GEOTHERMAL DEVELOPMENT IN AUSTRALIA

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ABSTRACT

In Australia. natural hot springs and hot artesian bores have been developed for recreational and therapeutic purposes. A district heating system at Portland, in the Otway Basin of western Victoria, has provided uninterrupted service for 12 years without significant problems, is servicing a building area of 18 990 m^2, and has prospects of expansion to manufacturing uses. A geothermal well has provided hot water for paper manufacture at Traralgon, in the Gippsland Basin of eastern Victoria. Power production from hot water aquifers was tested at Mulka in South Australia, and is undergoing a four-year production trial at Birdsville in Queensland. An important Hot Dry Rock resource has been confirmed in the Cooper Basin. It has been proposed to build an HDR experimental facility to test power production from deep conductive resources in the Sydney Basin near Muswellbrook.

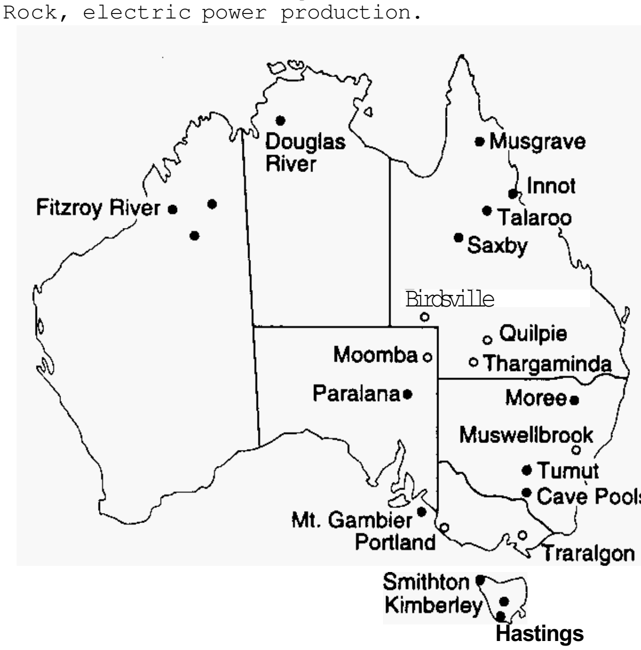


Figure 1: Locality map of Australia. Solid circles are natural resurgences. Open circles are mar-made developments.

1. INTRODUCTION

Some of the geothermal localities mentioned in this report are shown in Figure 1.

units of measurement used here include heat flow units (1 hfu = 41.84 mM/m^2); heat generation units (1 hgu = 0.4184 $\mu W/m^3$); and thermal conductivity units (1 tcu = 0.4184 W/m.K).

2. HEAT FLOW IN AUSTRALIA

Heat Flow in Basement Rocks: The provincial heat flow relation is $Q_t = Q_r + D*P$, where Q_t is the total heat flow observed at the surface, Q_r is the reduced heat flow, and P is a heat production (Roy et al., 1968). This corresponds to a crustal model in which Q_r is the heat flux from the mantle, while D is the logarithmic decrement of a distribution of heat production which decreases exponentially with depth (Lachenbruch. 1970).

In Australia, Sass & Lachenbruch (1979) recognized three heat flow provinces (Figure 2 and Table 1). The Western. Central and Eastern provinces correspond fairly closely to regions underlain by Archaean, Proterozoic and Palaeozoic basement rocks, respectively.

The Western province has very low heat flow, consistent with depletion of heat producing minerals at depth and their concentration near the surface. The Eastern province has very high heat flow, comparable to the Basin and Range in North America.

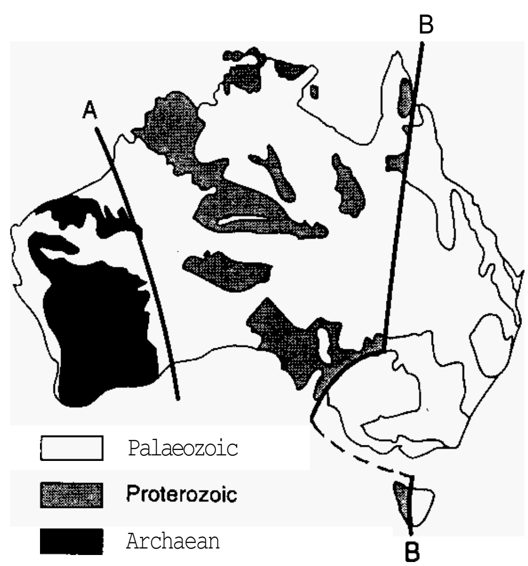


Figure 2: Map showing the Western, Central and Eastern heat flow provinces of Sass *L* Lachenbruch (1979). Lines marked A and B are the approximate boundaries between provinces. The shaded areas sketched in each province are the areas of outcrop of the basement rock of that province.

Province	n	Qt		Qr	D	P	
		mean	sd.			mean	sd.
Western	9	0.93	0.22	0.63	4.5	7.20	6.93
Central	13	1.93	0.48	0.64	11.1	11.74	4.66
Eastern	9	1.99	0.64	0.19	31.3	5.78	1.77
East 2	9	1.99	0.64	1.35	(11.1)	5.78	1.77
units		hfu	hfu	hfu	km	hgu	hgu

Table 1: Provincial heat flow in Australia. Qt and P are from n paired observations. Qr and D are from regression of Qt on P (Western, after Jaeger. 1970; Eastern and Central, after Sass & Lachenbruch, 1979). Row 4 is explained in the text.

Sass & Lachenbruch (1979) explained the high heat flow in the Eastern province by a model in which the geothermal regime was essentially the same as for the Central province, with the addition of superimposed advective disturbances. Using D = 11.1 km, they recalculated Q_r = 1.35 hfu for the Eastern province (row 4 in Table 1). Compared to heat flow values for the Central and Western province values near 0.65 hfu, this implies that as much heat is being carried into the crust by advection as is being generated internally.

Independently of heat flow studies, Wellman & McDougall (1974) found a pattern of basaltic magmatism, migrating southwards along the eastern seaboard, at the rate of 65 km/Ma. The magmatism at any one latitude changes from intrusive dykes and plugs to central volcanics. indicating a change from extensional to compressive stress. The advective component of heat flow is supplied by intrusion of magma into the upper crust. The result is higher heat flow in the southern part of the Eastern province, near the youngest volcanic rocks, which was therefore considered the most prospective geothermal area by Thomas (1975).

Heat Flow in Sedimentary Basins: The Australian basement is overlain by sediments up to 9 km deep in a large number of overlapping basins.

The conductive heatflow relation for an interval of a single dry well is $Q_s = K*G_s$ where K is the thermal conductivity of the rock and G_s is the temperature gradient. measured from temperature logs of the hole or from the difference between top- and bottom-hole temperatures.

For the Otway Basin near Porrland (Figure 1), King et al. (1985) found gradients ranging from 30 to 69 mK/m. with an average G_s of 36 mK/m. cull (1979) found single-weli gradients from 24 to 49 mK/m, which with a thermal conductivity of 6.0 tcu, yields conductive heat flows of 1.4 to 2.9 hfu. For the Gippsland Basin near Traralgon (Figure 1), G_s ranges from 10 to 250 mK/m (King et al., 1985).

For the Great Artesian Basin, in the Musgrave - Birdsville - Moree area (Figure 11, about 4700 water wells have been drilled. Polak & Horsfall (1979) found gradients in the range 15.4 to 102.6 mK/m, with G_s averaging 48 mK/m. With thermal conductivity of 4.8 tcu, the implied conductive heat flow is 2.3 hfu.

For the Cooper Basin; near Moomba (Figure 1), Kelemen (1993) reported temperatures of 204°C at 2926 m and 253°C at 3707 m, these are average temperature gradients of 70 and 68 mK/m. Middleton (1979) compiled gradients from 30 oil wells in three gasfields. Gradients G_s ranged from 45.36 to 65.38 mK/m. He estimated the average conductivity at 5.00 tcu, yielding conductive heat flows in the range 2.56 to 2.61 hfu. He attributed the high heat flow to a "hot" basement granite, with P in the range 17.5 to 24.2 hgu, overlain by about 2 km of sediments derived from the granite, with P about 2 hgu.

3. HYDROTHERMAL RESOURCES

Some natural hydrothermal manifestations in Australia are shown in Figure 1. Steam fields are unknown. Some hot Springs are due to hydrothermal circulation in fissures in impermeable basement rocks. However the principal hydrothermal resource is confined flow in hot water aquifers in the Sedimentary basins.

The locations of groundwater basins in Australia are shown in Figure 3. The basins can be ranked for permeability in terms of their potential productive capacity, as shown in Figure 3.

For basins, the multi-well "gradient" G_m is determined by linear regression of bottom-hole temperatures from a large number of different wells in the same basin. Figure 4 shows bottom-hole temperatures for the Otway Basin, after King et al. (1985), with the linear regression line. The gradient G_m is found to be 29 mK/m.

Hydrothermal Resources of the Otway Basin: This basin is an east-west trending wedge of permeable Cainozoic sediments which thicken from the northern edge to over 3000 m in the South.

Water temperatures of 30 wells in the Otway Basin range from 26.0 to 62.0°C (King et al., 1985). In Figure 4, they yield a gradient G_m of 29 mK/m. The scatter indicates potential vertical circulations up to 300 m.

The relatively low heat flow was attributed by Sass & Lachenbruch (1979) to a regional hydrodynamic heat sink Similar to the Eureka Low in Nevada. Water flows are generally

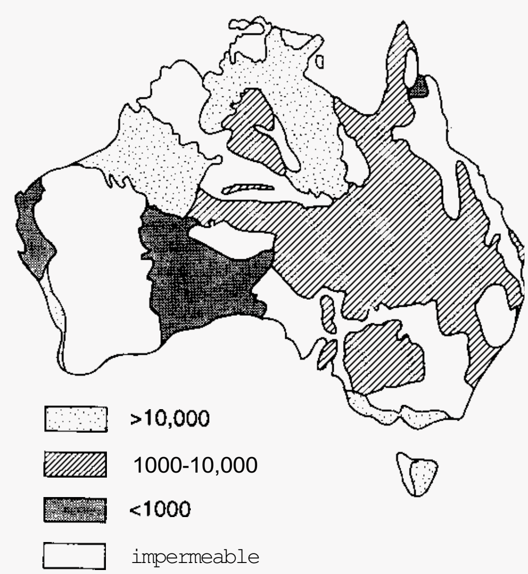


Figure 3: Sketch map of groundwater basins in Australia. Shading is according to potential annual yield of freshwater per unit area in units of m^3/km^2.

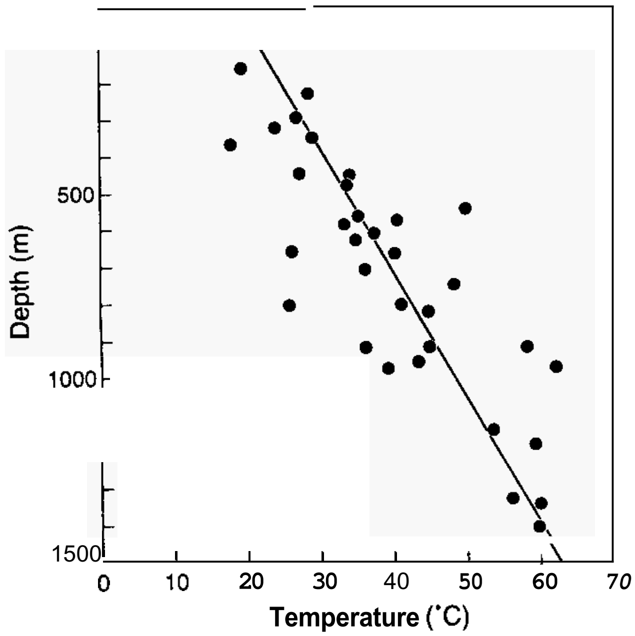


Figure 4: Temperature of water in open wellbores as a function of depth, Otway Basin, Victoria.

north to South. The main aquifers in the Otway Basin are in the Dilwyn Formation, and their estimated discharge to the sea. along 240 km of coastline, is 28 kL/s **(8.8E+8 m³/yr)**, representing a heat flow of 1.160 MW(t) (King et al., 19851. So in this case, the heat is carried across the Coastline into the sea.

Hydrothermal Resources of the Gippsland Basin: This basin is an east-west trending graben containing up to *6000* m of Cainozoic sediments. The main aquifer is the Latrobe Group. Water flows are generally from NW to the sea coast, at a rate estimated at 1800 ML/yr **(1.8E+6** m³/yr). The flow has been reversed near Morwell by massive dewatering of brown coal mines.

Water temperatures of 201 wells in the Gippsland Basin range from 19.1 to 166.8°C (King et al., 1985). Good quality water of 50°C or above is available in three sub-basins: 70°C at a depth of 524 m, 60°C at 1800 m, and between 35 and 50°C. Gradients G_s above 56 mK/m are due to structurally-controlled hydrothermal plumes.

Hydrothermal Resources of the Great Artesian Basin: This large central basin covers about 20% of Australia, with Mesozoic Sediments up to 3000 m thick. The aquifers are recharged along the eastern margin. Water flows to the southern and western margins, to discharge at structurally controlled mound springs. Aquifer thicknesses range **up** to 600 **m**, and flow rates near the intakes range from 1 to 5 **m/yr.**

Water temperatures are generally in the range 30 to 50°C, but in many areas the well head temperature exceeds 100°C, with values as high as 121°C (Polak & Horsfall, 1979). From 940 water bores, Cull & Conley (1983) estimated the multi-well gradient G_m at 51.1 mK/m for shallow wells (depth range 0 to 500 m), and 38.6 mK/m for all wells (depth range 0 to 2000 m). The scatter indicates a possible range of vertical circulation up to 700 m. The discharge at mound springs ranges from 20 to 40°C. Boiling water has been flowing from hot bores for periods of many years. Flows have been recorded from individual bores which exceed 10 000 m³/day.

4. HYDROTHERMAL DEVELOPMENT

The Only developments operating at the present time are at Portland and Quilpie. Developments at Traralgon and Mulka have been abandoned.

Developments in the Otway Basin: Since 1956, the city of Portland has drawn its water from aquifers in the Dilwyn Formation at a depth of 1400 m. There are four bores (Figure 5):

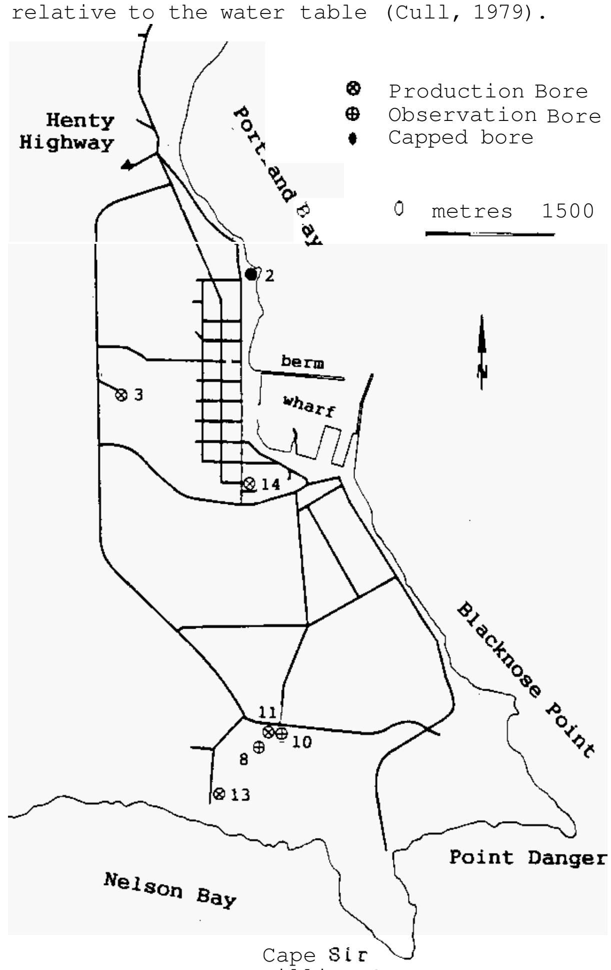
Wyatt Street Bore (No.3 on Figure 5) drilled in 1956, refurbished in 1988, which is artesian and flows at 45 L/s.

Bald Hill No.1 Bore (No. 11) drilled in 1970 which is subartesian and is presently fitted with a submersible 110 kW(e) Hitachi motor with a 75 L/s turbine pump.The head of this bore was enlarged in 1990 to allow flow to be increased to 100 L/s if required.

Bald Hill No. *2* Bore (No. 13) drilled in 1979/80 which is subartesian and is fitted with a submersible 132 kW(e) Hitachi motor with a 100 L/s turbine pump.

Henty Park Bore [No. 14) drilled in 1983 is an artesian bore which flows water at a surface pressure of 300 kPa (30 m head), at the rate of 90 L/s.

Most bores have to be pumped, and a flow rate of 70 L/s can generally be maintained for the subartesian wells at a drawdown of about 25 m relative to the water table (Cull, 1979).



Cape Sir William Grant

Figure 5: Portland area map, showing locations of bores. After King et al. (1985).

The temperature of the water of the bores is 56 to 59°C which until 1983 was cooled by forced ventilation cooling towers to between 26 and 34°C before being placed in the City's water reticulation system for consumption. The bore waters are palatable for domestic use. Chemical analyses in Buckingham (1993, App.A) show that the only Significant constituents in the untreated bore waters are chloride (Cl) 140 to 190 mg/L; bicarbonate (HCO_3) 330 to 465 mg/L; and sodium (Na) 200 to 250 mg/L. Total dissolved solids range from 640 to 780 mg/L; and total hardness from 30 to 110 mg/L as $CaCO_3$.

In 1983 a system was developed to utilize the geothermal energy from the Henty Park Bore to heat various Council buildings and complexes as listed below. In the Swimming Complex, the outdoor pool is held at a temperature of 26 to 28°C and the volume is currently 2000 m^3, consuming 800 kW(t). The Spa Bath is held at 38°C.

Municipal offices	2850 m^2
Civic Hall	1095 m^2
CEMA Arts Centre	417 m^2
Senior Citizens	325 m^2
Open Air Swimming Pool Complex (water volume)	2000 m3

Reticulation to these complexes was via a 150 mm diameter A.C. pipe with the Same Size return pipe to return the water after the heat has been extracted from it to the cooling tower where it is placed over the tower to further cool it and remove any H_2S gas before it is placed into the city's water reticulation system for consumption.

Since the initial installation, the system has now been extended to include the buildings listed below. The new hospital is 140 beds. The area of 7000 m^2 comprises 5500 m^2 for patient Services and 1500 m^2 for general services.

Portland & District Hospital	7000 m^2
Richmond Henry Hotel/Motel	2258 m^2
Police Station(except the cells)	1109 m^2
Municipal Library	810 m^2
Tourist Information Office	164 m^2
History House	172 m^2
Multi-Purpose Building	850 m^2
Indoor Leisure & Aquatic Centre	1940 m^2

The total length of the delivery line is 1,700 m (Figure 6). The water reaches the Hospital, at the end of the Pipe system. at 56°C which means that it bas lost only 3°C from the bore head.

Recently a section of the 150 mm diameter A.C. delivery main has been replaced with a 225 mm diameter CL/DI (cement lined ductile iron) pipe to reduce the friction head and allow a greater volume to be reticulated through the system.

In the last 20 years there has been only a slight reduction in the Static head of approximately 1.0 m but this is believed to be as a result of variations in climatic conditions over the years as it has been calculated that only 10% of the recharge of this huge basin is presently being utilised (approx. 10 000 km4). There has been no change in the bore head temperature Over the past 20 years.

Due to the quality of the water, no problems have occurred with scaling or corrosion. Care was taken when the system was first installed to use appropriate materials in the heater exchange plates and pump shaft etc. (i.e. Stainless steel). Heat exchangers are cleaned simply by washing down the plates in warm soapy water when they are checked as Part of a yearly preventative maintenance program.

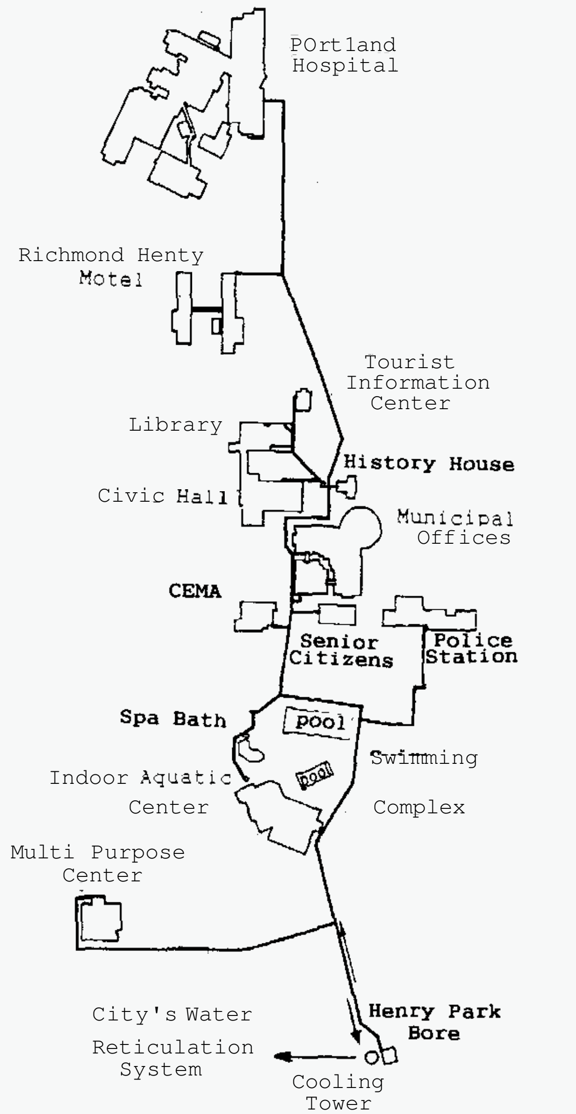


Figure 6: Geothermal reticulation at Portland at the end of 1994.

As the water being used to supply the geothermal heating is to he consumed by humans afterwards, care has also been taken to ensure that a positive pressure is maintained on the primary Side of the heat exchanger plates compared with the secondary side (i.e. building reticulation).

Savings in heating costs, compared to conventional fuels, are estimated to be over $300.000 (Aust.) per annum. The system is at present only using one bore (Henty Park) although it is likely in the near future that other bores will be brought into production for proposed new developments.

Development in the Gippsland Basin: During the 1950's. 68°C water from a depth of 600 m in two wells was used for paper manufacture near Traralgon (Cull, 1979). The wells were abandoned after a number of years due to unspecified problems (King et al., 1985).

Development in the Great Artesian Basin: Water supplies drawn from hot aquifers are fairly common throughout inland Australia.

One notable supply is Quilpie, in Queensland. where boiling water from bores 1000 m deep, is cooled for domestic use.

Binary cycle systems and flash-steam generators of 20 kW(e) capacity were tested using hot artesian bores at Mulka cattle station in South Australia hut no commercial development followed (Cull, 1993).

The Birdsville geothermal power Station has been built as an experimental unit to demonstrate the conversion of low temperature thermal energy into electricity. The plant utilises the energy in the town's water bore to operate an organic Rankine cycle engine designed to produce an electrical output of Some 150 kW(e). The plant provides electricity to the town grid which is an isolated System whose alternative source of electricity is from diesel driven generators.

The town bore taps into the Great Artesian Basin. It has been flowing for some 75 years. The depth is **1221** m and the aquifer depth is **1173** to 1220 m. The bore casing is **a** nominal 6 inch diameter and the flow is about 30 L/s with a shut in pressure of 1213 kPa. The water temperature at the surface is 99oC.

The plant consists of an evaporator in which the organic working fluid is vaporised under pressure and given a Small amount of superheat. This vapour then passes through **a** screw expander where work is extracted to drive a conventional alternator, producing 240 Volt, 50 Hertz. 3 phase ac power. The low pressure vapour leaving the expander is condensed against water from a cooling tower. The condensed working fluid is recycled to the evaporator via a multi Stage in-line **pump.**

The plant uses one of the Freon refrigerant gases as a working fluid hut a more environmentally acceptable working fluid is actively being sought. Due to the low working temperatures the thermal efficiency of the plant is low. Under maximum operating conditions the Freon enters the expander at about 95^{o}C giving a cycle efficiency of just over **5%**. however parasitic losses reduce the overall efficiency to under 4%.

To avoid any unnecessary losses the control system is designed to minimise parasitic losses especially in the recycle pump which is speed controlled to reduce pressure losses across the throttle valve on the expander inlet.

The town bas its own isolated grid. The electricity demand varies from about 60 kW(e) to around 150 kW(e). Interaction between the geothermal plant and the diesel sets is such that the geothermal plant will run on its own during periods of low demand. When the demand exceeds the capability of the geothermal plant a diesel set is commissioned and operated at its minimum safe load, with the geothermal plant following the load. When the geothermal plant reaches its maximum capacity it remains on a steady base load Operation with the diesel set following the load.

The system has been operating commercially since October 1992 and has achieved a service factor of around 50%.

The construction of the plant was funded jointly by the Federal Government, under its National Energy Research, Development and Demonstration Program, and the Queensland Electricity Commission. The plant was designed and built by Enreco Pty. Ltd. of Alice Springs. For the duration of a four year demonstration period the plant is being **operated** ***as a joint venture between the*** Commonwealth and the Queensland Electricity Commission.

5. HOT DRY ROCK DEVELOPMENT

In Victoria, a study by B. Thompson and A. Akberzadeh for the Victorian Department of Industry, Technology and Resources and the Victorian Solar Energy Council recommended a seach for prospective HDR (Hot Dry Rock) development sites in Victoria (King, 1985; King et al., 1985). In Tasmania, a 'hole of Opportunity'' was drilled for geothermal information in an east coast granite by the Department of Mines. In South Australia, an HDR development was proposed for the Cooper Basin **by** Haines (19841, and the prospect was again appraised **by** Swift (1993) and Wyborn (1993).

During 1994, AGSO (the Australian Geological Survey Organisation), in association with the University of NSW Centre for Petroleum Engineering and the Electricity Supply Association of Australia Ltd., in a Study partially funded by the ERDC (Energy Research and Development Corporation], undertook the largest and most systematic study yet undertaken of Australian HDR resources. AGSO used temperature data from more than 4 000 bores drilled in the course of oil and mineral exploration to delimit the boundaries of deep-seated geothermal anomalies (Somerville et al., 1994). A map of areas of hot rocks less than 5 km deep was published by Macey (19941.

The prime sites for development were buried granites at depth up to 5 km and temperatures exceeding 250^{o}C (Bladon, 1994). In the Cooper Basin. a temperature of 253^{o}C was observed at a depth of 3707 m (Wyborn, 1993), and temperatures of 300^{o}C were inferred at depths of 5 km. At Weipa in north Queensland, 800 m of sedimentary cover directly overlies granite, and a temperature of 200^{o}C was predicted at **a** depth of 4.5 km. At **Muswellbrook,** the predicted temperature was 275^{o}C at a depth of 5 km, and averaged 250^{o}C over the depth interval from 3.5 to 5.0 km (Scott, 1994, Macey, 1994).

Development of a $60.4 million experimental 20 MW(e) power plant designed around a resource of volume one cubic kilometre of hot rock at a temperature of 250^{o}C, to demonstrate hot-rock electricity production, was proposed for the Muswellbrook site (Macey, 1994, Somerville et al., 1994).

The Australian HDR resources were considered to be unique because of high values of heat production from basement granites; the low thermal conductivities of sedimentary blankets overlying those same "hot" granites; the mechanical suitability of untectonized basement granites for construction of artificial reservoirs; and a widespread crustal shortening stressfield (Somerville et al, 1994).

6. CONCLUSIONS

The Australian continent comprises sedimentary basins overlying basements of Precambrian and Palaeozoic metamorphics. Three heat flow provinces are recognized, the Western, Central, and Eastern. which correspond to areas of Archaean. Proterozoic and Palaeozoic basement, respectively. Heat flow in the Eastern province is augmented by magmatic intrusion into the upper Crust ahead of a travelling hot Spot. Geothermal gradients in the sedimentary basins are enhanced in places such as the Cooper Basin by high heat generation in the underlying hasement and low conductivity of the cover, and reduced in others. such as the Otway Basin, by water circulation.

The first geothermal developments took place in the last century, and comprised hot water spas and swimming pools near capital cities, such as at Hastings, near Hobart.

Hot artesian bores have been used for water supply, as at Quilpie, but the first development to use the heat is at Portland, in Victoria. The water, after circulation in the district heating system, is fed into the city water supply for human consumption.

Power production from hot water aquifers was tested at Mulka in South Australia, and is undergoing a four-year production trial at Birdsville in Queensland.

Recent research work at the Australian Geological Survey Organisation (AGSO) has confirmed the importance of the HDR resource near Moomba in the Cooper Basin of South Australia. It has been proposed to build a demonstration 20 MW(e) power plant on an HDR resource near Muswellbrook in the Sydney Basin of NSW.

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