

Northern Territory of Australia
POWER AND WATER AUTHORITY

Hydrogeology of the PINE CREEK MINING REGION

Explanatory Notes for 1:250 000 Scale Map

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1:250 000 SHEET INDEX

DARWIN SD 52-4	ALLIGATOR RIVER SD 53-1	MILLINGIMBI SD 53-2
PINE CREEK SD 52-8	MT. EVELYN SD 53-5	MOUNT MARUMBA SD 53-6
FERGUSON RIVER SD 52-12	KATHERINE SD 53-9	URAPUNGA SD 53-10

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SUMMARY

Pine Creek Mining Region is an area of 18000 sq km bounded by latitudes 13°15' and 14°15' and longitudes 131°15' and 132°45' that incorporates most of the important mining centres of the southern Pine Creek Geosyncline in the Northern Territory, Australia (see Figure 1). The mines use groundwater for ore processing and in the gold extraction process and place a substantial demand on local groundwater sources.

Reliable groundwater sources are traditionally difficult to locate in the fractured Proterozoic rocks of the Pine Creek Geosyncline. The hydrogeological map of the region provides a guide to the location of prospective fractured rock aquifers and other hydrogeological information to aid groundwater resource exploration and development.

The map is the first published hydrogeological map of an area in the Northern Territory and has been compiled on an Intergraph Computer Aided Drafting system. The CAD system has been utilised to provide a capability to produce larger scale maps with additional detail, a feature unique in Australian hydrogeological mapping to date. The map has been prepared to Australian Water Resources Council guidelines, with minor modification to suit the CAD system, and therefore conforms to the colour scheme and principles of the UNESCO International Legend for hydrogeological maps.

The project, including the compilation and production of the map and a data base containing information on over 600 bores, was completed in a period of approximately fifteen weeks.

1. INTRODUCTION

The 1:250 000 scale Hydrogeological Map of the Pine Creek Mining Region is the first published hydrogeological map of an area in the Northern Territory. It has the special purpose of aiding the location of groundwater supplies in a geologically complex area where extensive aquifers are remote from the centre of demand and reliable supplies are difficult to locate.

The map and explanatory notes provide an assessment of the hydrogeology and groundwater resource potential of an area of approximately 18 000 sq km,

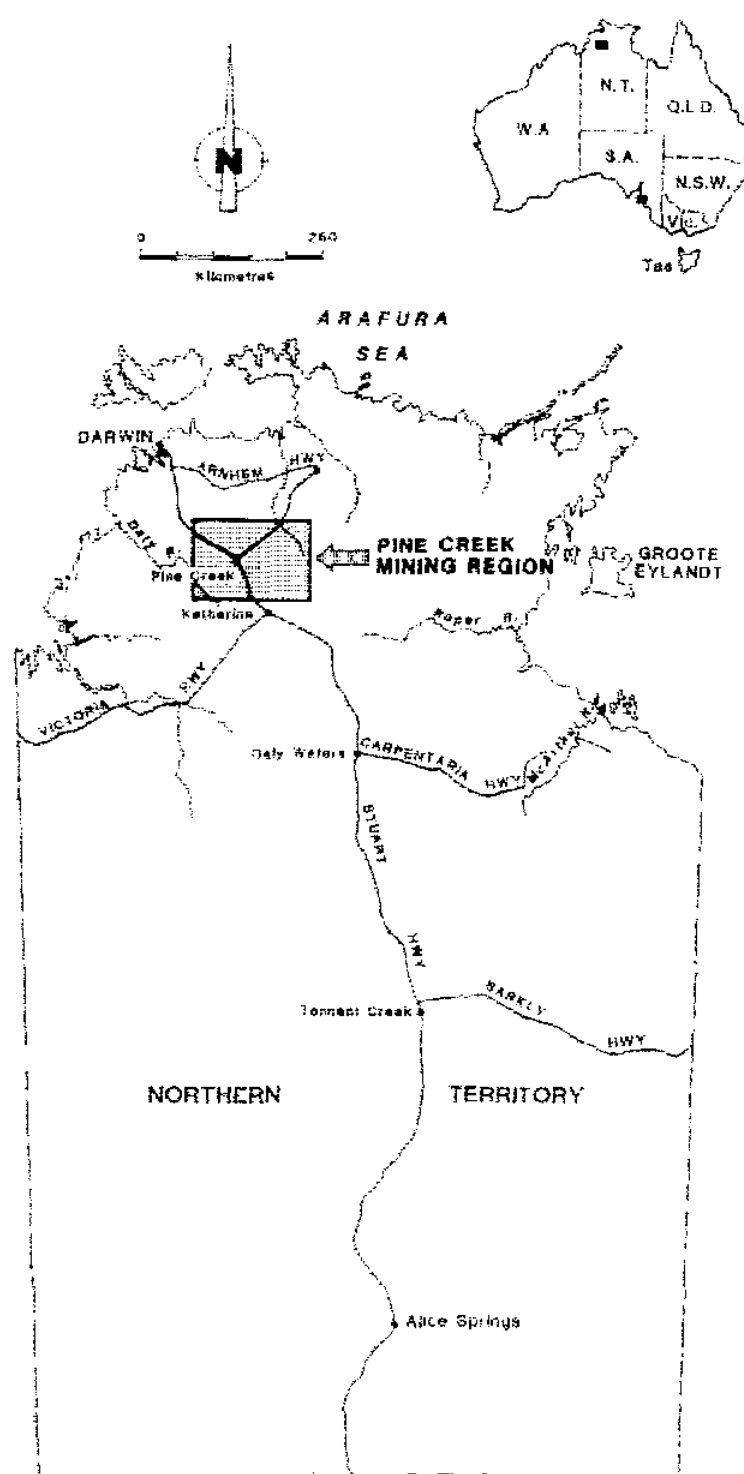


Figure 1 : Location Map

centred on the mining township of Pine Creek. Within the area are the main mining centres of the southern Pine Creek Geosyncline - Bridge Creek, Coronation Hill, Cosmo Howley, Fountain Head, Frances Creek, Moline, Mount Bonnie, Mount Todd, Mount Wells, Pine Creek, Union Reef and Woolwonga.

The map has been compiled on the Integrator Computer Aided Drafting system and provides for the production of larger scale maps, on demand, to provide detail within a specified area such as an existing or proposed mining centre. This capability is a new initiative in Australian hydrogeological mapping and is orientated to the special purpose of the map whilst maintaining the integrity of a 1:250 000 scale hydrogeological map prepared to Australian Water Resources Council guidelines (AWRC, 1988).

Mining company water supply and dewatering investigations provided much of the information on the groundwater resource exploration and development, this information has been incorporated in a bore data base, available as a supplement to these notes, in whole or in part and in floppy disk or hard copy format.

2. GEOGRAPHIC SETTING

2.1 Climate

The climate is monsoonal with a hot, wet season from October to April and a warm dry season from May to September. The hot wet season is characterised by a humid atmosphere carried in by north west to westerly winds.

The mean annual rainfall ranges from approximately 1050 mm in the south of the Pine Creek Mining Region to 1400 mm in the north. Virtually all the rainfall occurs in the summer months, mostly December to March. At Pine Creek the mean annual rainfall is 1142 mm with only 20 mm occurring in

the months May through to September. The mean monthly rainfall for the months December to March is 230 mm.

Air temperatures are high throughout the year. The mean monthly maxima range from about 30 to 32°C in June and July, to 35 to 37°C in October and November. The corresponding mean monthly minima are 12 to 14°C and 22 to 24°C.

The potential evaporation is high, the annual average Class A pan evaporation being 3500 mm. The rate is relatively constant for most of the year at 270 mm per month, except during the latter part of the dry season, the potential evaporation in October being 375 mm.

TABLE 1: MONTHLY AND ANNUAL MEAN RAINFALL AT PINE CREEK

MONTH	RAINFALL (mm)	RAINDAYS
January	268	16
February	244	15
March	203	12
April	48	3
May	6	1
June	3	0
July	2	0
August	1	0
September	8	1
October	41	4
November	115	9
December	203	13
TOTAL	1142	74

2.2 Physiography

The physiographic units are shown in Figure 2. The lowland areas include the alluvial floodplains of the Margaret and McKinlay Rivers in the north west and carbonate plains of the Daly River Basin in the southwest. Thick silty soil and sandy loam on the alluvial plains supports open savannah grassland and some open woodland. The subhorizontal sequences of limestone

bearing quartz in the Golden Dyke Dome and alluvial gold in the Margaret River. At the turn of the century, metals at Iron Blow and Mount Bonnie and tin at Mount Wells. Production declined as of the 1920's. The discovery of uranium in 1953 in the upper South Alligator River valley initiated a period of intense exploration and mining which slowed dramatically in 1956 with a worldwide slump in uranium prices. Thirteen uranium prospects were worked between 1954 and 1964. Between 1966 and 1974 iron ore bodies were worked at Frances Creek. Gold or tin have been produced from lode and alluvial deposits throughout the areas history and the large gold mining tonnage - low grade open-pit operations at old mine sites. Pine Creek townsite services much of the mining area.

Agricultural development has taken place primarily in the Daly Basin on Douglas Station.

2.4 Surfacewater hydrology

The area includes part of the Adelaide River, Daly River, Mary River and South Alligator River surface water catchments. The Adelaide, Mary and South Alligator Rivers flow northward while the Daly River flows west and is fed by a number of major tributaries including the Douglas, Edith, Fergusson and Katherine Rivers.

Drainage patterns are predominantly dendritic with significant lithological and structural control in some areas. In the Daly Basin there are fewer creek drainages as a result of there being less runoff. In the eastern Pine Creek Mining Region the drainage is dominated by the extensive mesa of lateritised Cretaceous sediments, which forms the headwaters of a number of large creek systems draining into the Edith, Fergusson, Katherine, Mary and South Alligator Rivers. A number of these creeks are spring-fed with groundwater discharging from the base of the sediment profile and providing some base flow in the creeks.

Perennial or semi-permanent pools are common along the main river and creek systems. This is due to shallow groundwater levels in topographically low areas and the locally permeable nature of the bedrock which allows groundwater flow to support these surface features. Sink-holes or dolines are common in parts of the Daly Basin and are discussed in Hydrogeology.

Stream gauging information is limited to five stations with substantial data on discharge volumes and a number of other stations with very limited discharge data or with river or flood-height information only. The five main gauging stations, as shown on the map, provide the data given in Table 2.

TABLE 2 STREAM GAUGING DATA

STATION	PAWA NO.	RECORD	MEAN FLOW m^3s^{-1}	AREA (sq km)	RUNOFF (%)
Bridge Creek	8170006	1968-88	0.72	126	13
Copperfield Creek	8140062	1973-87	0.06	9	18
Harriet Creek	8180252	1966-88	0.99	122	21
McKinlay River	8180069	1981-88	2.77	352	19
Mary River	8180026	1961-88	2.70	466	15

and shale of the Daly River Basin produce thick red sandy or clayey soils interspersed with low strike ridges of more resistant sandstone or sandy limestone. Karstic features occur in the limestone with sinkholes locally common and some development of clint and gryke features on pavements. The vegetation of the carbonate plains is scrub and open eucalypt woodland.

Prominent mesas are formed by lateritised Cretaceous sediments resting on Proterozoic bedrock, by far the largest of these features lying to the northwest of the Katherine River. The laterite profile usually contains a silicified pallid zone which has preserved the mesas at a fairly uniform relief above the general level of erosion. Tall, open eucalypt forest usually grows on top of the mesas.

On the eastern margin of the Daly River Basin, the Tablelands are formed by an approximately 5 km wide range of flat-topped rocky hills of late Proterozoic sandstone. The Douglas River and Stray Creek have formed deep gorges in the sandstone. Predominantly skeletal soils support sparse to tall open forest.

Undulating sandy rises characterise most of the granitic terrain and lower-lying areas of Proterozoic sedimentary and metamorphic rocks. Highly leached skeletal soils and lateritic podsol are common, with gravelly and sandy soil on granite and yellow earth soil on metamorphic rocks.

Granite pavements and tors and rocky ridges comprise most areas with an elevation in excess of 200 m. The pavements and tors have a patchy gravelly soil and vegetation limited to low shrubs, coarse grasses and small eucalypts. The rocky ridges are formed by Proterozoic sediments and metamorphic rocks and are characterised by steep gradients with surface boulders and low outcrops widespread. Vegetation on the slopes and ridges is open woodland with

grasses giving way to tall eucalypt forest and tall perennial grasses on the deeper soils of the creek systems.

2.3 Land use

The Pine Creek Mining Region includes the following major land uses:

- . Pastoral leases
- . Kakadu National Park
- . Kakadu Conservation Zone
- . Aboriginal land
- . Many isolated mining projects and camps
- . Mining town at Pine Creek
- . Small agricultural developments

Most of the area is under pastoral lease, the leases being Ban Ban Springs, Bonrook, Claravale, Douglas, Eva Valley, Gimbat, Goodparla, Jindare, Mary River, Mount Bunday, Ooloo, Prices Springs and Tipperary. The pastoralism is based on relatively uncontrolled grazing of feral buffalo and cattle.

A portion of Kakadu National Park Stage 3, including part of the Conservation Zone, comprises the northeast corner of the region. The Conservation Zone is an area intended to become a National Park in which mineral exploration is permitted prior to declaration as a park. Land may cease to be in a conservation zone only if it becomes a park or reserve or is to be used for mining operations. Katherine River National Park Reserve comprises the southeast corner of the region, much of this being catchment of the Katherine River and incorporating an extensive mesa with associated scenic cliffs and gorges.

There are two small Aboriginal communities within the Pine Creek Mining Region, one at Pine Creek and another at Kybrook Farm, 4 km south-southwest of Pine Creek townsite.

Mining, mainly for gold, is by far the most economically significant land use in the region. Mining began in 1872 after the discovery of gold-

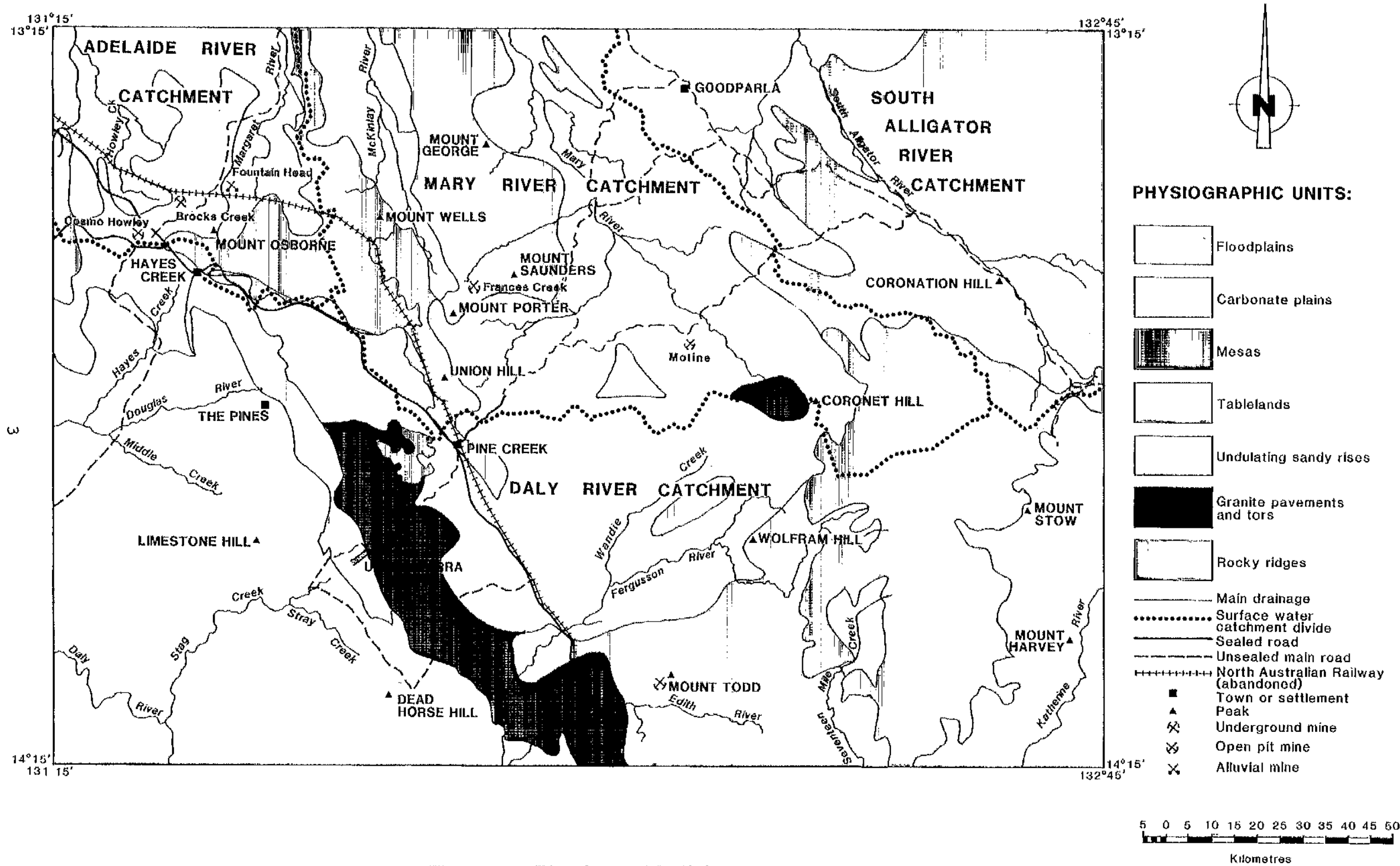


Figure 2 : Physiographic Units

The mean flow at each gauging station has been used to determine runoff as a proportion of the total rainfall on the catchment. The range of values of 13 to 21% reflects differences in catchment lithology, structure, topography and vegetation.

3. GEOLOGY

The Pine Creek Mining Region incorporates most of the southern part of the Pine Creek Geosyncline. The geosyncline comprises early Proterozoic metasedimentary and volcanic rocks resting on a basement of Archaean gneiss and granite. The sedimentary rocks are mainly shale, siltstone, sandstone, carbonate rocks and banded iron formation. The volcanic rocks are felsic and mafic lavas and tuffs. Dolerite sills and dykes intruded the sequence prior to major structural movement. The emplacement of granitic plutons and dolerite lopoliths occurred after the tectonism.

Largely undeformed platform cover of mid to late Proterozoic, Cambrian, Ordovician and Mesozoic strata rest on the rocks of the Pine Creek Geosyncline with marked unconformity.

3.1 Stratigraphy

For the purposes of the hydrogeological map a number of simplifications of the stratigraphy have been made by combining units of similar hydrogeological characteristics of significance. The lithology and stratigraphy of the mapped units are summarised in Table 3. Also included in this table are the Tertiary and Quaternary units that are present within the Pine Creek Mining Region but not shown on the hydrogeological map.

3.2 Structure

The early Proterozoic sediments, volcanics and dolerites have been intensely deformed and regionally metamorphosed, resulting in tight to isoclinal folding and extensive faulting. These structures have been modified by the intrusion of syn-orogenic to post-orogenic granites and the development of the Pine Creek Shear Zone (refer Figure 3). The area has been relatively tectonically stable since this time apart from period of uplift, block faulting and erosion.

The Early Proterozoic sediments have been subject to two major phases of folding, one set comprises tight to isoclinal folds and a younger set is of widely spaced open folds. Where these two fold sets interfere,

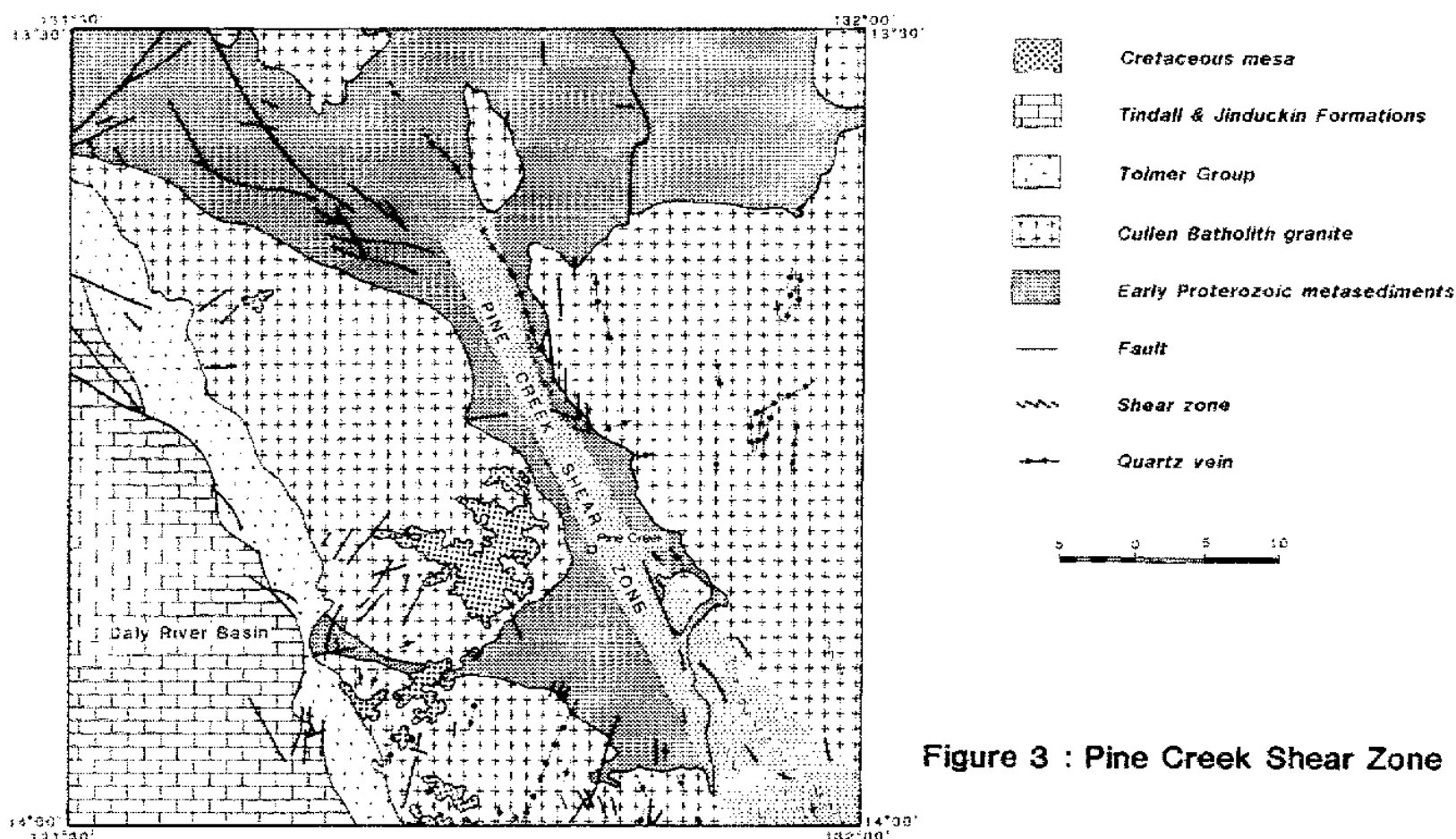


Figure 3 : Pine Creek Shear Zone

elongate basin and dome structures are formed, such as the Golden Dyke Dome near Mount Bonnie.

The earliest faults within the Pine Creek Geosyncline are in the Wildman Siltstone and contain lenses of haematitic ironstones. The main fault sets are syn-orogenic to post-orogenic and affect the Early Proterozoic rocks, one of the most significant features being the Pine Creek Shear Zone.

The Pine Creek Shear Zone trends north-northwest through Pine Creek within a 4 to 5 km wide embayment of Burrell Creek Formation flanked by two major Cullen Batholith granite plutons. The metasediments within the shear zone are schistose and chloritic, and the bedding and cleavage are vertical and parallel. Where the shear zone intersects the granite to the south-southeast of Pine Creek it splays out into many discrete zones of fault breccia and shear zone mylonite. Within the metasediments of the shear zone, fault displacements of the order of 1 to 2 km horizontal movement have been identified.

The main fault sets in the Early Proterozoic rocks trend north-northwest and northeast and are prominent within the rocks of the South Alligator Group, probably due to the range of distinct lithologies in these rocks. To the southwest, in the Middle Proterozoic sediments, a number of north to northwest trending faults occur along the western margin of the Daly River Basin. They are steep, normal faults, downthrown to the southwest and probably have a history of movement through the Middle Proterozoic to the Mesozoic as a result of deposition in the Daly Basin.

Within the Daly Basin, lineations on aerial photographs and Landsat images indicate there is extensive faulting but the faults are probably of small displacement.

4. HYDROGEOLOGY

The complex geology and structure of the Pine Creek Geosyncline has created a similarly complex hydrogeologic environment in which aquifer characteristics show extreme variation according to lithology, tectonic history, weathering and recharge conditions. The Cambro-Ordovician deposits of the Daly Basin and the lateritised Cretaceous sediments have aquifer characteristics that vary mainly according to lithology.

Representation of aquifer types at 1:250 000 scale has required that these be shown according to stratigraphic Formation or Group without further subdivision. The aquifer units presented on the map are Formations or Groups categorised according to the groundwater resource potential that is typical for the unit.

4.1 Superficial sediments

The superficial sediments of the Pine Creek Mining Region are not shown on the hydrogeological map as they do not present a significant groundwater resource. The sediments are usually less than 5 m thick, contain a high proportion of silt and clay and would usually be unsaturated, except along main drainages. Alluvial sands may, rarely, have sufficient permeability and thickness to provide a yield through a well, or sand spear. Isolated pockets of such sands exist in the Mary and McKinlay River alluvium but do not present mappable units.

4.2 Porous Sedimentary Rock - Aquifer

The lateritised Cretaceous sandstone, siltstone and conglomerate that form prominent mesas in the area can provide small groundwater supplies where these rocks are extensive. Due to their location high in the landscape, the saturated thickness is supported only by direct rainfall recharge with no throughflow from adjacent areas. The sediments also

TABLE 3 STRATIGRAPHIC SUMMARY

UNIT	MAIN ROCK TYPES	RELATIONSHIPS	THICKNESS (m)	REMARKS
Qa	Silt, sand, clay		< 3	Alluvium
Qf	Black and brown humic soil		< 2	Floodplain deposits at upper reaches of drainage courses
Cz	Sandy to gravelly lithosols	Veneer over Mesozoic and older units	< 2	Regolith
Czt	Sand and rubble of granite and sandstone	Flanks scarps of resistant Middle Proterozoic and Mesozoic rocks	< 10	Talus deposits
Czg	Unconsolidated gravels	Flanks steep ridges of Early Proterozoic hornfels	< 3	Older colluvium
Czs	Unconsolidated sand	Veneer on laterite and older formations	< 10	Fan deposits
Czl	Ironstone	Flat-lying cappings on older formations	< 3	In-situ and reworked remnants of laterite profile
K	Ferruginous quartz sandstone and conglomerate	Flat-lying veneer unconformable on older formations	25	Epicontinental sediments
Golloo Limestone (Olo)	Sandy dolitic dolomite limestone	Conformably overlies (Oloj)	200	Shallow marine
Jinduckin Formation (Oolj)	Limestone, calcareous sandstone, sandy limestone, quartz sandstone, siltstone and shale	Conformably overlies (Omt)	3	Shallow marine, possibly intertidal
Tindall Limestone (Omt)	Massive thinly bedded limestone with chert bands and nodules in places	Unconformably overlies Pts	< 150	Marine, fossiliferous
Stray Creek Sandstone (Pts)	Thinly bedded fine brown quartzite, micaceous sandy siltstone, limonitic micaceous siltstone, minor ferruginous silicified dolomitic siltstone	Conformably overlies Ptd	450	Shallow marine
Depot Creek Sandstone (Ptd)	Laminated to thickly bedded, pink to brown, medium to coarse quartz sandstone micaceous siltstone, minor ferruginous, silicified dolomite and dolomitic siltstone	Unconformably overlies Early Proterozoic metasediments and granitoids	450	Continental to shallow marine
Kombelgie Formation (Phk)	Medium to coarse quartz sandstone, minor siltstone and conglomerate	Unconformably overlies older strata	600	Epicontinental sediments
Oenpelli Dolerite (Pdo)	Porphyritic olivine dolerite	Intrusive	150	
Lewin Springs Gneiss (Paw)	Porphyritic microgranite, rhyolite, porphyritic quartz microsyenite and quartz micromonzonite	Numerous dykes intruding granitoids in the south	250	
Cullen Granite (Pgc)	Granite, leucogranite granodiorite	Numerous coalesced plutons intruding older Early Proterozoic metasediments and dolerite		

TABLE 3 STRATIGRAPHIC SUMMARY (cont'd)

UNIT	MAIN ROCK TYPES	RELATIONSHIPS	THICKNESS (m)	REMARKS
Plum Tree Creek Volcanics (Pep)	Ignimbrite, rhyolite, tuff sandstone siltstone	Diachronous with Pek	200	
Kurrundie Sandstone (Pek)	Purple quartz sand-boulder conglomerate minor brown shale and siltstone	Diachronous with Pep	200	Post-orogenic
El Sherana Group (Pb)	Metasiltstone, greywacke, sandstone, shale ignimbrite	Unconformable on Pfb	-	Syn-orogenic. Includes Tollis Formation
Zamu Dolerite (PdZ)	Chloritised medium quartz dolerite and amphibolite	Sills intruding (and folded and meta- morphosed with older Early Proterozoic strata	150	Continental tholeiite
Burrell Creek Formation (Pfb)	Fine to coarse feldspathic greywacke shale, slate, phyllite and siltstone; slate, phyllite and minor conglomerate	Conformably overlies or faulted against Pso intruded by Pgc and PdZ	1000	Flysch deposits derived from a dominantly volcanic source
Mount Bonnie Formation (Pso)	Shale, mudstone, phyllite, siltstone, medium feldspathic greywacke, minor tuffaceous chert, glassy black crystal tuff, carbonaceous shale, and rare banded iron formation	Conformably overlies Psg	700	Transition between low energy, shallow-water reduced environment and deeper water flysch facies
Gerowie Tuff (Psg)	Brown and grey siltstone phyllite and argillite, glassy black tuffaceous chert, crystal tuff and vitric tuff	Conformably overlies Psk	300-400	Reworked subaqueous deposits of siliceous ash in low energy energy reduced environment
Koolpin Formation (Psk)	Ferruginous and carbonaceous phyllite with chert bands, lenses and nodules in places; minor massive limonitic ironstone, silicified dolomite, marl, pyritic and graphitic hornfels, marble, para-amphibolite and muscovite-quartz schist	Unconformably over- lies Ppw	200-300	Fresh to brackish shallow, acid and reducing environment
Wildman Siltstone (Ppw)	Siltstone, phyllite, silty phyllite, carbonaceous phyllite and minor quartz sandstone dolarenite and hornfels	Conformably overlies Ppw and unconformably overlain by Psk	750	Transgressive sequence of shallow-water facies
Mundogie Sandstone (Ppm)	Coarse, pebbly feldspathic quartzite, arkose, and micaceous quartzite; minor chert and quartz pebble conglomerate. Red and white banded phyllite; carbonaceous phyllite; sandy siltstone; micaceous hornfels, and chialstolite carbonaceous hornfels	Unconformably? or disconformably over- lies Pnm	500	Fluvial fans
Masson Formation (Pnm)	Carbonaceous phyllite, slate silty phyllite, siltstone, sandy siltstone minor laminated medium to coarse grained quartzite and feldspathic quartzite, and massive ironstone. Rare muscovite tremolite marble	Unconformably? or disconformably over- lain by Ppm	1000	Low-energy marine

drain through spring discharge at their margins. Consequently unless the deposits are extensive they are subject to seasonal dewatering.

The large mesa that forms much of Katherine River National Park and the area north thereof represents a significant groundwater resource although it is relatively inaccessible and likely that bore yields would be low. The mesa produces substantial spring discharge to tributaries of the Katherine River and at the headwaters of the Mary and South Alligator Rivers.

The other Cretaceous mesas in the area are much smaller. Only two are shown on the map - one to the west and one to the southwest of Pine Creek. The former is the most significant and covers an area of about 15 sq km, is 8 km west of Pine Creek and is known locally as the 'Tabletop'. A program of geophysics and drilling, carried out by the PAWA in 1988, assessed the prospects of this source supplementing Pine Creek township water supply (Pidsley, 1989). The results indicate a thickness 15 to 20 m of sandstone, claystone and clay resting on weathered granite with no potential for substantial supplies. The presence of perennial soaks and creek discharge at the base of the 'Tabletop' suggests that patchy sand or sandstone may be present but bores

in such zones would yield only 0.05 to 0.5 L/s. The field relations of the Cretaceous sediments, as typified by the 'Tabletop' are shown in Figure 4.

4.3 Fractured and Karstic Rocks - Extensive Aquifer

These units provide the most substantial and reliable groundwater resources within the Pine Creek Mining Region. They consist of the Oolloo Limestone, Jinduckin Formation and Tindall Limestone of the Daly River Group and occur only in the Daly River Basin which comprises the southwest corner of the map area (Refer Figure 5). In terms of mine water supplies, these aquifers are remote from the mining centres.

4.3.1 Oolloo Limestone

Comprising a dolomitic sandy limestone, the Oolloo Limestone is a highly productive karstic aquifer capable of bore yields well in excess of 15 L/s. The maximum thickness of the aquifer in the area is approximately 200 m based on results from bore RN 6825, just outside the sheet area (Jolly, 1984).

A high secondary permeability has been developed through the full aquifer thickness by dissolution of the limestone matrix that has produced cavernous, vuggy strata. The features are best developed close to the zone of water table

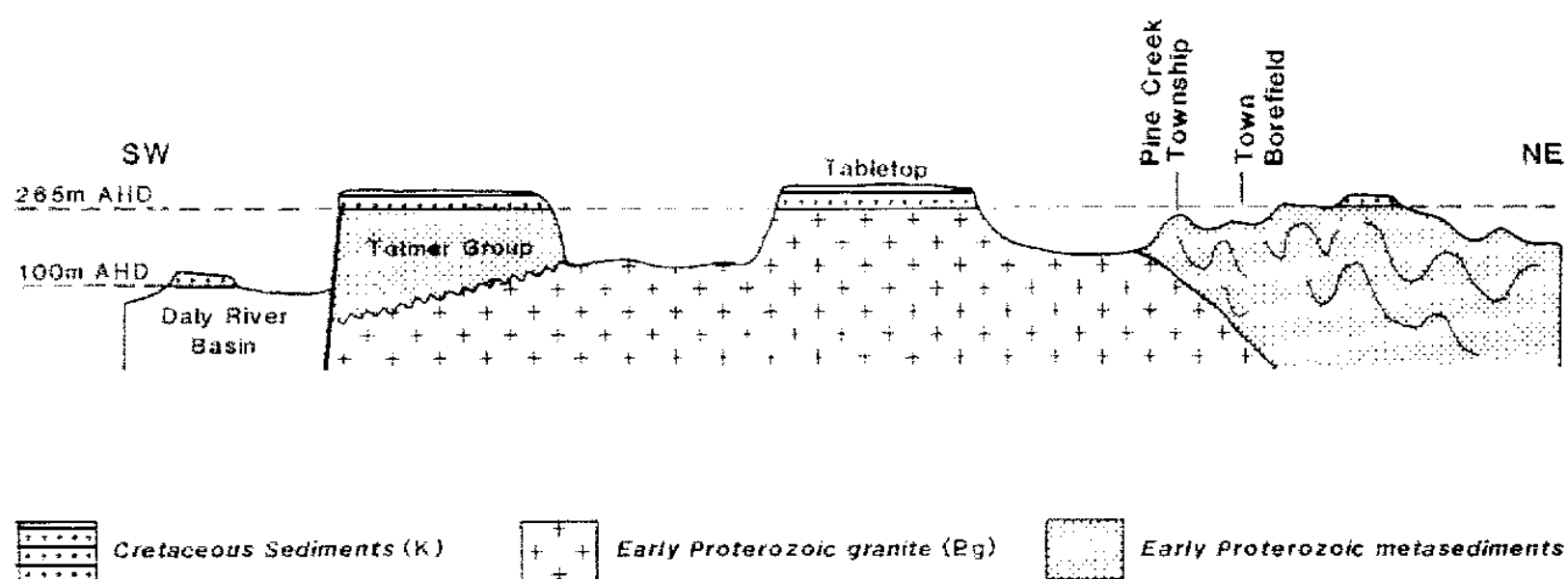


Figure 4 : Schematic diagram showing field relations of Cretaceous sediments

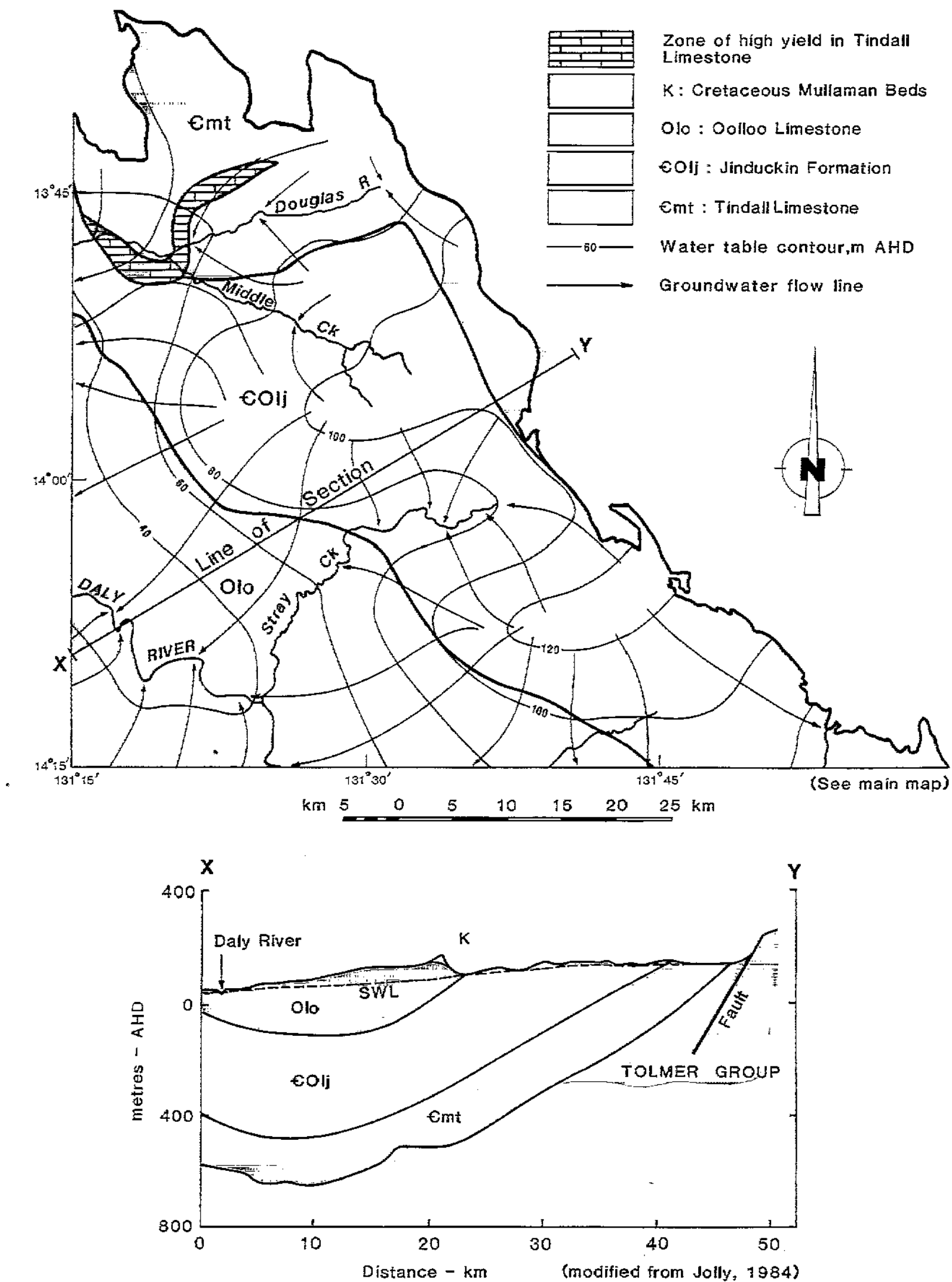


Figure 5 : Daly River Basin – Hydrogeology, water table contours and Cross-section

fluctuation and the formation appears to decrease in permeability with depth. Jolly (1984) estimated the bulk transmissivity of the Oolloo Limestone to be $1500 \text{ m}^2\text{d}^{-1}$ and the specific yield to be 0.05.

4.3.2 Jinduckin Formation

The Jinduckin Formation comprises limestone, siltstone and shale and is the least productive of the formations of the Daly Basin. The maximum thickness is estimated to be 350 m. Secondary permeability is dependent on lithology and the intensity of weathering. In the zone of water table fluctuation, permeability is sufficiently enhanced that bore yields of 1 to 5 L/s, and exceptionally 10 L/s, may be obtained. Lower in the Formation, high yields may be related to a zone of high secondary permeability due to gypsum dissolution.

4.3.3 Tindall Limestone

The Tindall Limestone comprises massive thinly bedded limestone with siltstone and is locally highly permeable and capable of bore yields in excess of 15 L/s. The maximum thickness is estimated to be 200 m. Weathering, lithology and the intensity of stress fracturing are significant factors in the development of secondary permeability. As in the other formations the intensity of chemical dissolution is greatest in the zone of water-table fluctuation and seasonally the water table varies from about 3 m below ground level to as much as 25 m below ground level (Jolly 1984) (as seen in Figure 6). At the edge of the Daly River Basin the Tindall Limestone has been subject to greatest stress due to downwarping and this is associated

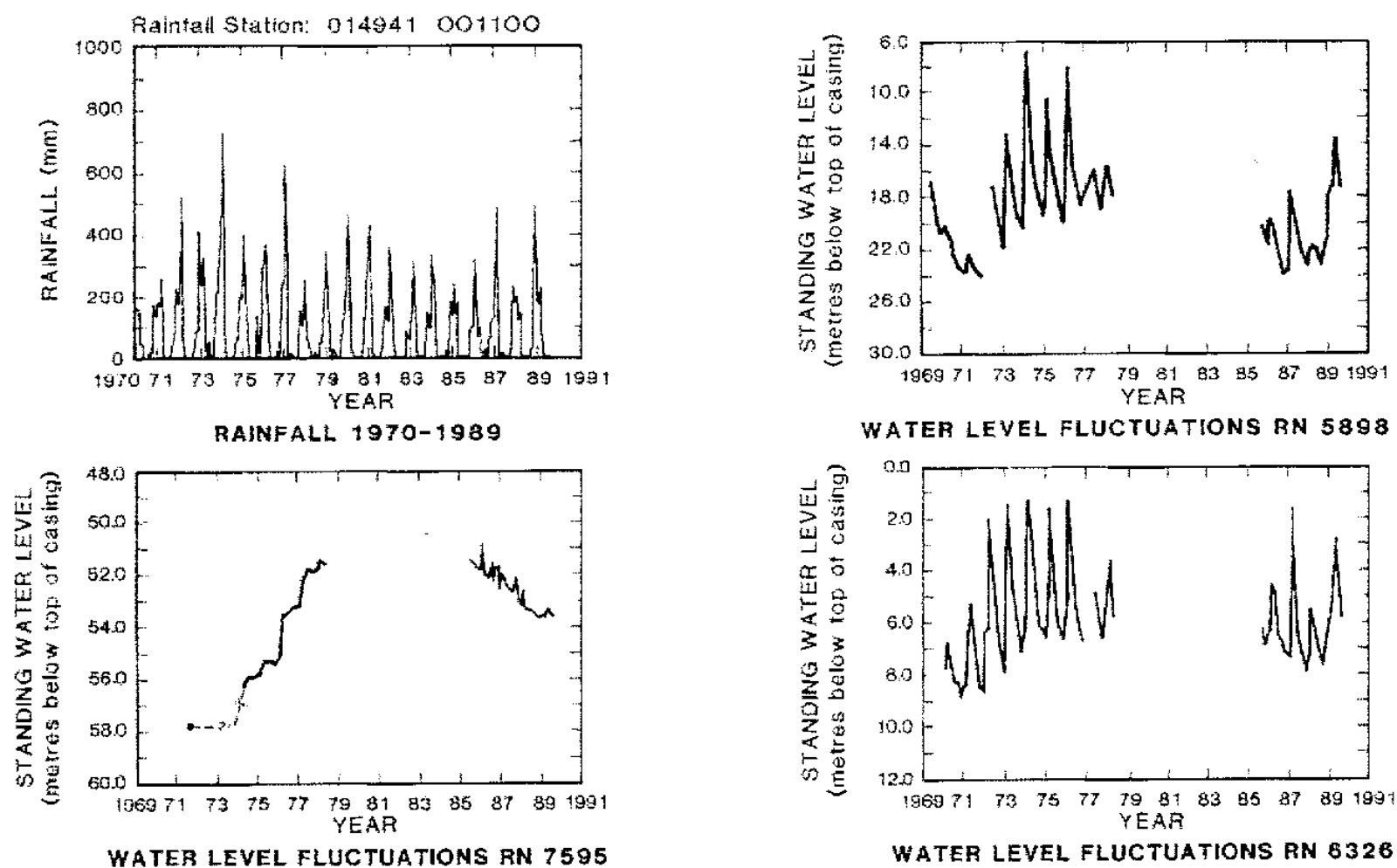


Figure 6 : Water table fluctuation in Tindall and Oolloo Limestone

with the development of high secondary permeability. At the surface, this is demonstrated by the abundance of sink-holes and other karstic features.

4.4 Fractured Rocks - Local Aquifers

Fractured rock aquifers are typically extremely varied in hydraulic characteristics, making the yield production, and therefore classification for the purposes of mapping, a difficult task. Four units have been mapped as the most consistently productive fractured rocks in the Pine Creek Mining Region, these being:

- (i) El Sherana Group, including the Tollis Formation.
- (ii) Mt Bonnie and Koolpin Formations of the South Alligator Group.
- (iii) Gerowie Tuff of the South Alligator Group.
- (iv) Mundogie Sandstone of the Mount Partridge Group.

A fractured rock aquifer may be relatively consistent in producing groundwater from permeable zones due to the effects of the following factors:-

- Intensity and type of folding and faulting.
- Lithology and tendency for brittle failure under stress.
- Susceptibility of rock to chemical degradation.
- Intensity of weathering.
- Typical topographic location, affecting recharge from rainfall and surface water.
- Ease of structural interpretation and bore site selection.

Two or more of these factors have contributed to the productive nature of the units now described.

4.4.1 El Sherana Group

Comprising an extremely varied suite of sedimentary and volcanic rocks, the El Sherana Group is an important local aquifer in the El Sherana - Coronation Hill area and at Mount

Todd, these being the two main areas where the Group outcrops in the Pine Creek Mining Region.

At Coronation Hill the El Sherana Group has been subject to intensive strike-slip faulting and anticlinal folding. The intensely varied nature of the volcano-sedimentary sequence probably promotes strike-slip and differential movement resulting in brittle fracture. Recharge conditions are locally favourable due to the proximity of the South Alligator River and concentration of surface waters in steep-sided valleys. Structural interpretation is not simple due to the strike-slip fault type and absence of distinct units on which to base air photograph interpretation. Yields of up to 10 L/s have been obtained from bores in the El Sherana Group at Coronation Hill although the long term sustainable yields should be in the range 0.5 to 5 L/s.

At Mount Todd, intense faulting and a complex series of anticlinal and synclinal folds have contributed substantially to the intensity of fracture permeability. Limited groundwater exploration to date has shown bore yields of less than 5 L/s from short-term testing, suggesting low long-term yields. The yields may not reflect the full potential of the El Sherana Group in this area as many prospective fault and fold features remain untested.

4.4.2 Mount Bonnie and Koolpin Formations

These formations of the South Alligator Group are stratigraphically separated by the Gerowie Tuff but have been mapped as one unit due to similar hydrogeologic characteristics. The formations comprise mainly greywacke, siltstone, shale, tuff, chert and dolomite and form an important local aquifer that has been developed at Brocks Creek, Coronation Hill, Cosmo Howley, Moline, Mount Bonnie and South Howley mines.

TABLE 4 SUMMARY OF AQUIFER CHARACTERISTICS, DALY RIVER BASIN

FORMATION	SYMBOL	TRANSMISSIVITY m^2d^{-1}	SPECIFIC YIELD	'SAFE YIELD' $m^3/km^2/yr$
Goolloo	Olo	1500	0.05	190 000 (100 000)*
Jinduckin (Upper)	€01j	10	0.01	55 000
Jinduckin (Lower)	€01j	1500	0.02	100 000
Tindall	€mt	1500	0.035	100 000

(Modified after Jolly, 1984)

*Figure in brackets gives lower 'Safe Yield' where aquifer overlain by Cretaceous sediments.

The Mount Bonnie and Koolpin Formations usually occur within tectonised zones with tight to isoclinal folding and intense faulting. This factor, in combination with the varied lithology and tendency for brittle fracture, has produced a locally intensely fractured aquifer. In zones of dolomite the secondary permeability has been enhanced by weathering with the dissolution of the rock matrix, a feature noted in high yielding bores at both Coronation Hill and Cosmo Howley.

The zones of highest permeability appear to occur along prominent faults and long term bore yields of 10 L/s are possible in such zones, but are not typical. Yields of 0.5 to 2 L/s are obtainable outside major structural features.

4.4.3 Gerowie Tuff

Occurring between the Mount Bonnie and Koolpin Formations, the Gerowie Tuff is lithologically distinct in that it comprises mainly cherty tuff and tuffaceous greywacke. The Formation is prospective for reliable yields up to and sometimes in excess of 5 L/s. Highly permeable zones appear to be confined to fault and shear zones. These are relatively straightforward to identify because

of the contrast between the resistant tuff sequence and the deeply eroded fault zones.

Mine water supplies have been developed in the Gerowie Tuff at Cosmo Howley and Mount Bonnie. It is less extensive than the Mount Bonnie and Koolpin Formation in the Pine Creek Mining Region but is a similarly prospective aquifer in fault zones.

4.4.4 Mundogie Sandstone

The Mundogie Sandstone has been included as a locally prospective aquifer on the basis of results outside the Pine Creek Mining Region and because it occurs in zones of intense folding and faulting. The Formation has a significant extent in the Mount Bonnie - Frances Creek area, in the fold belt northwest of Coronation Hill, and near Goodparla. Bores in a fault zone at Goodparla gave yields of 1 and 1.5 L/s and give the only yield data obtained on the Formation in the region.

4.5 Fractured and Weathered Rocks with Minor Groundwater Resources

The rocks within this category are usually of very low permeability except on fault lines, tensional fold features and where they have been intensely weathered. Even in these

features the zone of enhanced permeability is usually sufficiently restricted such that the sustainable yield is less than 0.5 L/s.

A detailed description of each of the mapped units is not presented due to the relatively uniform nature of the groundwater prospects and lack of significance for mine water supplies. The Burrell Creek Formation is atypical in that sustainable bore yields of 0.5 to 2 L/s are locally obtainable in some shear and fault zones, as is discussed in relation to Pine Creek and Frances Creek in Section 6.2. The granites of the Cullen Batholith are effectively impermeable and offer exceptionally poor groundwater prospects except in fault zones and some quartz veins where small yields may be obtained.

5. GROUNDWATER QUALITY

Throughout the Pine Creek Mining Region the groundwater is typically of low salinity with high levels of bicarbonate and a pH that is slightly acid to slightly alkaline. There are differences in the hydrochemistry of groundwater from the Daly River Basin and Pine Creek Geosyncline.

5.1 Daly River Basin

The groundwater of the Daly River Basin within the Pine Creek Mining Region is usually of low salinity with calcium and bicarbonate water being the predominant major ions. There are significant differences between the water quality of the three Formations comprising the Basin.

5.1.1 Oolloo Limestone

Characteristics of groundwater in the Oolloo Formation are:

- Salinity less than 500 mg/L. Total Dissolved Solids (TDS)
- Total hardness 250 to 500 mg/L and high bicarbonate concentrations
- pH 6.9 to 7.5

This permeable limestone aquifer shows little hydrochemical variation and has reliable water quality.

5.1.2 Jinduckin Formation

The upper part of the Jinduckin Formation generally contains groundwater of less than 500 mg/L TDS but with a hardness in excess of 300 mg/L. The lower part of the Jinduckin Formation has been shown to contain groundwater with high concentrations of calcium and sulphate, probably due to the dissolution of gypsum, corrosive due to the high sulphate content in combination with a slightly acidic pH of between 6.5 and 7.0

5.1.3 Tindall Limestone

The salinity of groundwater in the Tindall Limestone is usually less than 600 mg/L with hardness of between 250 and 450 mg/L. The pH is slightly alkaline and the major ions are predominantly calcium and bicarbonate. The water is therefore suitable for irrigation and domestic use although relatively high fluoride concentrations can be encountered. Fluoride is present in the limestone and in zones where groundwater flow rates are low, the fluoride dissolves such that the concentration of fluoride is close to saturation at the ambient temperature. In the shallow groundwater of the Tindall Limestone, such as shown on the map to the west of Douglas Hot Springs, fluoride concentrations are between 0.3 and 0.4 mg/L.

5.2 Pine Creek Geosyncline

The fractured aquifers of the Pine Creek Geosyncline are characterised by groundwater that rarely exceeds a salinity of 700 mg/L, is high in bicarbonate and contains the cations magnesium, calcium and sodium in proportions tending to be highest in magnesium. The chemistry has been summarised in a modified Durov Diagram (Figure 7).

Although the water quality is generally good, the presence of high

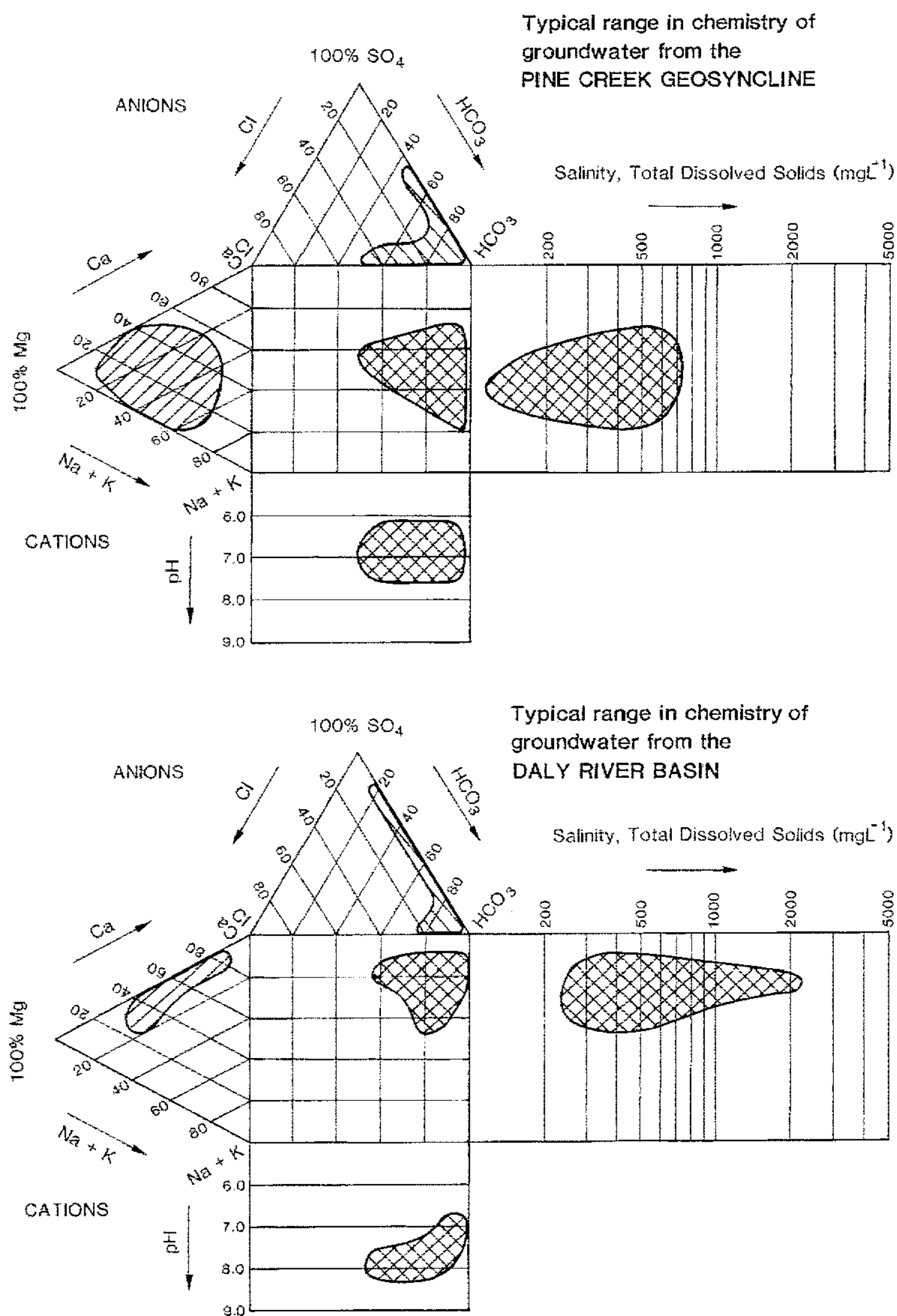


Figure 7 : Durov diagrams showing chemistry of groundwater from the Pine Creek Geosyncline and Daly River Basin

concentrations of heavy metals is of concern in some areas and typically in mining areas where mineralised zones provide the source. The most significant of these trace metals is arsenic which is derived from arsenopyrite and is locally present in concentrations in excess of the Australian Water Resources Council/National Health and Medical Research Council (1987) guideline value of 0.05 mg/L.

At Pine Creek arsenic concentrations are particularly high in the mineralised shear zones adjacent to the granite contact aureole west of the town (Prowse, 1982). The concentration of arsenic decreases eastward in the direction of groundwater flow, due to changes in the hydrochemical environment. The solubility of arsenic is controlled by a number of factors, primarily:

- The distribution of arsenic in host rock
- Eh (oxidation - reduction) potential and pH
- The presence of clay minerals

At Pine Creek the arsenic concentrations decrease from 1.0 mg/L near the contact aureole to less than 0.05 mg/L in the town area, a distance of about 0.5 km. A change from well oxygenated water to near reducing conditions and an increasing proportion of clay minerals in the aquifer produce this rapid change within the flow system.

Supplies for domestic use in mineralised areas should be analysed for other heavy metals to ensure health guidelines are met. The analysis should include copper, iron, lead, manganese, selenium and zinc.

6. EXISTING GROUNDWATER SCHEMES

6.1 Town Water Supply

Pine Creek is the only town in the Pine Creek Mining Region and has a groundwater sourced supply operated

by the Power and Water Authority. The town supply is augmented by groundwater from the borefield of the Pine Creek Goldfields mine (previously Enterprise mine).

It is an indication of the difficulty of obtaining good bore yields in the area that in excess of 100 bores have been drilled for Pine Creek water supply with approximately 10 currently used as production bores. The borefield and area of exploratory drilling is spread over an area of about 15 sq km of the Burrell Creek Formation. Pine Creek town and most of the successful bores are aligned on the Pine Creek Shear Zone. West of the town, high bore yields have been obtained in the zone of mineralisation within the contact aureole of the granite, but in this area the groundwater has high arsenic levels.

Successful exploratory bores typically show initial airlift yields of up to 5 L/s but the sustainable yield of production bores is 0.5 to 1.0 L/s. The sustainable yields are typical of what should be expected in the Burrell Creek Formation which has generally low permeability. The Burrell Creek Formation of the Pine Creek borefield is shown on the map as "Fractured and Weathered Rock with minor groundwater resources". However, at Pine Creek the intensity of investigation work in the area may explain the atypical number of bores with yield in excess of 0.5 L/s.

The safe yield of the borefield has been estimated to be 170000 cubic metres a year (Prowse, 1982), representing an average bore yield of 0.54 L/s, which is only slightly above the upper yield limit for fractured and weathered rocks with minor groundwater resources.

6.2 Mine Water Supply

Mine water supplies in the Pine Creek Mining Region utilise surface water as well as groundwater, as is the case at the active mines of Bridge Creek, Cosmo Howley, Fountain Head,

Moline, Mount Bonnie, Mount Wells, Pine Creek Goldfields and Union Reef. Mining areas usually have sites suitable for surface water storage and impoundments are used to collect runoff and store pumped groundwater.

Data has been obtained for pumping rates and total pumpage from a small number of the mines and a brief description of the schemes at the main mines is given.

At Pine Creek Goldfields, adjacent to Pine Creek townsite and borefield, 34 exploration bores were drilled to establish the groundwater supply, which is used in conjunction with two surface water storages. As in the Pine Creek town water supply borefield, the source is Burrell Creek Formation with attendant problems of low bore yield. Bore yields differ substantially between the wet and dry season. A bore yielding 2.5 to 3 L/s when water levels are highest, toward the end of the wet season, may decline in yield to less than 0.5 L/s toward the end of the dry season.

During 1988 Pine Creek Goldfields, in common with a number of mines, were severely pressed for water supplies due to two successive poor wet seasons which failed to replenish surface water supplies. The operators carted water from Frances Creek and Katherine as well as maximising groundwater extraction. The total pumpage for 1988 was 144000 m³, representing an average bore yield of 0.43 L/s over the year.

At Cosmo Howley, extensive exploratory drilling comprising 41 bores (including 15 on the haul road to Woolwonga) has established a substantial groundwater source in the folded and faulted rocks of the South Alligator Group. Successful bores are mainly on fault features in Mount Bonnie Formation and Gerowie Tuff. The scheme was commissioned in 1988 and hence no long term production data is available but the main production bores are estimated to

have sustainable yields of up to 10 L/s.

To the north of Cosmo Howley at Metana Howley (South Howley), 18 bores were drilled to intersect groundwater supplies from the South Alligator Group. Initially airlift yields of up to 11 L/s were obtained in exploratory drilling but with long term pumping the yields of the few production bores are reported to have declined to about 30% of the airlift figure. No extraction figures are available.

At Moline mine, 38 km northeast of Pine Creek, 13 exploratory bores were drilled in Mount Bonnie Formation and Burrell Creek Formation with seven developed as production bores. Some bores gave initial airlift yields recorded at 20 L/s or more. No extraction figures are available for the recently commissioned scheme. The mine water supply also uses substantial surface water resources.

At Mount Bonnie mine, a few production bores supply process and camp water when surface water supplies are inadequate. In 1989 the pumps were withdrawn from three of these bores as they became submerged under surface water. One of the bores yielded 12 L/s during extended production. The bores are in an area of highly faulted and folded South Alligator Group rocks that should be prospective for good sustainable yields but long term extraction data is not available.

Bridge Creek, Fountain Head and Union Reef mines process alluvial gold only and each obtains groundwater supplies from a small number of bores in combination with surface water supplies.

6.3 Mine Dewatering

Most of the mining operations are open pits of up to 50 m depth. Due to the low intrinsic permeability of most of the rocks, dewatering requirements are generally low. In some cases dewatering requirements

can be met by pumping from a sump in the base of the open pit. Due to the competent nature of the pit wall materials there is no requirement for dewatering to aid slope stability. Where permeable zones are intersected these are liable to dewater quickly due to limited groundwater storage.

6.4 Agricultural Water Supplies

There is no substantial agricultural development outside the Daly Basin within the Pine Creek Mining Region. A grain-growing project in the Douglas/Daly Rivers Area has been established. Supplies of up to 5 L/s are usually available from the Tindall Limestone and Jinduckin Formation in the area, with supplies in excess of 15 L/s in localised areas.

Pastoral water supply needs are not high due to the relative abundance, in many areas, of accessible surface water supplies and the low intensity of stocking. Small stock supplies of up to 0.5 L/s are available in most areas and careful bore siting in the more prospective rock types may obtain much higher yields if required.

7. GROUNDWATER EXPLORATION AND DEVELOPMENT TECHNIQUES

Important tools in groundwater exploration are hydrogeological reconnaissance, interpretation, evaluation of remotely sensed imagery such as Landsat, geological mapping, surface geophysical methods and exploratory drilling. A well designed exploration program will usually incorporate most of these elements, the emphasis on each depending on the area involved and the findings of early results. With the publication of the hydrogeological map of the Pine Creek Mining Region and associated Groundwater Bore Data Base, the following base data is readily accessible:

- Hydrogeology showing rock units, yield potential and important

structural features at 1:250 000 scale, or larger if required

- More detailed geology at 1:100 000 scale from Northern Territory Geological Survey maps
- Location and information for each recorded bore in the area
- Description of the groundwater resource potential and hydrogeological characteristics of each rock unit

In the fractured rock aquifers the success of a groundwater exploration and development program is largely dependent on understanding the factors controlling the location of permeable fracture zones. These are usually dependent on both structure and rock type. In the Pine Creek Mining Region the most prospective rocks are Lower Proterozoic units within zones of tight folding and associated faulting. The rocks have been well indurated and undergo brittle fracture under stress, producing secondary fracture permeability. Sandstones, greywackes and other more massive rock types tend to produce extensive fractures where as shales and fine-bedded siltstones deform rather than produce continuous fractures. In zones of high stress such as faults and the nose of folds, fracturing is likely to be more extensive.

As part of the Pine Creek Mining Region study, a field investigation program was used to determine the optimum method for bore siting in the South Alligator Group rocks. This provided information for bore siting with general application to fractured rock aquifers and data on the relative importance of structure and stratigraphy.

7.1 Field Investigation of South Alligator Group

The area selected for the investigation was the Cosmo Howley - Bridge Creek mining area due to the

large amount of existing drilling information and relatively good access. To provide systematic data coverage within a representative area the geophysics and test drilling were limited to the anticline structure of Cosmo Howley area (refer Figure 8).

Using the aquifer units defined on the new hydrogeological map, a detailed structural interpretation was made using panchromatic aerial photography, Landsat imagery and SPOT (System Probatoire d'Observation de la Terre) imagery. MicroBRIAN (Barrier Reef Image Analysis Network) image processing system was used to enhance the SPOT scenes and improve the definition of structure. Although the full potential of the MicroBRIAN system was probably not realised, the most detailed structural interpretation was obtained using the panchromatic aerial photography at 1:25000 scale. Information from in excess of 50 bores in the area was used to relate bore yield to structural features and stratigraphy. Surface electrical resistivity traverses (refer Figures 9(a) and 9(b)) were run past a number of the higher yielding bores to identify if these were located on any anomalies or had characteristic signature. Seven exploratory bores were drilled to assess anomalies lacking existing bore data and to determine if permeable zones were limited to fault zones or if they extended along strike. Investigation drilling data is summarised in Table 5.

The upper unit of the South Alligator Group, the Mount Bonnie Formation, appears highly permeable along extensive fault zones but is otherwise quite tight. A number of high yielding bores have been drilled on north trending faults transecting the northeast limit of the anticline. Resistivity Line B was run along the strike of the rocks (Figure 9(a)) and shows a broad resistivity trough in which Cosmo Howley bore RN 26247 intersected a permeable zone. Bore RN 26177 was drilled within the same

resistivity low to investigate if the low indicated an extensive fracture zone. Bore RN 26176 gave an airlift yield of 10 L/s, in contrast to Bore RN 26179 and 26178 on the adjacent resistivity highs which gave yields of nil and 2.5 L/s. On the same line, bore RN 26246, sited on a photolineation, is a production bore yielding 10 L/s but showed no resistivity contrast along strike.

In running the resistivity line along strike, the rock types may be assumed to be fairly constant and that zones of lower resistivity are mainly due to fracturing or weathering. The results indicate that along the strike of the rocks the fracture permeability varies considerably, zones of lower resistivity may be a good indicator of fracturing. Koolpin Formation, Gerowie Tuff and Mount Bonnie Formation were incorporated in traverse A which showed two zones of extremely low resistivity in Koolpin Formation. Drilling bore RN 26174 showed these features are due to the presence of highly conductive graphitic black shale, produced in the low grade thermal metamorphism of carbonaceous shale by dolerite intrusions. Bore RN 26248, a high yielding production bore, is in Gerowie Tuff and was sited on a fault line. Bore RN 26175 is in the same zone of variable resistivity closer to the zone of graphitic black shale but not on a defined fault and gave a very low yield. Line A intersects Line B at bore RN 26246, which again showed no resistivity contrast. Bores RN 26245 (28 L/s) and 26173 (10 L/s) both gave high yields in resistivity features that correspond to fault zones.

In summary, fault lines, as identified by air photograph interpretation, generally offer the most favourable drilling targets. Geophysics, in the form of resistivity traverses, can be used to define fault zones of high fracture permeability. Strong resistivity lows in the Koolpin Formation indicate graphitic shale with usually

TABLE 5 COSMO HOWLEY - BRIDGE CREEK AREA DRILLING RESULTS

BORE (RN)	BORE NAME	TOTAL DEPTH	SWL (mbns)*	DEPTH (m)	YIELD (L/s)	EC (uScm ⁻¹)	LITHOLOGY
26174	HC1	56.2	-	-	NIL	-	Black shale(Psk)
26175	HC2	50.1	-	50.1	0.5	430	Shale tuff (Psg)
26173	HC3	44.0	13.0	30.0	3.6	250	Shale, siltstone & quartz (Pso)
				42.8	10.0	250	
26176	HC4	31.8	10.7	30.0	1.6	270	Amphibolite (PdZ)
26177	HC5	66.5	24.9	45.6	0.8	-	Shale, phyllite & quartz (shear zone)
				60.0	2.2	200	(Pso)
				65.0	10.0	200	
26179	HC6	77.1	-	-	NIL	-	Phyllite, tuffaceous shale & chert (Pso)
26178	HC7	52.7	19.0	39.0	1.3	250	Shale, phyllite, chert, vein quartz
				52.7	2.5	-	(Pso)

*mbns - metres below natural surface

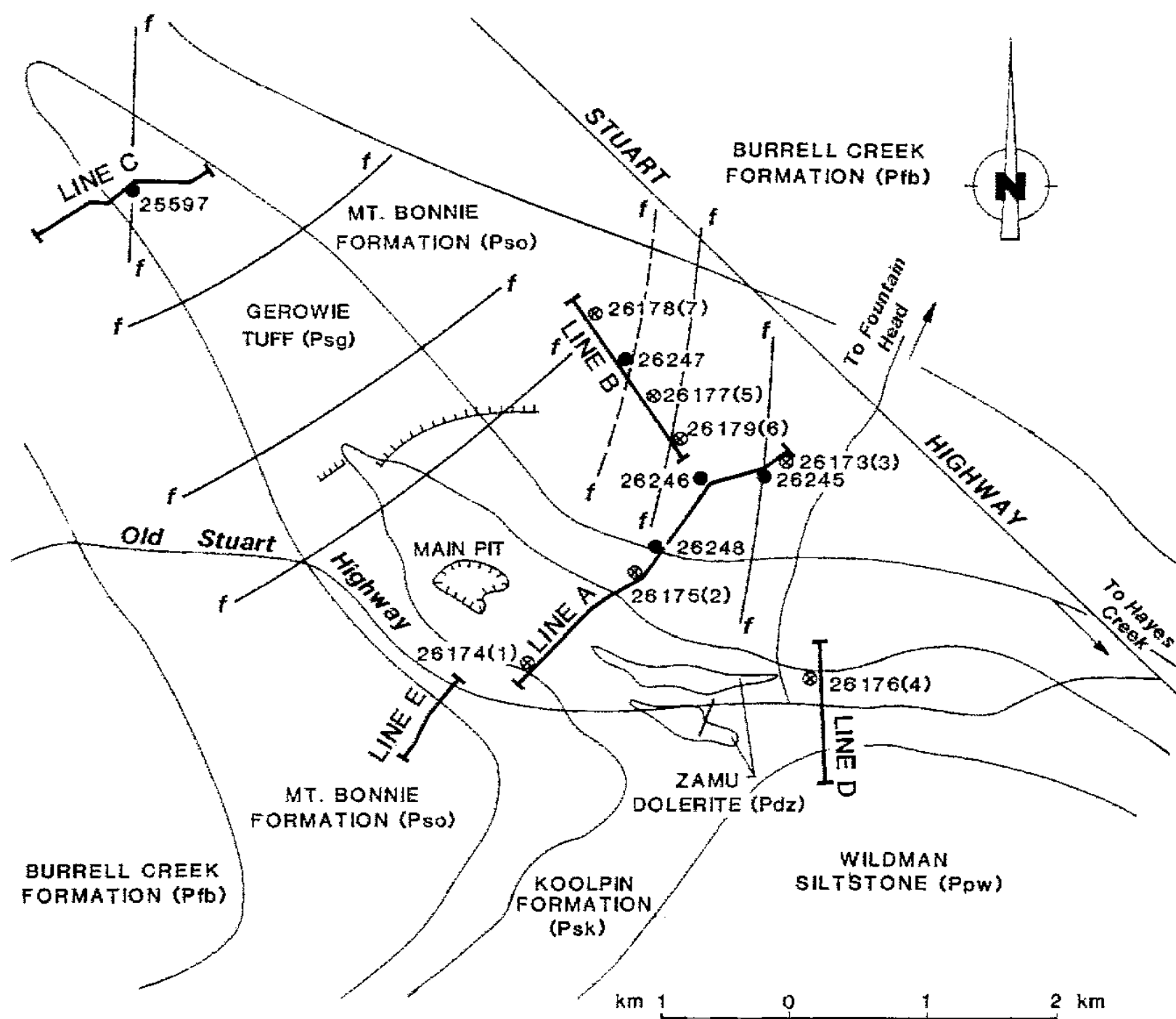
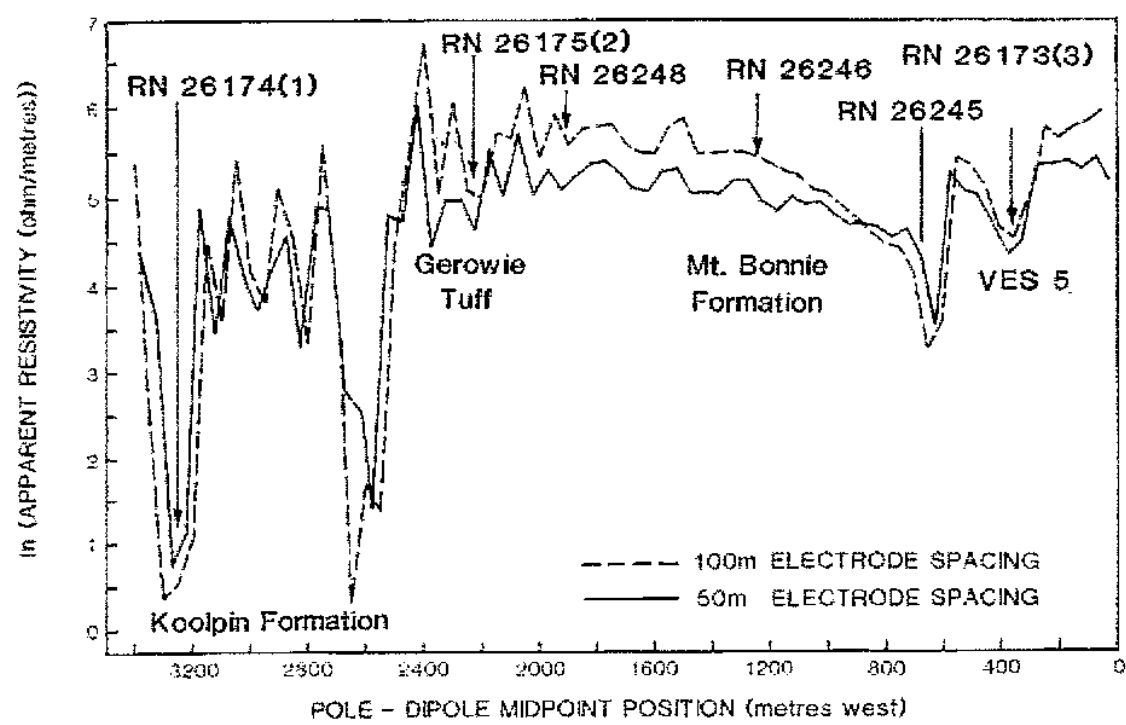
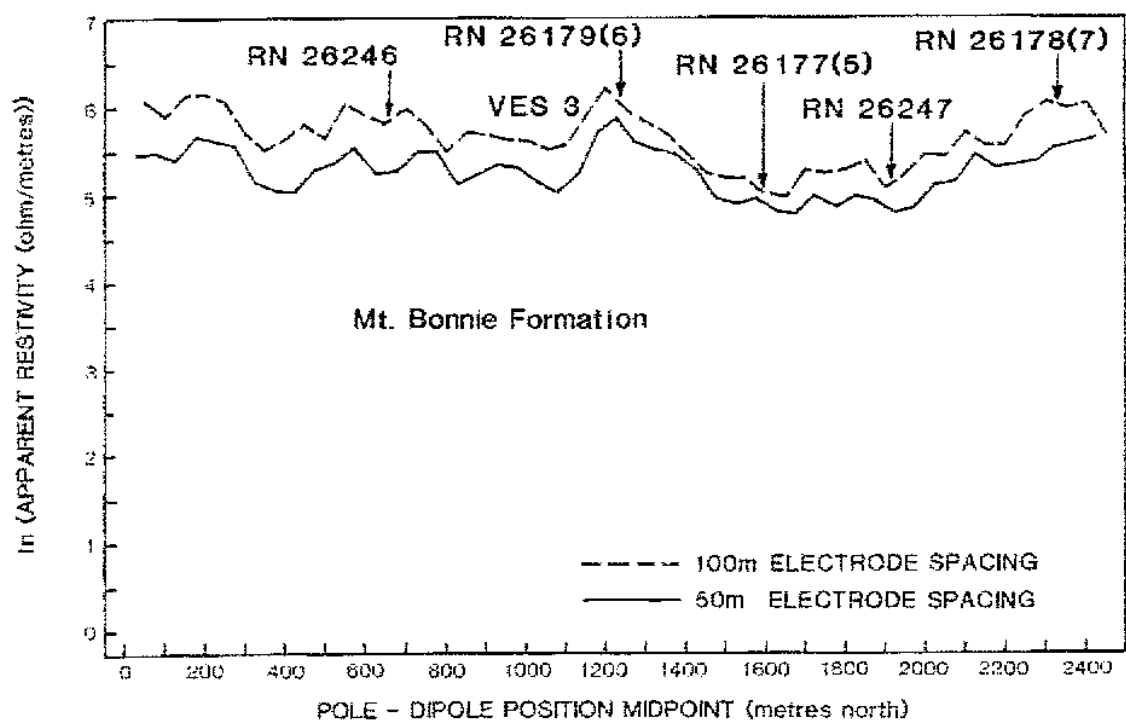


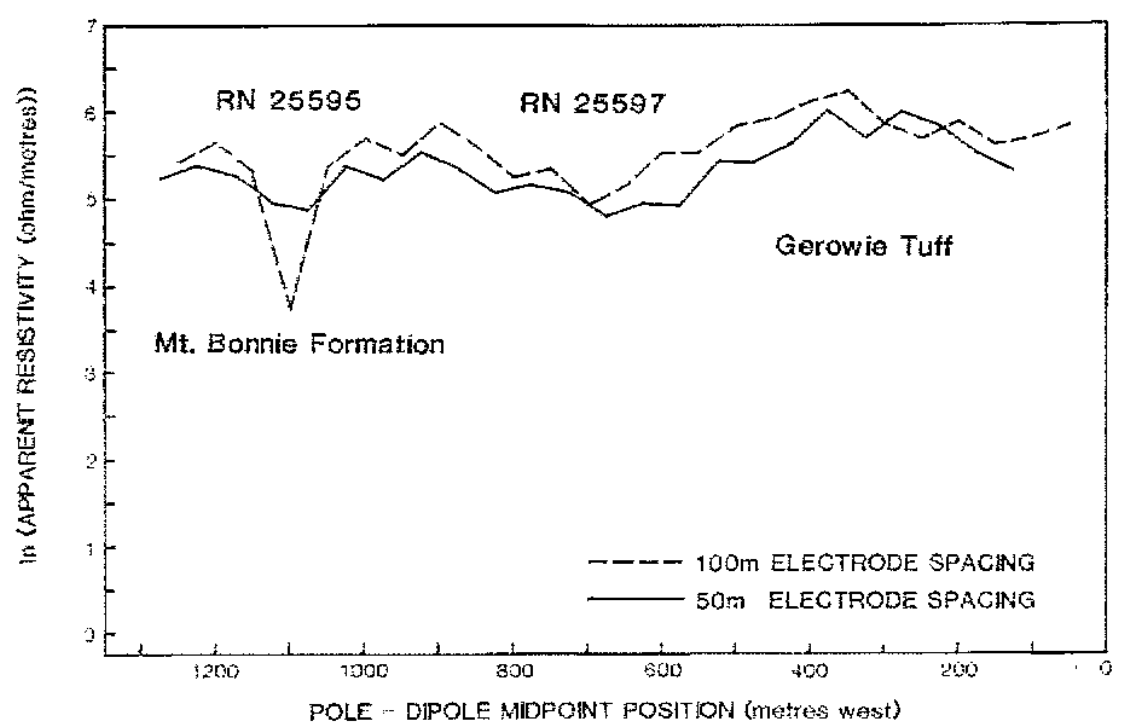
Figure 8 : Field investigation of South Alligator Group



AREA :
COSMO HOWLEY
LINE :
A

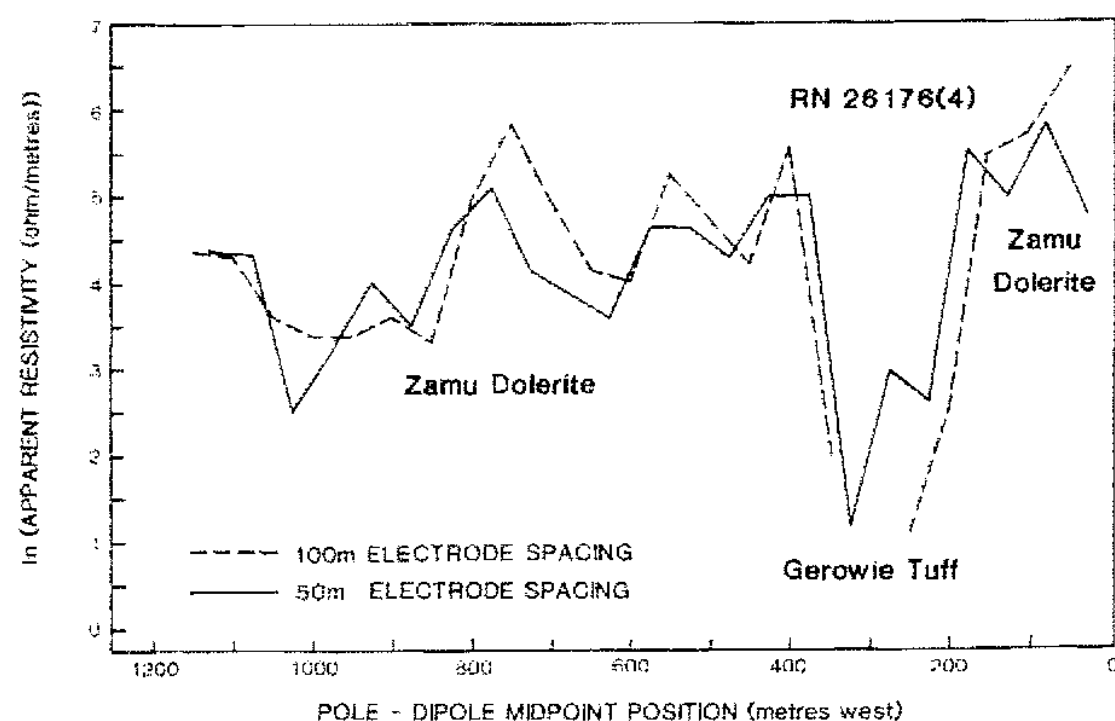


AREA :
COSMO HOWLEY
LINE :
B



AREA :
COSMO HOWLEY
LINE :
C

Figure 9(a) : Surface Resistivity Profiles for South Alligator Group

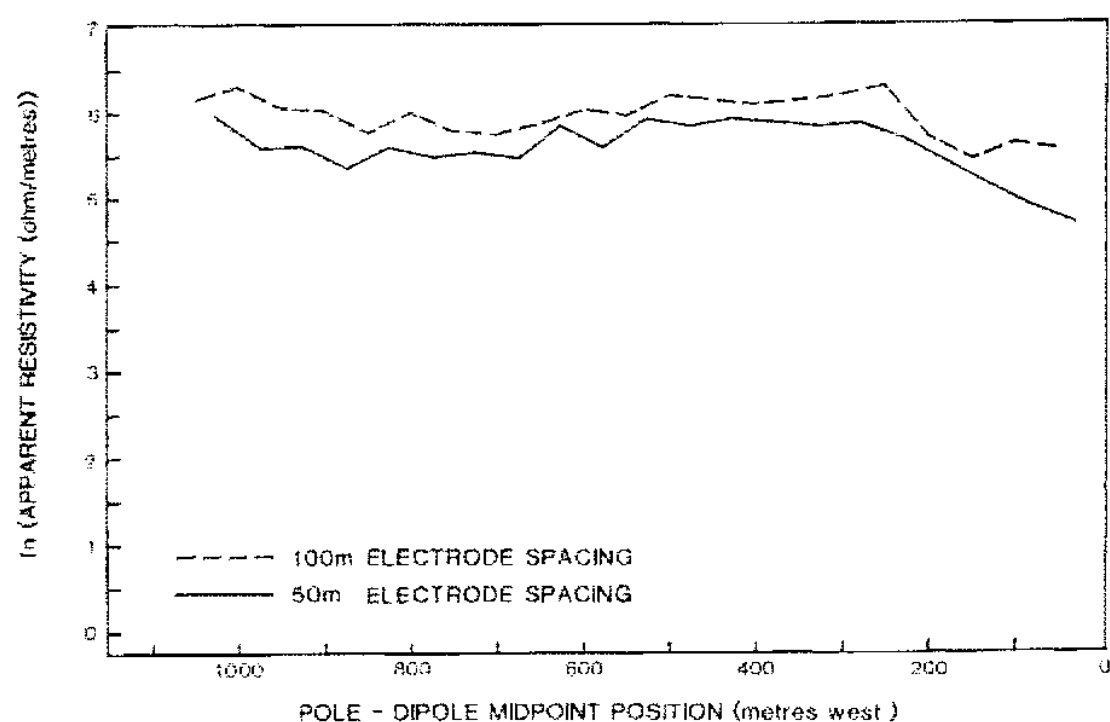


AREA :

COSMO HOWLEY

LINE :

D



AREA :

COSMO HOWLEY

LINE :

E

Figure 9(b) : Surface Resistivity Profiles for South Alligator Group

no supply potential. Based on the investigation and results from other areas, the Mount Bonnie Formation may be the most prospective unit in the South Alligator Group.

7.2 Bore Depth

Determining the depth to which a groundwater bore should be drilled in a fractured rock environment can be critical to the successful intersection of a high yielding zone and to maintaining cost effective operation.

Table 6 summarises the results of a statistical analysis of bore depth and yield data in the Pine Creek Mining Region. The results provide a guide to target drilling depth in the different aquifer units. Areas have been identified by 1:100 000 sheet name (1:10 000 in the case of the area of high bore density at Pine Creek). Where only small numbers of bores in one aquifer unit occur in an area, the statistics are probably not meaningful and are not shown.

TABLE 6 BORE DEPTH AND YIELD STATISTICAL SUMMARY

1:100 000 Sheet	Aquifer Unit	Mean bore Depth (m)	Mean Airlifted Yield (L/s)	Number of Bores
Batchelor	Pso	46	4.7	11
	Psg			
	Psk			
McKinlay River	Pfb	38	0.8	21
Pine Creek 0910 (1:10 000)	Pfb	52	2.7	17
Playford 0906 (1:10 000)	Pfb	45	1.7	53
Pine Creek 1010 (1:10 000)	Pfb	52	0.8	17
Ranford Hill	Pfb	75	7.3	32
	Psg			
Ranford Hill	Pso	81	6.2	20
Tipperary	Olo	94	5.0	5
Tipperary	COlj	79	2.0	9
Tipperary	Cmt	65	6.8	2
Tipperary	Ppw	57	0.8	11

7.3 Bore Yield Prediction

In the fractured rock aquifers of the Pine Creek Mining Region the yields initially obtained from bores, typically by airlift testing, are rarely sustainable.

With prolonged pumping the cone or zone of drawdown becomes more extensive and intersects less permeable zones. As the more permeable zones dewater, the rate of flow at the bore is not sustained.

The problem of yield reduction is often seasonal, with the problem becoming acute toward the end of the 'dry' season. Natural seasonal variation in water table levels often exceeds 5 metres so the saturated aquifer thickness reduces considerably when there is no rainfall recharge.

As a general guide approximately one-third the initial yield may be sustainable but it is not uncommon for the yield to reduce even further. Test pumping can give an

indication of 'barrier' or lower permeability boundaries that will reduce yield in the short term but prohibitively long tests are required to adequately assess the long term effects. It is therefore essential to design a groundwater supply scheme with the assumption that initial yields will reduce substantially. It is also important to monitor the performance of borefields once commissioned and reassess sustainable yields after production for 12 months.

8. SUMMARY OF GROUNDWATER RESOURCES

The groundwater resources of the hydrogeological units shown on the Pine Creek Mining Region map are summarised:

Oolloo Limestone (Olo):

Bore yields in excess of 15 L/s and often up to 50 L/s are available from the extensive and highly permeable sandy dolomitic limestone aquifer. Yields are likely to be sustainable.

Jinduckin Formation (Jolj):

The lower part of the Jinduckin Formation is quite prospective for bore yield although locally the salinity is in excess of 2000 mg/L TDS mainly due to dissolved calcium sulphate. The upper section of the Jinduckin Formation will give yields in the range 0.5 to 5.0 L/s that will generally be sustainable.

Tindall Limestone (Tnt):

Typically the Tindall Limestone in the Pine Creek Mining Region yields between 0.5 and 5.0 L/s but a more permeable zone has been defined to the west of Douglas Hot Springs with bore yields exceeding 15 L/s. Yields should be sustainable except where the aquifer has limited areal extent.

South Alligator Group (Pso, Psg, Psk):

Sustainable bore yields of 0.5 to 5 L/s can be obtained from fracture zones. Bores require careful siting on fault or shear zones to obtain good results. Very high initial yields, say up to 30 L/s, will usually reduce substantially with prolonged pumping.

Mundogie Sandstone (Ppm):

This unit has been classified as a prospective fractured aquifer on the basis of results from other areas but it has not been adequately tested in the Pine Creek Mining Region.

The Mundogie Sandstone is very limited in occurrence, being present only along the extension of the fold belt through Coronation Hill, El Sherana and Goodparla.

Fractured and Weathered Rocks with Minor Groundwater Resources

The units within this classification are generally not significant in terms of groundwater resource potential for substantial developments such as mines. Exceptionally the Burrell Creek Formation can provide sustainable bore yields of 0.5 to 2 L/s in zones of intense alteration, faulting or shearing as at Pine Creek.

9. USE AND APPLICATION OF THE MAP

The 1:250 000 scale hydrogeological map of the Pine Creek Mining Region can be used to:

- Provide a basic understanding of the hydrogeology of the region.
- Assist the planning of groundwater resource development and management.
- Identify areas of groundwater resource potential to aid future developments, particularly for mining.
- Obtain hydrogeological data for application to land-use planning, waste disposal management, civil engineering and environmental studies.
- Highlight areas of underdeveloped groundwater resource potential where industry and agriculture may be viable.

It is strongly recommended that users who are not familiar with the principles of hydrogeology utilise the map in combination with these Explanatory Notes and specialist groundwater guidance.

10. ACKNOWLEDGEMENTS

The Hydrogeological Map of the Pine Creek Mining Region and accompanying Explanatory Notes and Bore Data Base are the product of a co-operative project by the Power and Water Authority of the Northern Territory, and Dames and Moore Pty, acting as consultants to the PAWA.

The project team comprised:-

P Jolly - Project Co-ordinator
 R J McGowan - Project Manager
 (Dames & Moore Pty)
 L J Fritz - Cartographer
 H Qureshi - Senior Hydrogeologist
 M Verma - Senior Hydrogeologist
 H Lino - Technician
 N Kato - Technician

Particular thanks are due to L Fritz for his work on the PAWA Intergraph Computer Aided Drafting System, to M Verma for his work on the geological maps, bore data base and drilling program, to H Lino for valuable technical support and to N Kato for his dedication to compiling the bore data base. P Jolly provided valuable technical advice throughout the project.

The project benefitted substantially from the data provided by mining companies and special thanks are due to Billiton Australia Gold, Coronation Hill Joint Venture, Cyprus Australia Gold Corporation, Dominion Gold Operations and Pine Creek Goldfields. A substantial amount of data was also supplied by R Hunt of the Environmental Section of the Department of Mines and Energy.

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APPENDIX I

MAP PREPARATION METHOD

COLLECTION OF DATA

The data on which the map is based comprised:

- 1:100 000 scale geological maps published by the Northern Territory Geological Survey (NTGS).
- Bore information from the Power and Water Authority bore data files.
- Results from groundwater investigations by the Power and Water Authority and previous government instrumentalities, including major studies for Pine Creek town water supply and for the Daly River Basin.
- Information from a bore census conducted in late 1988.
- Hydrometric gauging information from the records of the Power and Water Authority and Bureau of Meteorology.
- 1988 air photography, Landsat imagery and SPOT imagery.

The geological maps, most of the bore data and most of the reports were available at the commencement of the project, other data was compiled during the project.

DATA PROCESSING

The basis of the hydrogeology shown on the map is the geology on the BMR and NTGS 1:100 000 scale maps. The detail shown on those maps is too great for successful reproduction at 1:250 000 scale and not essential in the representation of the groundwater resources. Geological Formations or Groups are shown on the maps according to their hydrogeological significance. Boundaries have been simplified where necessary and in some instances subjected to slight revision according to new information or air photograph interpretation.

The groundwater resource potential of the various Formations and Groups was assessed using bore data, report information and with some reference to work outside the Pine Creek Mining Region. The bore data was plotted on 1:100 000 scale maps to assist identification of the geologic units intersected by each bore, and provide an overview of the data in plan form. The appropriate subdivision of the geology was finalised using the data. The field investigation of the South Alligator Group confirmed previous ideas of the water resource potential of these rocks.

As part of the determination of aquifer yield characteristics and also to provide a guide to appropriate bore depths a statistical analysis of bore yield and depth data was undertaken using Stat View IV software on a Macintosh PC. A full description of the results of this analysis are outside the scope of these Explanatory Notes but some simplified results are given in the main text in Section 7.

Water table contours for the Daly River Basin were drawn on the basis of groundwater levels from bores, the RL of perennial pools, springs and groundwater-fed rivers, and the control provided by surface topography.

APPLICATION OF THE CAD SYSTEM

The data for the production of the hydrogeological map is held on 29 levels in one design file on the Integrator CAD system. Sixty-three levels are available. The information contained on each level used is as follows:-

3. Rivers, creeks for 1:250 000 topographic map
4. Creeks for 1:100 000 topographic map
5. Major roads, major tracks, railway, telephone lines, airstrips

6. Buildings, built-up area
7. Swamps
8. Fences, gates, grids for
1:100 000
9. Mountain symbols
10. Cadastral
12. Geological boundaries for
1:250 000
13. Faults, shear zones, quartz veins
for 1:250 000
14. Anticlines, synclines and other
structure symbols
15. Hydrogeological patterns for
1:250 000
16. Hydrogeological patterns for
1:100 000
17. Geological boundaries for
1:100 000
18. Bore locations, areas of open cut
mining for 1:250 000
19. Bore locations, areas of open cut
mining for 1:100 000
20. Mine symbols
21. Perennial ponds, water holes,
dams and sink holes
22. Springs
23. Surface water divides
24. Water table contours
25. Groundwater flow lines
26. Faults, additional detail for
1:100 000

54. 5' points
55. Australian Metric Grid (for set
up purposes only)
56. Border (for set up purposes only)
57. Border ticks (for set up purposes
only)
58. Latitude and longitude text
59. 5' cross marks

The legend, cross sections, side maps and text were compiled in a second design file which was linked to the main map file for plotting purposes.

The process of digitising all the data is time consuming but once installed on the CAD system provides great flexibility in finalising the information to be shown on the map. Initial experience guided the level of details used for digitising the rest of the data. In complex areas considerable editing was required to maintain visual clarity for the 1:250 000 scale map. In the case of geological boundaries and structural features the additional detail was transferred to another level so that it could be included in the production of large scale maps.

APPENDIX 2**BORE DATA BASE****DESCRIPTION**

The Bore Data Base is held on the Power and Water Authority Vax mainframe computer and is also available for use on PC-based word processing software. The data was input using MicroSoft (Inc) WORD (Version 4.0) using 132 character width format.

ACCESS

The complete Bore Data Base, in either Lithologic or Stratigraphic Versions, is also available in bound hard copy format as a supplement to these notes or separately. The Bore Data Base incorporates information on 602 bores detailing:-

RN	-	Registration Number
Grid Reference	-	Australian Metric Grid Reference, given in full to the nearest 100 m or 10 m.
Bore Name	-	Name of project reference number
Date drilled	-	Simplified information giving dimensions of cased and open or "perforated" sections
Construction Details	-	Depth to which bore was drilled, rather than base of bore as completed
Depth Drilled	-	Depth at which a permeable zone was intersected
Aquifer Depth	-	Static water level in metres below natural surface usually from date drilled unless shown as otherwise
SWL(m)	-	Usually airlift yield unless pumping test indicated
Yield (L/s)	-	Description of geology based on drillers log or other if available
Drillers Log (Lithology Version)	-	Interpreted geology based on drillers log and knowledge of local rock types
Lithology (Stratigraphic Version)	-	Geologic formation symbol - refer to Table 3, Stratigraphic Summary in main text
Stratigraphy (Stratigraphic Version)	-	Additional information, as available, in bore status, date of SWL, availability of geophysical log, whether test pumped etc
Remarks	-	

