity are common, such as in the Eastern borefield where the salinity ranges from 3100 to 118 600 mg/L. Mine dewatering of underground operations throughout LEONORA shows that there is an appreciable increase in groundwater salinity with depth.

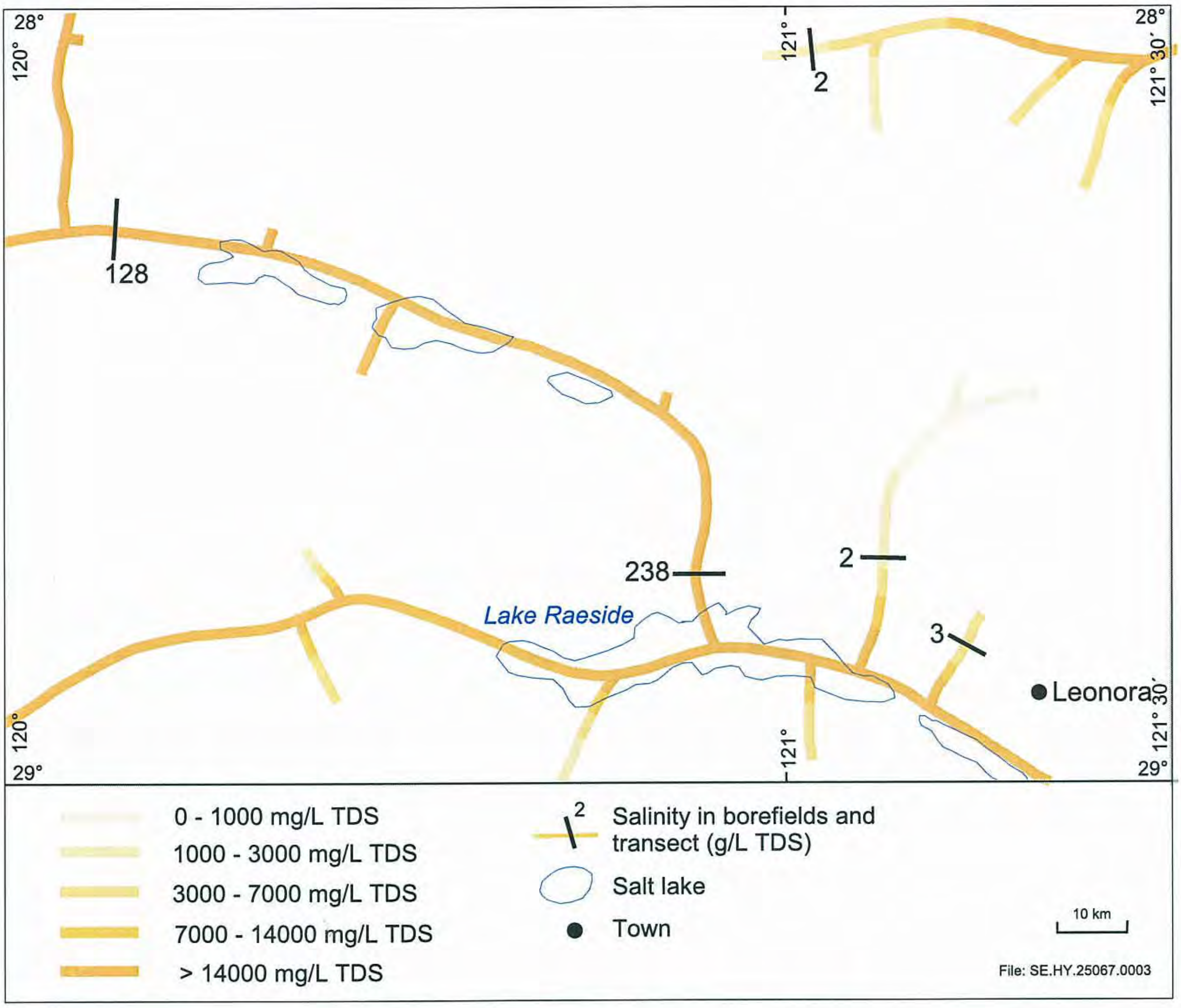

Figure 3. Groundwater salinity in the palaeochannels.

4.2 Hydrochemistry

The results of chemical analyses of groundwater from 26 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.

Groundwater from the mafic and ultramafic rocks (Bores EWB12, EWB50 and F9) contains an anomalously high proportion of magnesium, which is the result of weathering of Mg-rich basalt and dunite. The proportion of sulphate is higher in the groundwater samples from the Lawlers area (PB1 and DQ3), which may be the result of recharge through the highly weathered, sulphide-rich gossanous caprock. Most analyses from the calcrete aquifer are similar in composition, except for Bore ETP5 that has higher proportions of bicarbonate. 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.

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 (Snowys Well – Tarmoola)	7.5	-	1 580	-	-	83	64	345	17	260	520	195	85	-	-	0.5
BBW 22P (Marshall Creek – Bannockburn)	7.7	1 630	1 120	-	-	33	63	238	10	292	313	120	62	61	-	0.4
P5 (Station Creek – Harbour Lights)	7.5	3 150	2 020	-	-	75	65	460	18	270	720	240	76	-	-	-
NEC-5c	7.8	84 000	67 600	7 700	190	220	1740	24 000	540	190	24 000	6 900	130	21	-	-
NEP-1c	8.1	2 800	1 860	520	200	70	83	450	38	200	660	260	81	94	1.9	0.8
NER-4 @ 50m	7.0	77 000	44 160	8 300	250	690	1 600	17 000	510	250	21 000	3 100	46	64	-	-
Calcrete																
SGW2 (Western Borefield – Sons of Gwalia)	7.5	67 000	41 000	-	-	660	1 100	12 000	280	275	21 000	2 900	200	32	-	-
ETP5 (Depot Springs)	7.6	5 180	4 050	460	695	108	115	1 150	63	1 775	275	465	91	82	-	3.6
NEQ-9b	7.6	64 000	55 600	10 000	230	290	2 300	19 000	520	230	29 000	4 200	50	73	-	-
Eocene sedimentary rocks (palaeochannel sand)																
CW3T1 (Charcoal – Murrin Murrin)	7.0	6 530	4 140	-	-	160	180	1 020	62	200	1 860	480	13	63	-	0.7
GCAT1 (Granite – Murrin Murrin)	7.1	7 690	5 080	-	-	290	270	980	58	180	2 330	405	13	54	-	1.0
GMET1 (Grey Mare – Murrin Murrin)	7.4	4 880	3 120	-	-	80	80	860	50	220	1 150	540	15	37	-	0.6
STAT1 (Station – Murrin Murrin)	7.4	3 110	1 780	-	-	74	74	440	22	280	620	320	13	55	-	0.7
SCAT4 (Sullivan – Murrin Murrin)	7.2	5 140	3 000	-	-	100	110	760	42	230	1 200	480	14	33	-	0.9
NEC-5b	7.5	217 000	128 400	21 000	59	340	5 000	69 000	2 900	59	11 000	20 000	110	14	-	-
NEO-1	8.0	3 200	1 850	460	270	43	85	500	17	270	560	350	78	58	1.9	0.6
NEP-1b	8.0	3 200	1 860	560	290	67	84	420	24	290	670	310	67	28	2.5	1.6
NEQ-9a	7.2	223 000	238 700	41 000	50	430	9 800	98 000	2 400	50	110 000	18 000	1	11	-	-
NER-9	7.4	167 000	127 500	17 000	100	900	3 700	47 000	1 200	100	68 300	6 600	3	19	-	-
Granitoid rocks																
DQ3 (Daisy Queen borefield – Lawlers)	7.6	3 650	2 500	-	-	300	265	220	9	275	670	875	165	33	-	-
Leonora TWS																
Sedimentary, felsic volcanic and volcaniclastic rocks																
SG 18P (Eastern borefield – Sons of Gwalia)	8.0	5 000	3 200	-	-	110	120	860	35	340	1 300	550	86	11	-	-
Mafic and ultramafic rocks																
F 9 (Fairyland borefield – Lawlers)	8.0	1 000	695	-	-	8	70	90	6	245	130	60	87	8	-	-
PB1 (Lawlers borefield – Lawlers)	7.4	5 350	4 340	-	-	455	430	370	10	215	1 080	1 640	110	31	-	-
EWB12 (Emu borefield – Agnew)	7.9	940	605	-	-	11	83	66	5	250	116	27	51	17	-	-
EWB50 (New Woman borefield – Agnew)	7.8	1 150	650	-	-	6	90	114	5	270	214	136	48	9	-	-

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

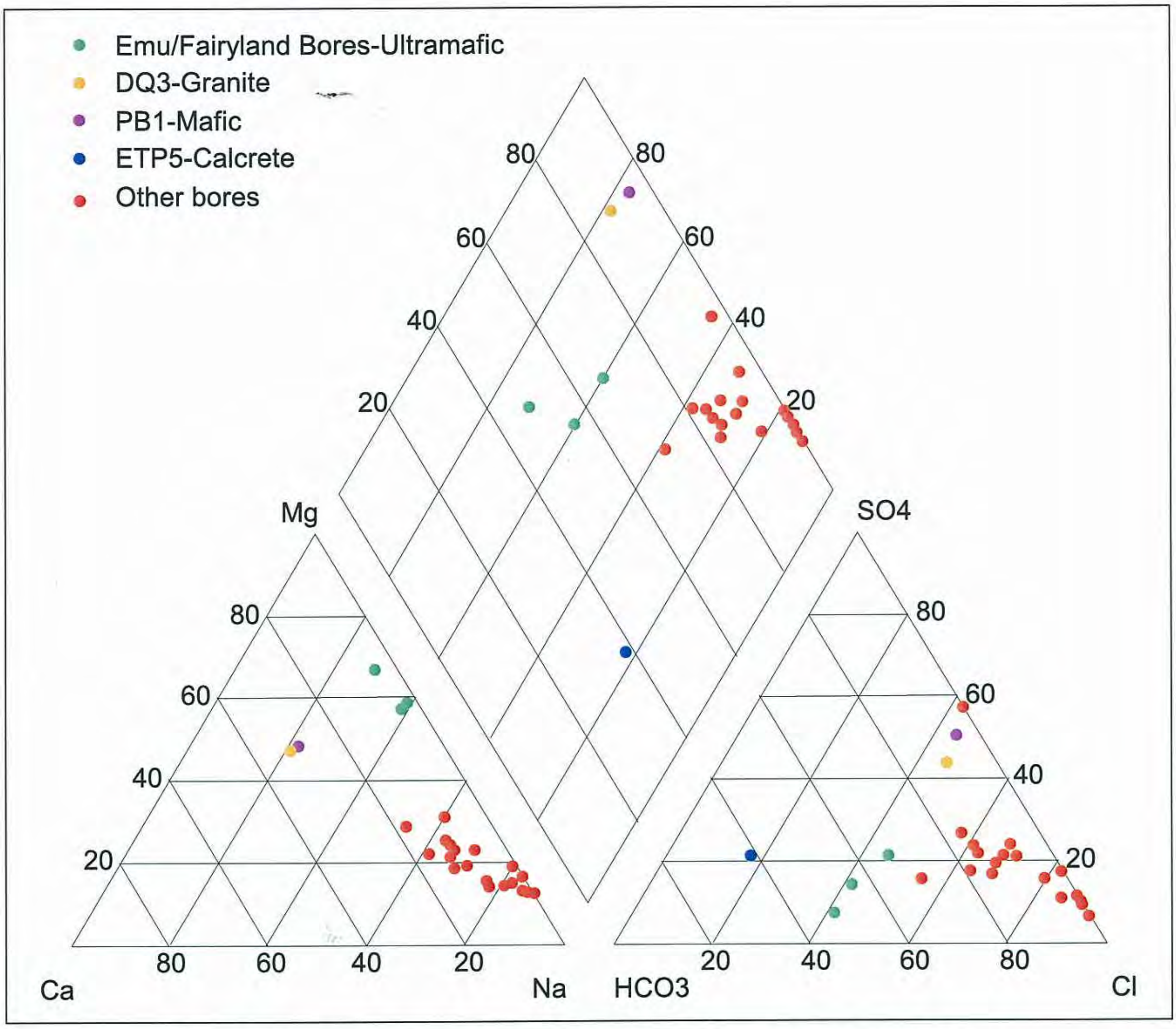

Figure 4. Piper trilinear diagram of selected chemical analyses of groundwaters.

The pH ranges from neutral to slightly alkaline with most groundwater sampled having a pH between 7.0 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 LEONORA. The analyses listed in Table 2 show that nitrate commonly exceeds the 45 mg/L standard for drinking water, with a maximum concentration of 200 mg/L in the Western borefield at Sons of Gwalia mine. 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 94 mg/L at Transect P, although these are not considered harmful. Elevated concentrations of boron, which exceed the 0.3 mg/L standard for drinking water, are probably related to surface runoff from weathered granitoid catchments. Fluoride is generally very low, although there are elevated levels in the calcrete aquifer at Depot Springs with up to 3.6 mg/L in Bore ETP5 (Geotechnics, 1972).

5 Groundwater development

5.1 Groundwater exploration

Geophysical techniques have been used with varying success to locate palaeochannels on LEONORA. 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 LEONORA 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 alluvium and calcrete aquifers are widely utilised by the mining industry. Groundwater allocation from the alluvium is about 3.1 x 10^6 m^3/yr (as at 1997) from the Marshall Creek (Bannockburn), Station Creek (Harbour Lights) and Snowys Well (Tarmoola) borefields. In addition, there is also an allocation of 0.6 x 10^6 m^3 for the Leonora TWS at Station Creek. The Western borefield (Sons of Gwalia) has an annual groundwater allocation of 0.9 x 10^6 m^3 and is the only borefield on LEONORA established in the calcrete aquifer.

At present, there are no borefields developed in the palaeochannels on LEONORA. There has been extensive groundwater exploration in the Charcoal, Granite, Grey Mare, Station and Sullivan Palaeochannels, as part of the proposed Murrin Murrin process water supply. A groundwater allocation of 5 x 10^6 m^3/yr had been issued to Murrin Murrin for the development of a borefield in the Grey Mare Palaeochannel.

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 which are likely to remain after several years of pumping.

Groundwater allocation from fractured and weathered bedrock, including mine dewatering, was estimated to be about 10.2 x 10^6 m^3 in 1997. The Emu (Agnew), Daisy Queen (Lawlers) and Eastern (Sons of Gwalia) borefields are the major borefields in highly weathered and fractured bedrock.

Groundwater obtained from mine dewatering is also used for ore processing and mining requirements. Information on actual groundwater abstraction related to mine dewatering is limited on LEONORA, however, the Tarmoola opencut abstracted about 0.7 x 10^6 m^3 in 1996 (Ultramafics, 1996) and Ag Pit at Agnew abstracted 0.4 x 10^6 m^3 in 1997 (Puretech, 1998) 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 Leonora is obtained from 12 production bores in the Station Creek borefield, which is sited in a weathered granite aquifer overlain by alluvium. The borefield is operated by the Water Corporation and groundwater abstraction in 1998/99 was 0.5 x 10^6 m^3. Salinity of the scheme ranges between 1200 and 1400 mg/L TDS during periods of high demand. At present, there are adequate supplies to meet the water requirements of Leonora.

Martin (1991) identified areas to the north of Station Creek borefield with the potential to supply fresh to brackish groundwater from fractured-chert aquifer. There is further potential for moderate supplies of brackish groundwater at Transect O, 3 km west of the Station Creek borefield, in alluvium and palaeochannel sand (Johnson *et al.*, 1999).

Sufficient supplies of potable to marginal groundwater are available acceptably close to mine sites throughout LEONORA, with the majority of domestic water supplies on mine sites being abstracted from fractured-rock and calcrete 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 300 bores and wells, is a major groundwater user on LEONORA. 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 8000 mg/L TDS is used occasionally.

5.5 Further development

The palaeochannel sand aquifer is considered to be the most prospective aquifer for further development on LEONORA. 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 the tributaries on both LEONORA and LAVERTON are being increasingly exploited for laterite-nickel ore processing.

The calcrete aquifer has potential for further development on LEONORA. There are significant stored groundwater resources in the thick calcrete deposits at Depot Springs (Geotechnics, 1972). 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 LEONORA, are detailed in Johnson *et al.* (1999). Because the annual recharge from rainfall is very small, groundwater resources on LEONORA 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, the groundwater storage in the alluvium on LEONORA is estimated at 2500 x 10^6 m^3 (Johnson *et al.*, 1999). On a regional scale, groundwater resources in the alluvium probably represent about 60% of the total groundwater resources on LEONORA.

Geotechnics (1972) estimated stored groundwater resources in the calcrete aquifer at Depot Springs at 78 x 10^6 m^3. In areas with no information, groundwater storage was estimated using a specific yield of 0.1 and saturated thickness of 5 m. This amounts to a total of groundwater in storage of 245 x 10^6 m^3 within the calcrete on LEONORA. Groundwater in the calcrete probably represents about 6% of the total groundwater resources of the area.

The palaeochannels on LEONORA contain significant groundwater resources held in storage. Based on a specific yield of 0.2, this groundwater storage is estimated at 1320 x 10^6 m^3 for 582 km of palaeochannel length (Johnson *et al.*, 1999). The groundwater storage of 2.2 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 30% of the total groundwater resources on LEONORA.

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 LEONORA to be about 200 x 10^6 m^3. It is likely that the groundwater in the bedrock represents about 5% of the total groundwater resources of the area.

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Appendix 1

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

Design file	Level	Description	Scale of capture (where applicable)
Leontopo.*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	
Leonhydro.*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	
Leonsal.*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	

LEONORA 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	
Leonwc.*dgn*	L45	AMG grid	
	L50	Catchment divide	
	L53	Direction of groundwater flow	
	L54	Isopotential lines	
	L55	Isopotential labels	
Leonbores.*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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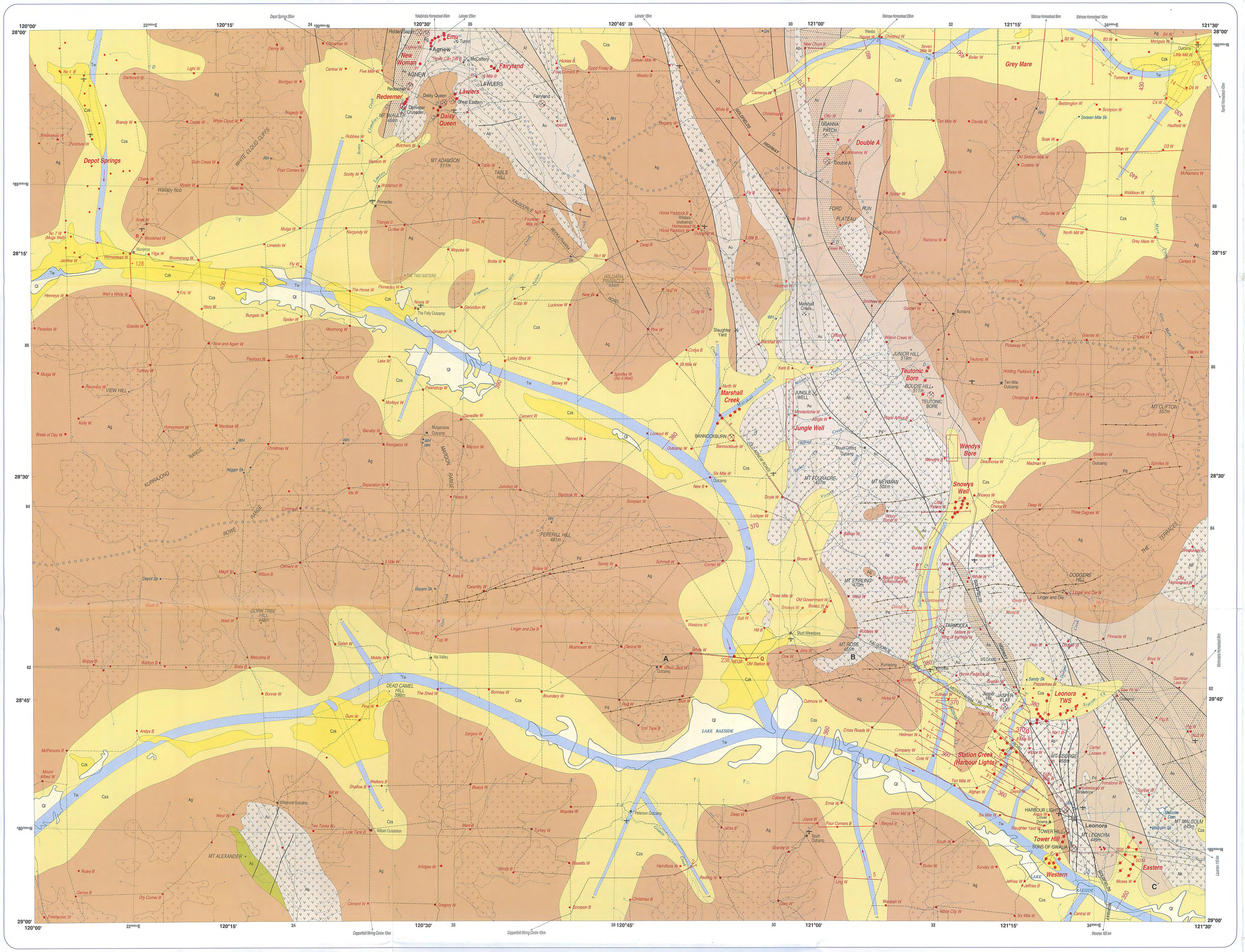
1 : 250 000 HYDROGEOLOGICAL SERIES

LEONORA

WATER AND RIVERS COMMISSION

SHEET SH 51-1



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

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			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)
• 238	salinity in palaeochannel (TDS g/L)

MINING INFORMATION

⚒	underground mine, opencut
AGNEW	mining locality
Crusader	mine name

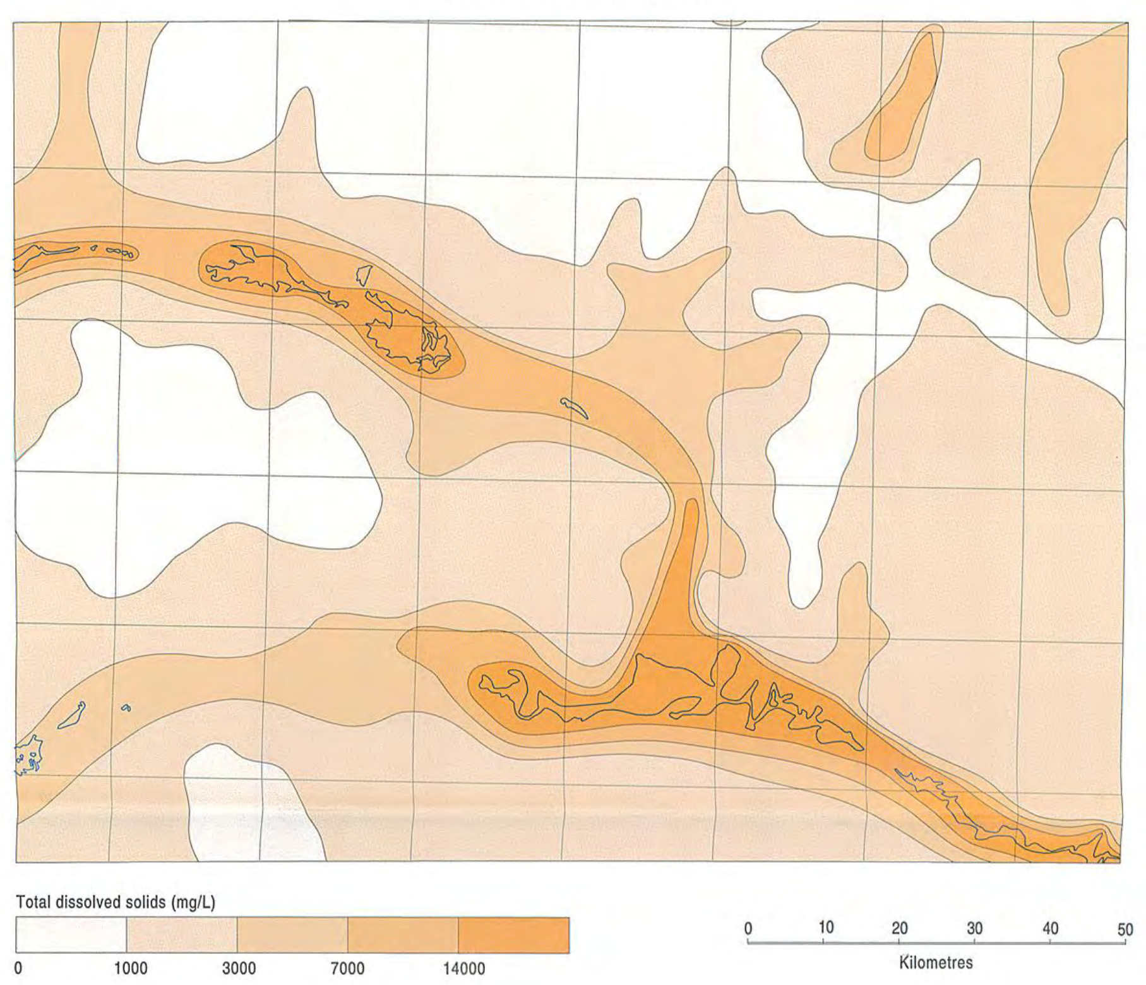
ARTIFICIAL FEATURES

● SG5	production bore; yield >50 m³/day
	abandoned bore; yield >50 m³/day
•	bore
■	well
□	area of detailed groundwater investigation
Emu	borefield name, cluster of bores
Q	WRC exploratory line
	mining company exploratory line
	storage reservoir
P	groundwater pipeline
○	mine dewatering
	historical mine dewatering

TOPOCADASTRAL INFORMATION

———	highway
———	formed road
- - - - -	track
✈	airfield, landing ground
Leonora	townsite, population less than 10 000
■ Pinnacles	homestead

GROUNDWATER SALINITY



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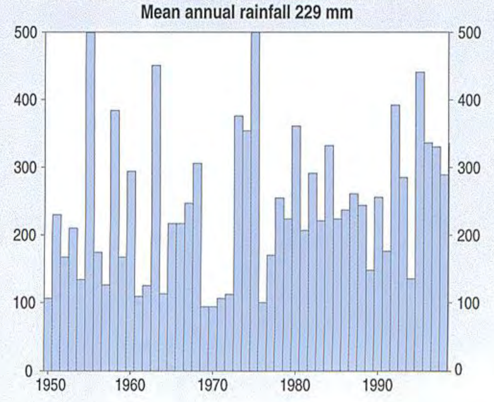
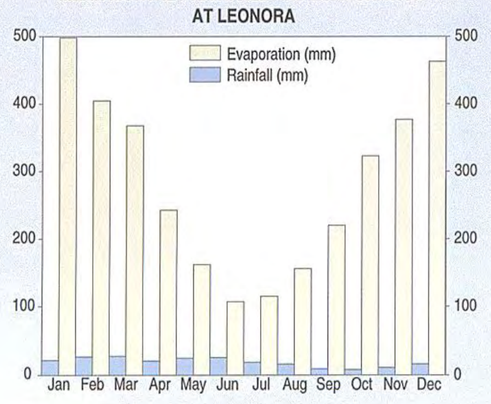
YOUANMI SH 50 - 4	LEONORA SH 51 - 1	LAVERTON SH 51 - 2
BARLEE SH 50 - 8	MENZIES SH 51 - 5	EDJUDINA SH 51 - 6

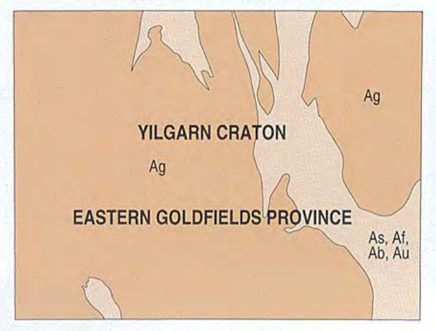
ANNUAL RAINFALL (mm) AT LEONORA (1950-1998)
Mean annual rainfall 229 mm



MEAN MONTHLY RAINFALL AND EVAPORATION AT LEONORA



REGIONAL GEOLOGICAL SKETCH



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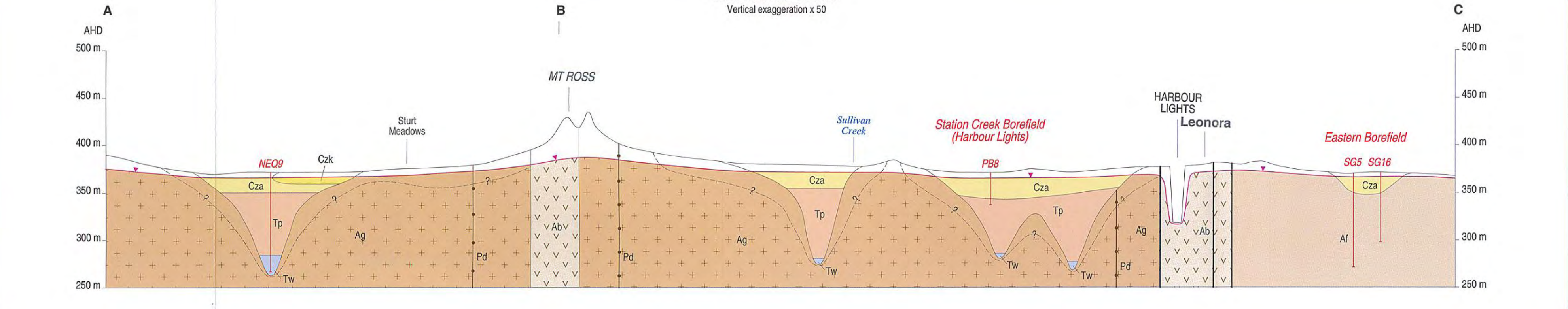
DIAGRAMMATIC SECTION
Vertical exaggeration x 50



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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
LEONORA
SHEET SH 51-1

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