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Record 1978/55

RESULTS OF THE 1976 CANNING BASIN GEOTHERMAL SURVEY

by

J.P. CULL

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ABSTRACT

Heat flow has been determined using shallow boreholes in the region of the north Canning Basin. Values range from 30 to 70 mW m^{-2}. Temperature data obtained during pauses in the drilling of St George Range No. 1, an oil exploration well, are consistent with regional heat flow values obtained from the shallow holes. It is concluded that apparent temperatures in this well are close to actual formation temperatures. Oil-mature sediments are most probably located at depths of 2000-4000 m.

INTRODUCTION

The 1976 Canning Basin Geothermal Survey was designed with two principal aims:

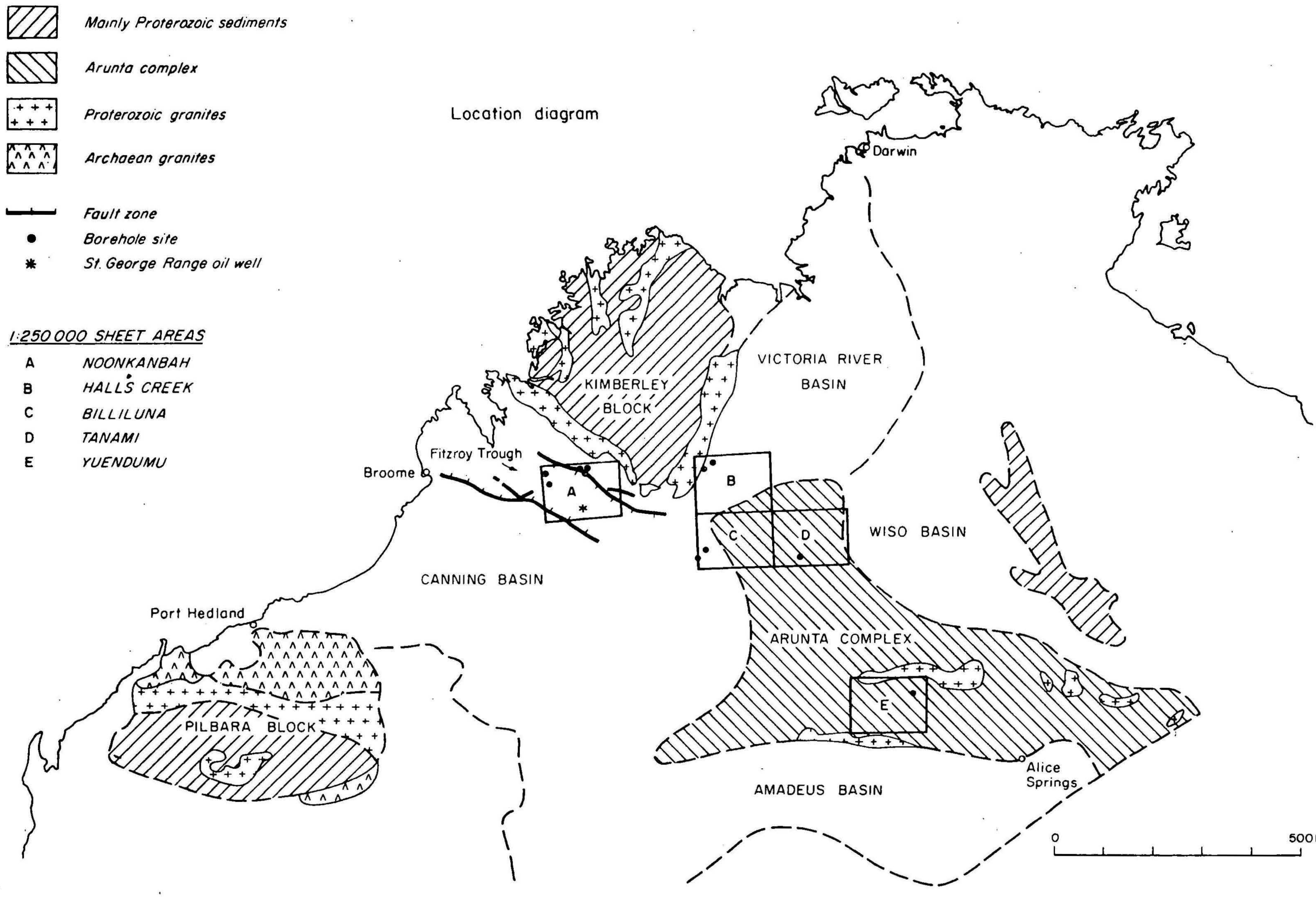
(1) to obtain regional heat-flow data in the north of Western Australia as an aid to formulation of models of regional tectonism and basin formation, and

(2) to examine local temperature gradients in boreholes known to be in thermal equilibrium, so that comparisons could be made with data previously obtained during pauses in petroleum exploration drilling.

No new holes were drilled for this survey, instead data were obtained using existing bores judged to be long standing and in thermal equilibrium. These bores are located in five 1:250 000 sheet areas: Noonkanbah (A), Billiluna (B), Gordon Downs (C), Tanami (D), and Mount Doreen (E) (Fig. 1). Representative core sa-mples were extracted for each group from the BMR Core and Cuttings Laboratory in Canberra. Data sources are noted in Table 1.

The Canning Basin is about 400 000 km^2 in extent and contains sediments dating from the Ordovician. It is bounded in the south by the Archaean Pilbara Block, and in the north by the Proterozoic Kimberley Block (Fig. 1). In cross-section the basin is highly asymmetric with a maximum sediment thickness of at least 10 km in the Fitzroy Trough. Petroleum prospects have been indicated by the presence of several well-defined structures acting to trap hydrocarbons generated from probable source rocks (Veevers & Wells, 1961). Oil shows have been recorded in several wells and a paraffin-base crude was recovered during production tests on WAPET Meda No. 1 (Burne & Kantsler, 1977). However, petroleum exploration has been largely unsuccessful. An unfavourable thermal history is one of the reasons advanced for this lack of success.

Geothermal studies in the Precambrian shield suggest that the survey region is probably depleted in trace-element radioactivity. As a result, surface heat flow may be below the world average (i.e. less than 62 mW m^{-2}, Sass & others, 1976). However the thermal history of the sediments in this region is probably complicated by successive erosional and


Mainly Proterozoic sediments
Arunta complex
Proterozoic granites
Archaean granites
Fault zone
Borehole site
St. George Range oil well
1:250 000 SHEET AREAS
A NOONKANBAH
B HALLS CREEK
C BILLILUNA
D TANAMI
E YUENDUMU
Location diagram
Darwin
VICTORIA RIVER BASIN
KIMBERLEY BLOCK
Fitzroy Trough
Broome
A
B
C
D
WISO BASIN
CANNING BASIN
Port Hedland
ARUNTA COMPLEX
E
PILBARA BLOCK
Alice Springs
AMADEUS BASIN
0
500 km

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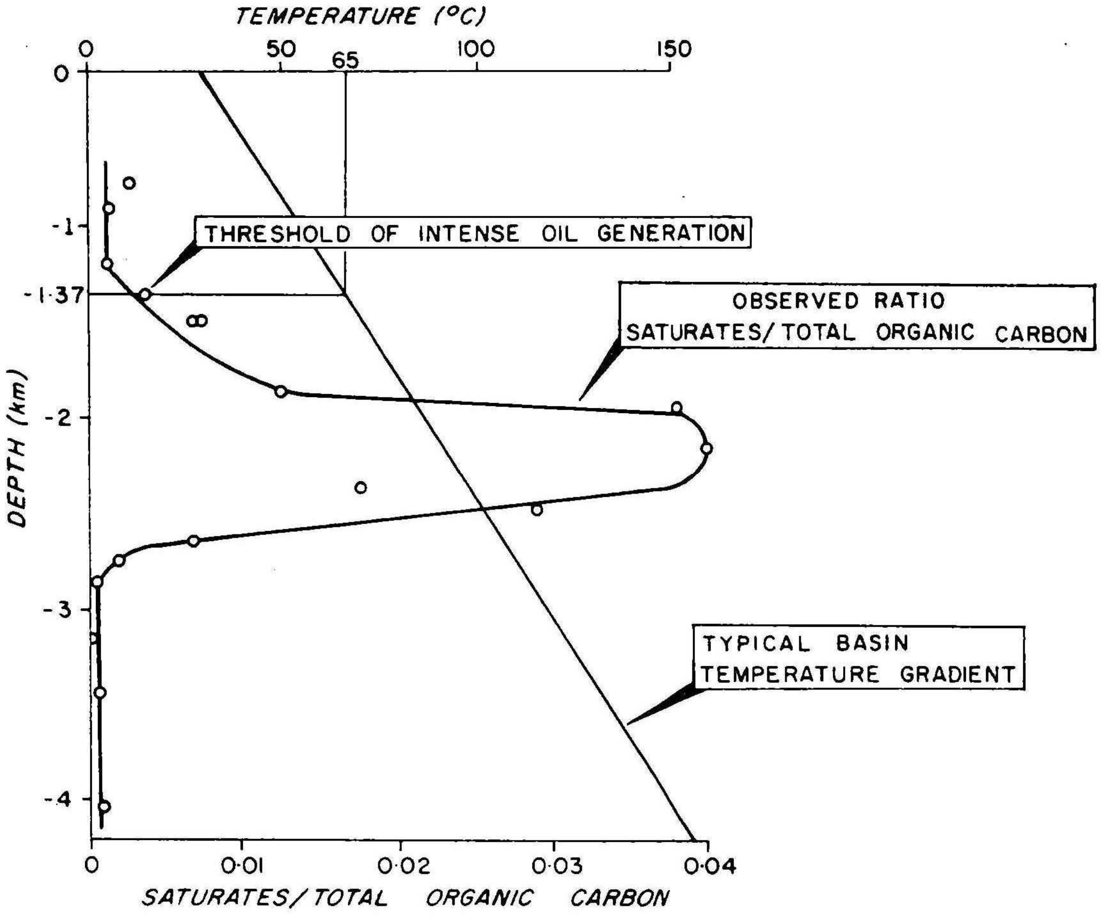
depositional cycles involving radioactive trace elements. Major heat sources may be concentrated in basin structures of relatively small volume. Additionally, basin temperatures may be significantly higher than in adjoining basement rocks because of the low thermal conductivity of sediments. Thermal anomalies conductive to hydrocarbon maturation may also be associated with groundwater movements, and with exothermic or endothermic reactions of the contained organic materials (e.g. oxidation).

Formation temperatures have been estimated from studies of vitrinite reflectance (Burne & Kantsler, 1977) but these apparent temperatures are not easily related to geothermal gradients. Only palaeotemperatures can be deduced; these may result from transient conditions prevailing at different epochs and for different lengths of time in each formation. The only other temperature data have been obtained from petroleum exploration wells during pauses in drilling; however, these data are affected by the circulation of drilling fluids (Cull & Sparksman, 1977) and do not give true formation temperatures.

OIL MATURATION

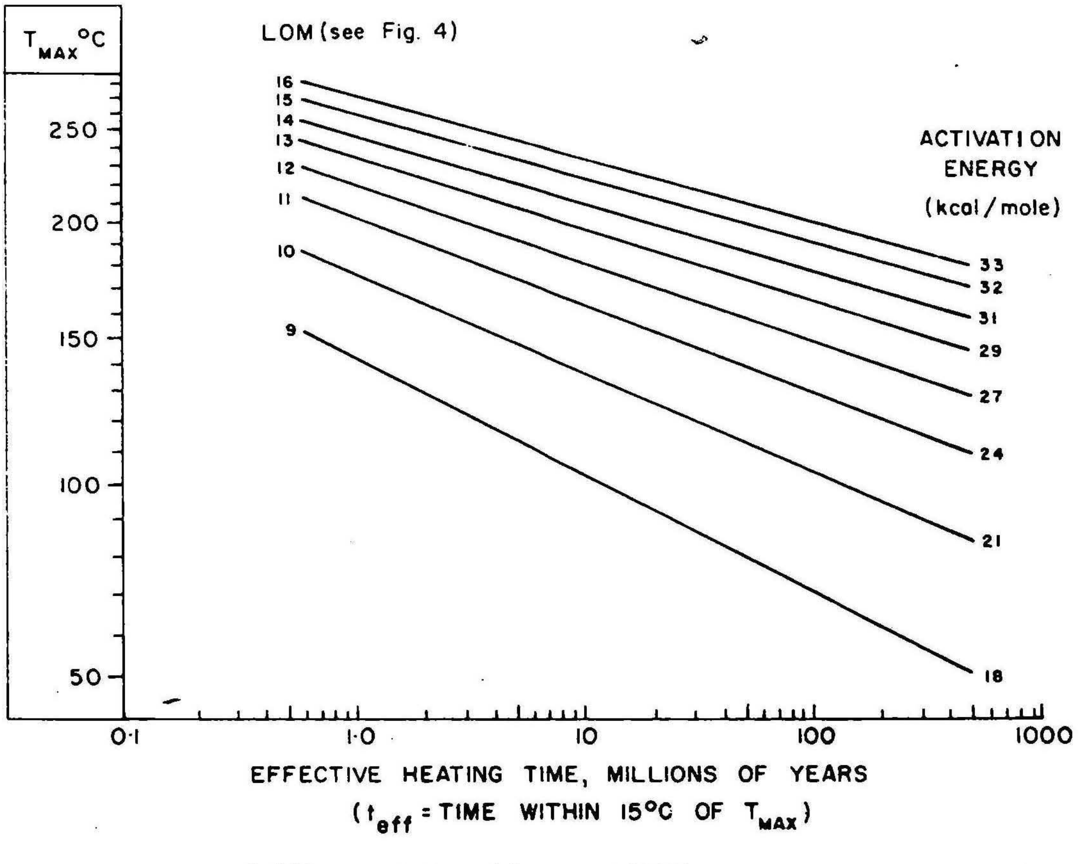
Hydrocarbons are derived from source rocks by geothermal heating of kerogens (Fig. 2). After migrating to suitable reservoirs the hydrocarbons may be altered through the effects of pressure, temperature, and catalysis (Hedberg, 1964). The level of organic metamorphism (LOM) can be specified on an arbitrary scale of 20 (Hood & others, 1975) and correlations can be made with coal rank, thermal content, and stages of petroleum genesis (Fig. 4). The threshold of intense thermal cracking (LOM 9) is determined by formation age as well as formation temperature (Connan, 1974) (Fig. 3). Predictions of LOM then require detailed knowledge of burial history, so that estimates can be made for palaeotemperature fluctuations. As an approximation, Hood & others (1975) relate LOM to the maximum formation temperature and the 'effective heating time' (Fig. 3), defined as the total time for which the source rock has been within 15^{o}C of the maximum temperature. LOM can be determined from the tectonic history alone, if that is well enough known, and target depths can be set for exploration drilling. Alternatively, if the burial history is poorly known, vitrinite reflectance studies can establish the LOM, and thus the burial history.

Fig. 2



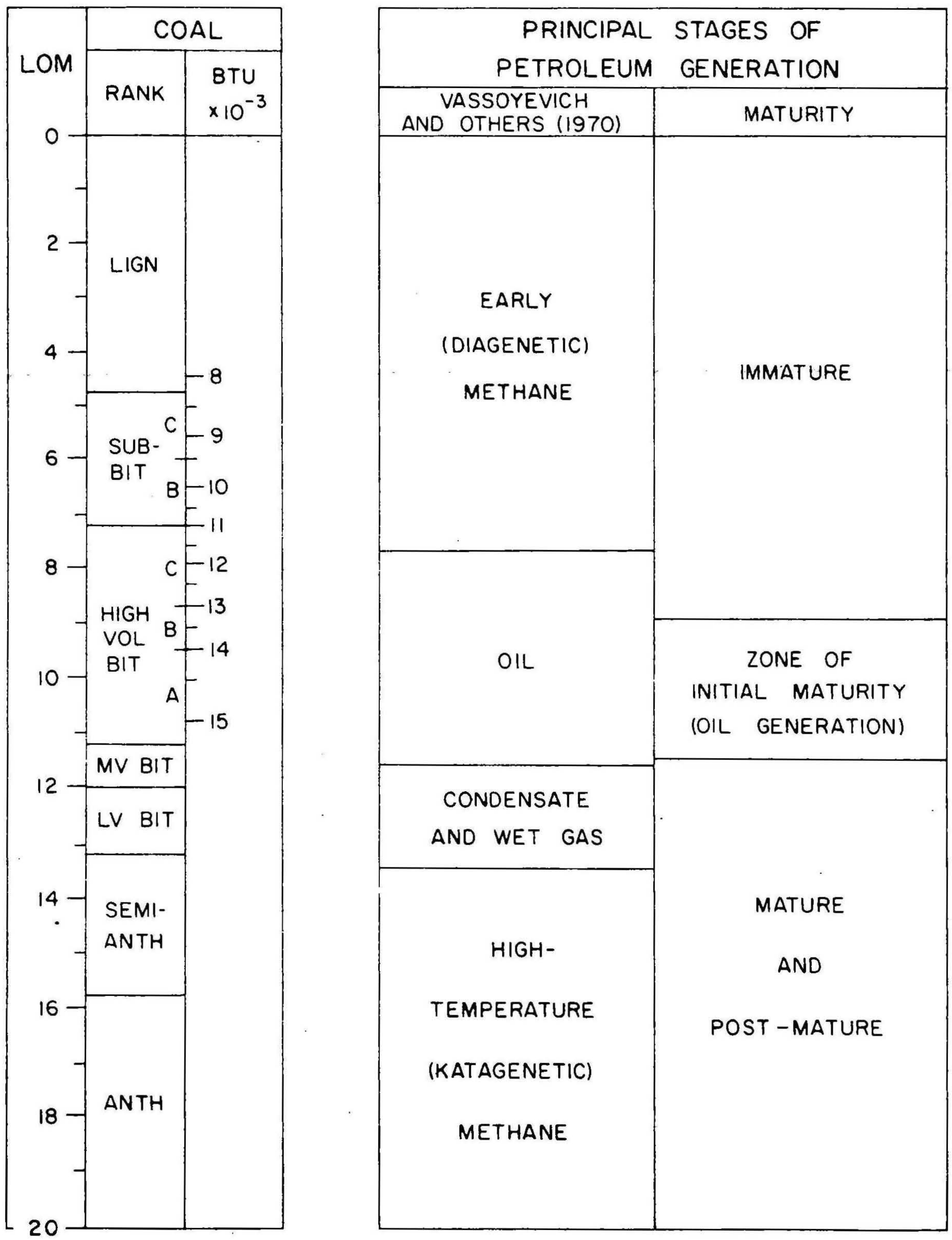
Effect of temperature on oil genesis (Connan, 1974)

Fig. 3



LOM correlation (Connan, 1974)

Fig. 4



Stages of organic metamorphism
(after Connan, 1974)

Burne & Kanstler (1977) state that 'the majority of oil-mature sediments (on a LOM basis) in the Palaeozoic rocks .... of the Canning Basin occur at T_L values of between 50^oC and 75^oC' (T_L values are bottom-hole temperatures taken routinely during the logging of exploration wells). They consider (p. 287) that present formation temperatures are close to the maximum palaeotemperatures in most areas of the basin, and that ' a basin-wide correspondence between LOM and present temperature is demonstrated' (p. 285). These authors have estimated source-rock depths from apparent geothermal gradients (using T_L), and have suggested prospective lithologies for several structural units (p. 287). However, because of changes in lithology, geothermal gradients may vary with depth and drilling targets may not be well defined. If heat flow is assumed constant with depth in the present study, variations in thermal conductivity can be obtained from stratigraphic logs and changes in gradient can be readily calculated. The depth to oil-mature sediments can then be estimated with greater accuracy.

TEMPERATURE GRADIENTS

Temperatures were measured in 15 bores along the NE margin of the Canning Basin and in the adjacent Arunta Complex (Fig. 1). The logging system consisted of a thermistor probe attached to a 300-m cable; changes in resistance were monitored at the surface using a Wheatstone bridge (Cull & Sparksman, 1977). Data were obtained at depth intervals of about 9 m with a resolution better than 0.01^oC (Table 2). Depths are considered accurate to 0.1 m.

There is a considerable variation in thermal gradient between the different areal groups (Figures 5-10). However, within each area the agreement is generally good. The gradients obtained for BIL 3 and BAN 1 in the Billiluna group are an exception. In the region of BIL 3 surface rocks are quartzitic sandstone which generally has a much higher thermal conductivity than other rock types. No sandstone is evident at BAN 1 and consequently different gradients can be readily attributed to differences in thermal conductivity.

Gradients for the Yuendumu bores are obviously perturbed by water movements. The bores were drilled to supply water to local settlements. At the time of logging they were unequipped but the casings had been perforated during installation to allow future access to the supply aquifers. The low

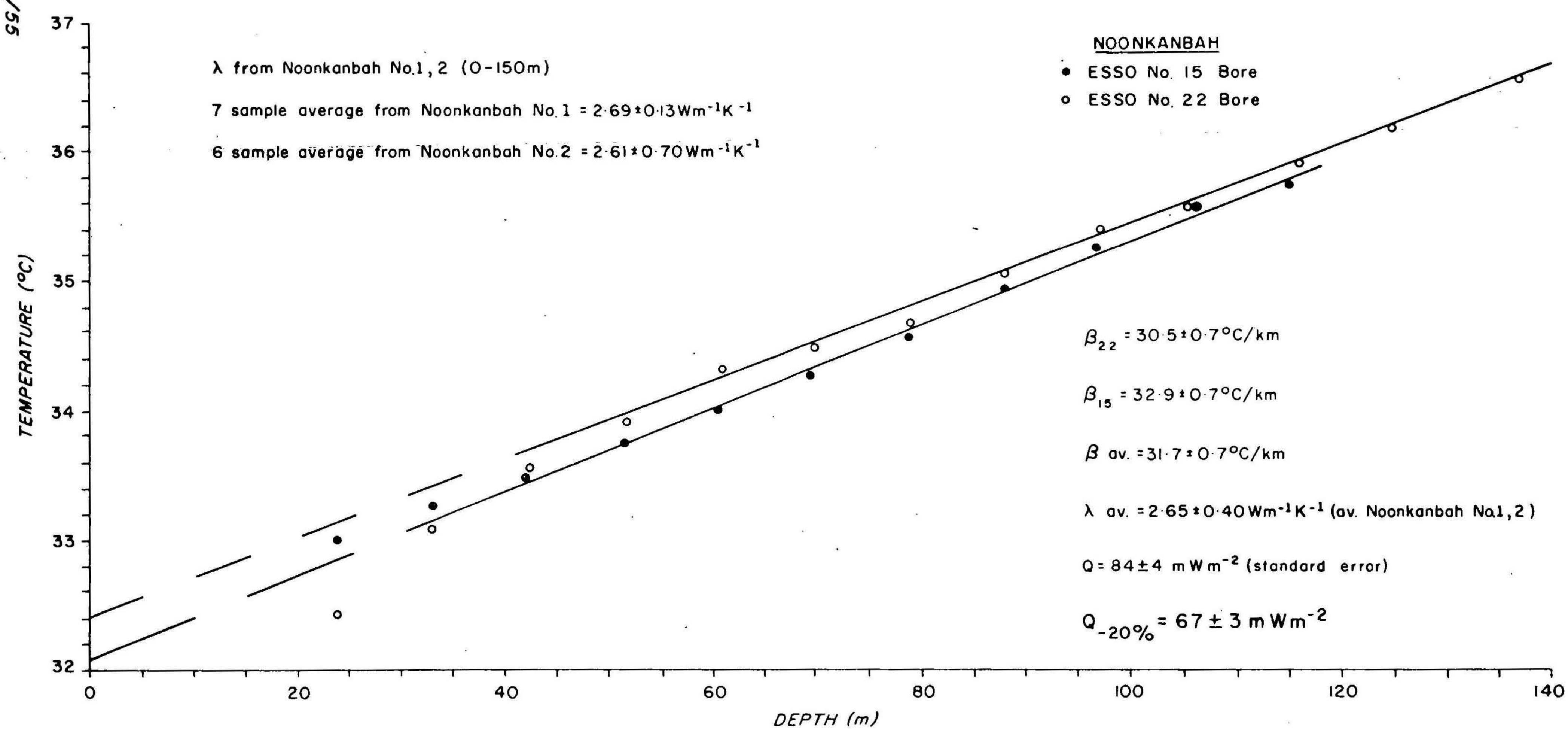


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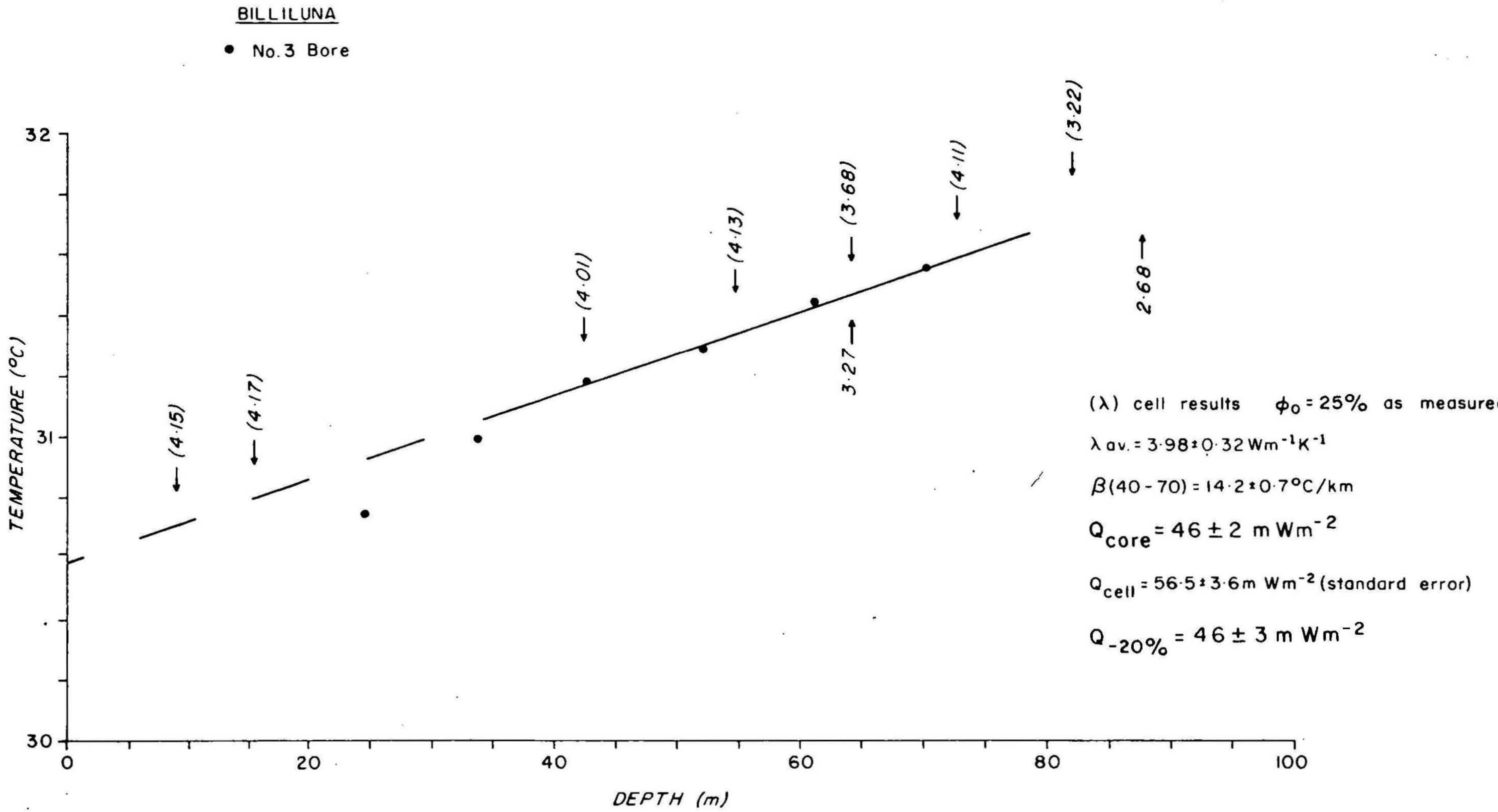
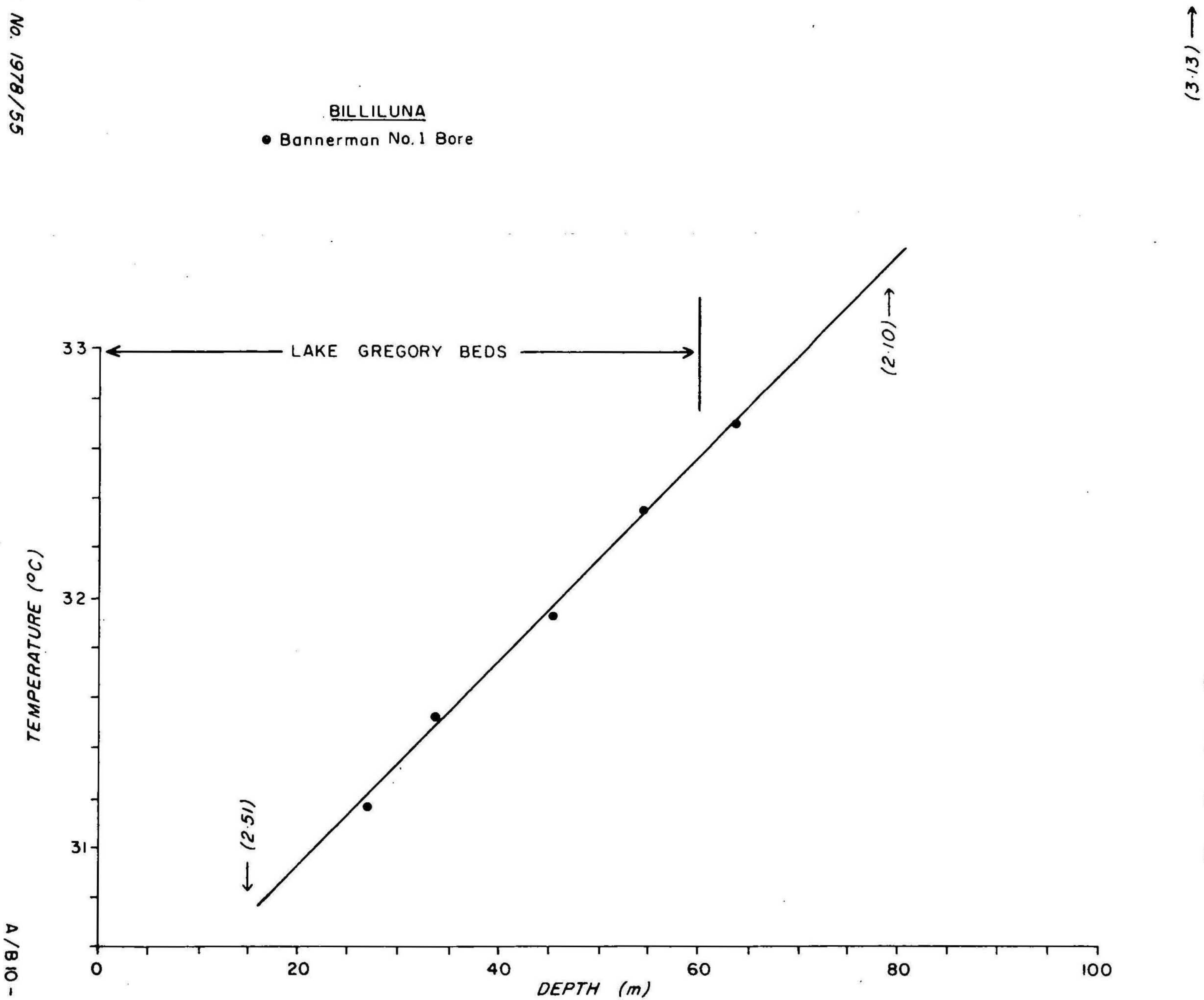
Fig. 5

Temperature gradients - Noonkanbah



Temperature gradient - Billiluna

Fig. 6



Samples from CORNISH No. 3 (0 - 100 m)

56m	(1·70)
54m	(1·82)
50m	(2·01)
	av. (1·84) $Wm^{-1}K^{-1}$

(λ) cell results uncorrected

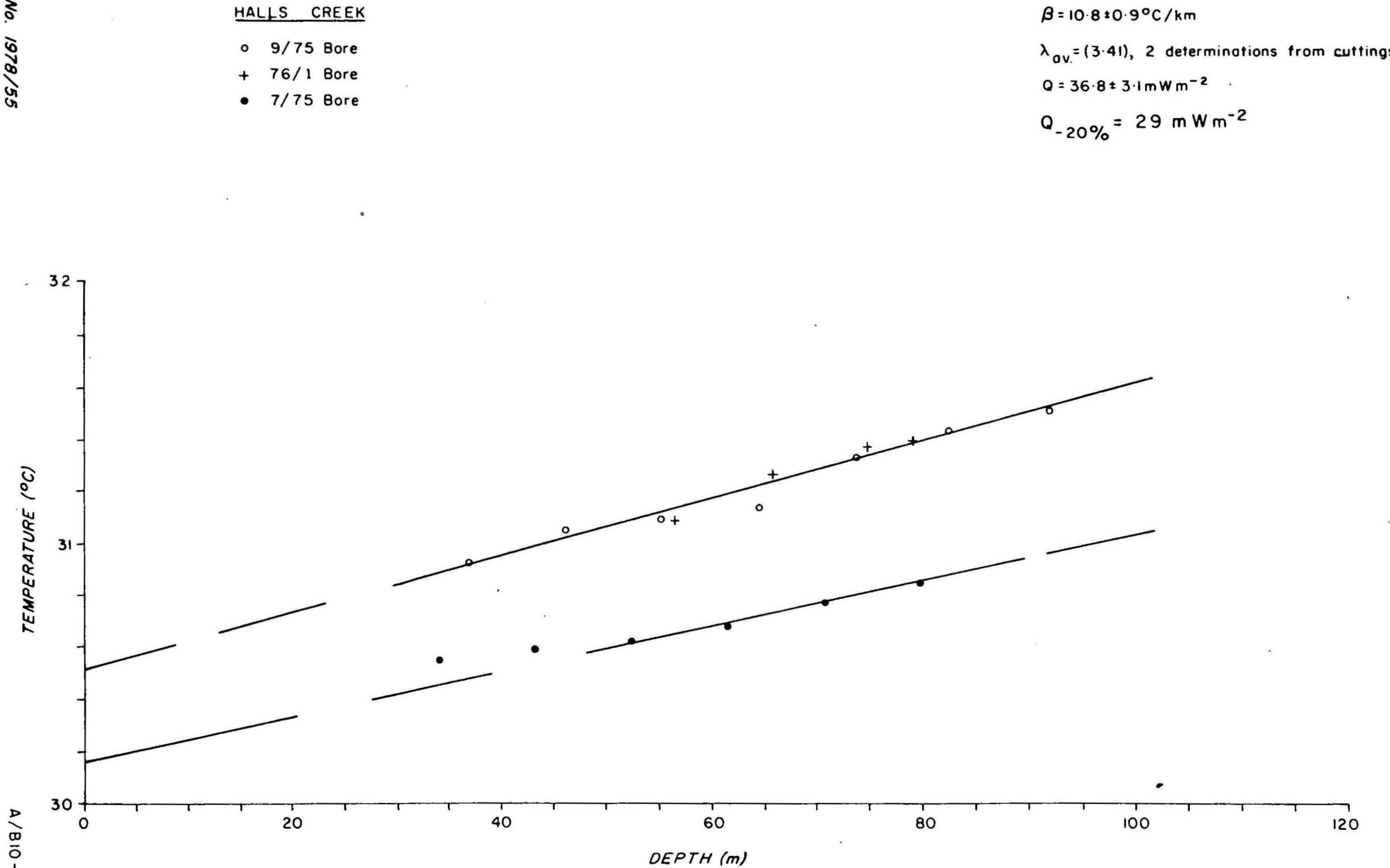
$\beta(40-65) = 39{\cdot}9 \pm 1{\cdot}6°C/km$

$Q_{cell} = 73{\cdot}4 \pm 9{\cdot}3\, mW\, m^{-2}$

$Q_{-20\%} = 59 \pm 7\, mW\, m^{-2}$

Temperature gradient - Billiluna

Fig. 7



Temperature gradients - Halls Creek

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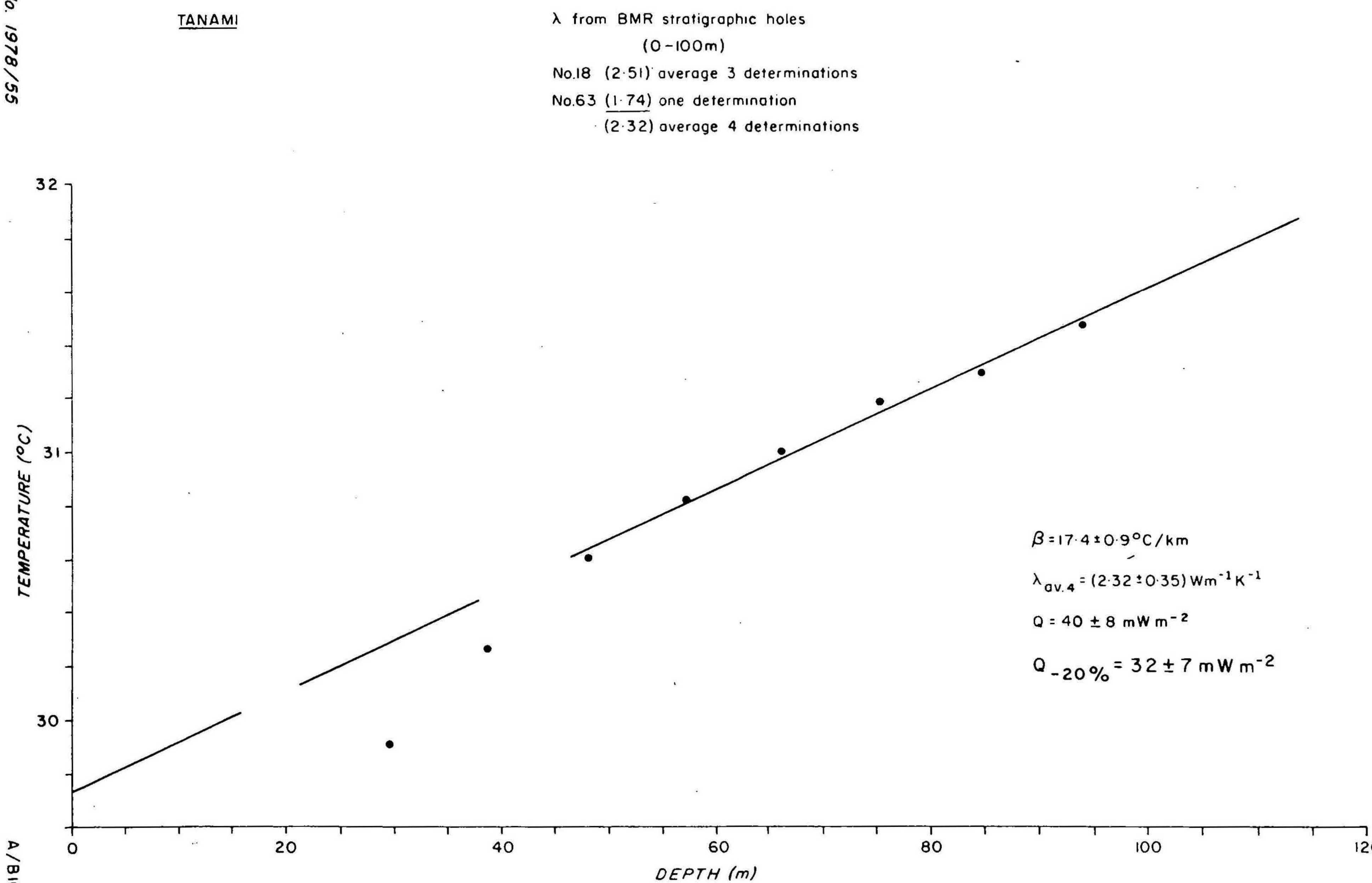
Fig. 8



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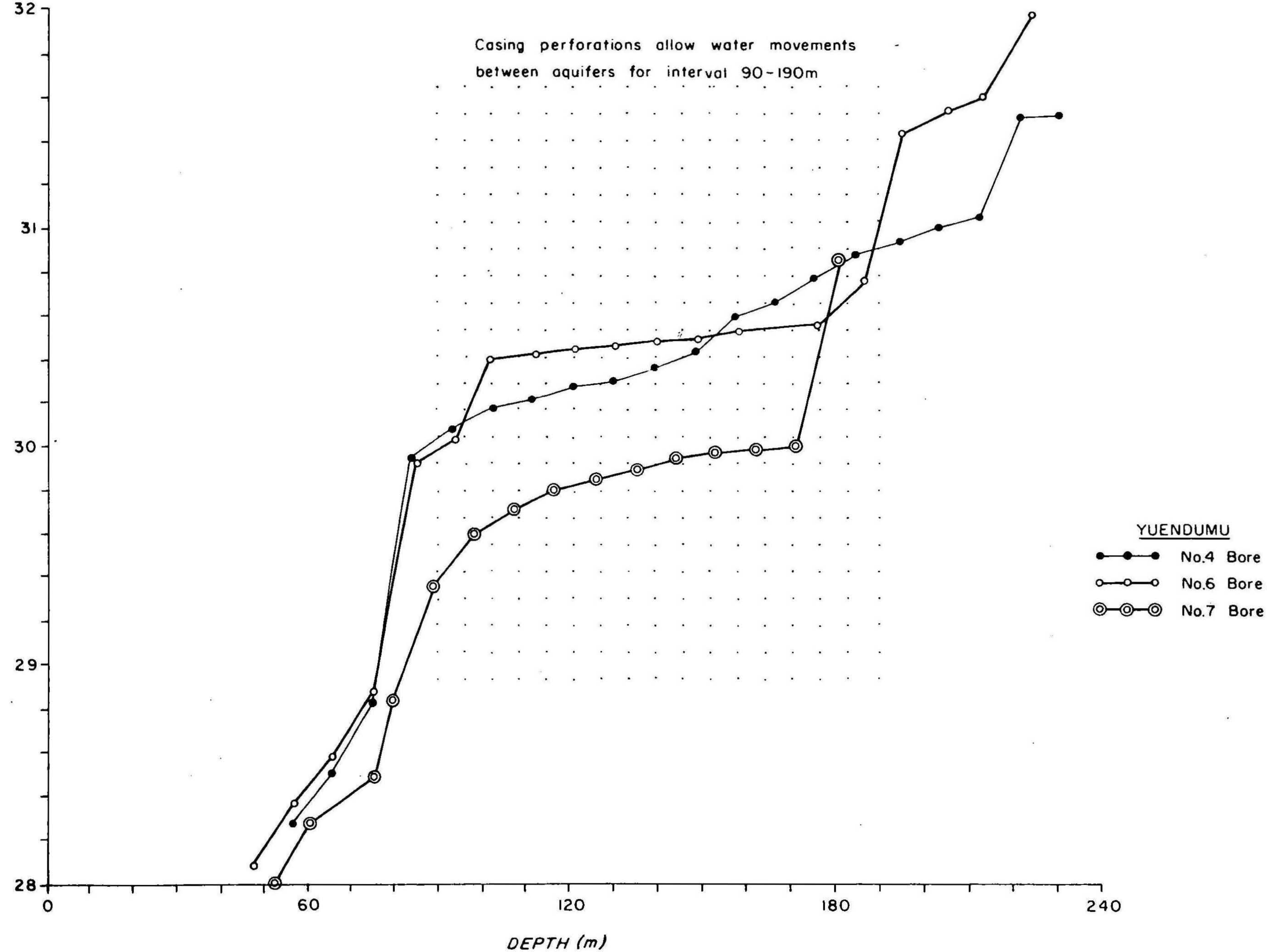
Temperature gradient - Tanami

Fig. 9



Temperature gradients - Yuendumu

Fig. 10

gradients occur along the full length of these perforations. It is apparent that at least two aquifers have been intersected and pressure differences have caused a continual flow to be established.

The gradients obtained in the Halls Creek bores are all low. No water movements were observed during logging and no aquifers are known. There is no evidence of near-surface perturbations, and extrapolated surface temperatures are close to the mean annual air temperature (Cull & Sparksman 1977). It is concluded that these gradients are caused solely by high thermal conductivities or low heat flow in the Precambrian basement.

THERMAL CONDUCTIVITIES AND DETERMINATIONS OF HEAT FLOW

Heat flow (Q, W m^{-2}) is determined from the expression

$$Q = \beta \lambda$$

where β is the geothermal gradient ($^{o}C/km$) and λ is the thermal conductivity of the rocks (W m^{-1} K^{-1}) in which the gradient is established.

Well-consolidated core samples were available for measurements of thermal conductivity in only a few instances (Table 3). For these samples measurements were made using standard divided-bar techniques (Birch 1950, Cull & Sparksman 1977).

For most boreholes only drill cuttings were available. The cell technique described by Sass & others (1971) was used to contain the cuttings in the divided bar. However it has been noted previously (Cull & Sparksman 1977) that the cell technique gives results which are too high by approximately 20 percent. Core from BIL No. 3 was used to check this previous observation and the discrepancy in results was verified. The conductivities noted in the present work (Table 3) are uncorrected, but calculations of heat flow have been adjusted wherever the cell technique was used.

For the Noonkanbah location, thermal conductivities were determined with the cell technique on thirteen samples from two boreholes (Table 3). Samples were available over the total depth 0-150 m. The thermal gradients (Fig. 5) are in close agreement and are linear for depths greater than 40 m. This linearity reflects the uniformity in the conductivity values and heat flow is calculated from gross averages. At this location the uncorrected heat flow was calculated as 84 $\pm$ 4 mW m^{-2} (standard error of mean). A 20-percent correction should be applied to the conductivity measurements; consequently the value adopted for the heat flow is reduced to 67 $\pm$ 3 mW m^{-2}.

Core was available from a depth of 64 m from borehole BIL No. 3 in the Billiluna Group (Fig. 6). A single determination of thermal conductivity was combined with the local geothermal gradient. The heat flow was calculated to be 46 $\pm$ 2 mW m^{-2} but conductivity sampling errors are unknown. Cuttings were also available in this borehole, and the cell technique was used to obtain an average thermal conductivity for the interval with linear geothermal gradient (40-70 m). Heat flow was calculated as 57 $\pm$ 4 mW m^{-2} (standard error of mean). With the 20-percent correction this result is reduced to give 46 $\pm$ 3 mW m^{-2}, in close agreement with the result from solid core.

The second hole in the Billiluna group Mount Bannerman No. 1 penetrated the Cainozoic Lake Gregory Beds to a depth of 65 m (Fig. 7). Considerable difficulties were experienced in measuring conductivities with the cell technique because of the tendency of the clays to swell during saturation and escape confinement. Furthermore, since the original in-situ porosity was unknown, a value of 10 percent had to be assumed for data reduction. A corrected heat flow of 59 $\pm$ 7 mW m^{-2} (mean deviation) was determined using an average thermal conductivity for the Lake Gregory Beds derived from three samples obtained from Cornish No. 3 (100 km SE). This result conflicts with the calculations for BIL No. 3; a variation in heat flow of 30 percent is indicated and this is unlikely for two such closely spaced holes.

Only two samples of cuttings were available for the Halls Creek group (Fig. 8). The cuttings were obtained at 10 m and 60 m for a single hole (76/1A) close to the group logged for temperature. No control was available for estimates of original porosity and a value of 10 percent was assumed. Both samples gave similar high results for thermal conductivity; this was expected from the very low thermal gradient ($<11.0^{o}$C/km). Heat flow (corrected) was calculated to be 29 mW m^{-2}. Insufficient data were available for calculations of statistical error but a 20-percent sampling error could be expected from previous calculations.

Drill cuttings were obtained at depths from 50 m to 80 m for two separate holes (63; 1488) in the Tanami region (Fig. 9). Four determinations of thermal conductivity were averaged and were combined with the linear segment of the geothermal gradient in the depth interval 50-95 m. The corrected heat flow was calculated to be 32 $\pm$ 7 mW m^{-2} (mean deviation). If the single low value of conductivity is omitted, heat flow is increased to 34 $\pm$ 2 mW m^{-2}.

As mentioned previously the thermal gradients in the Yuendumu boreholes are disturbed by water movements (Fig. 10). Determinations of heat flow in such circumstances are extremely difficult. Calculations can be confined to stable intervals or alternatively a Bullard reduction can be used (Cull & Sparksman, 1977). The Bullard reduction in these circumstances can be viewed as a simple means of averaging data in the stable regions. An effective conductivity can be assigned to the disturbed interval so that the Bullard plot is approximately linear. The data for Yuendumu have been reduced in this manner (Fig. 11) and a value of 56 $\pm$ 3 mW m^{-2} (using least squares) was obtained for the heat flow (20-percent cell conductivity corrections included). The surface temperature adopted for the Bullard reduction was obtained by adding $3^{o}C$ to the mean annual air temperature (Howard & Sass, 1964; Cull & Sparksman, 1977). An estimate of error is difficult in this case because of the need to assume constant thermal conductivities over large intervals. Within each interval sampled, the mean deviation for conductivity is about 5 percent, but between intervals (i.e. between different rock types at different depths) there are variations of up to 20 percent. If the measured conductivities are not representative of the intervals sampled, heat flow calculations may contain a total error of 20 percent.

DEEP-BASIN TEMPERATURES

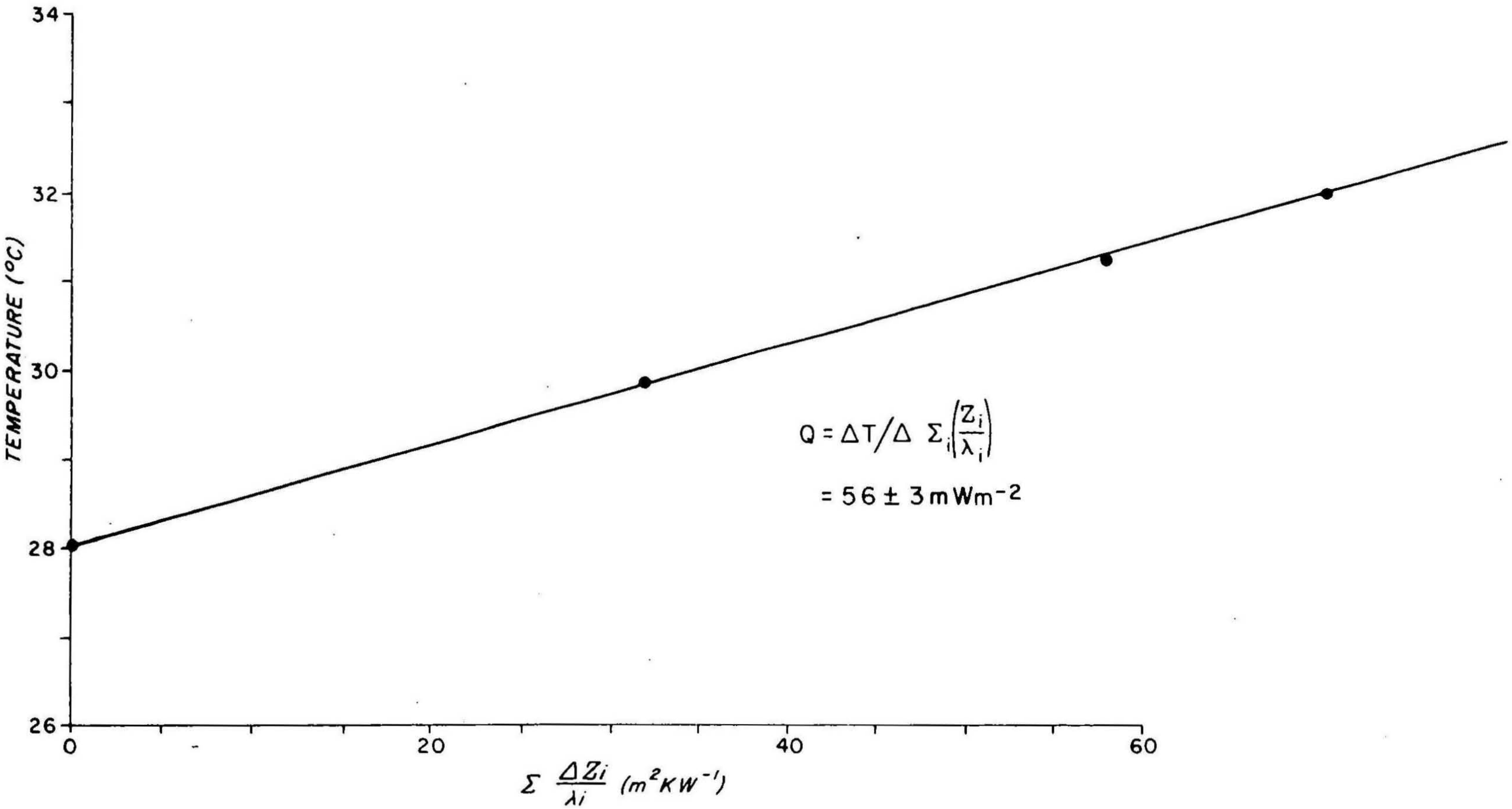
Temperature data are available for numerous subsidised oil exploration wells in the Canning Basin (Burne & Kantsler, 1977). However, the data do not reflect true formation temperatures (Cull & Sparksman, 1977) because all measurements were made during pauses in drilling. The circulation of drilling fluids causes increasing temperature excursions as the drilling moves progressively deeper. Apparent temperatures are expected to be less than actual temperatures; depressed gradients may be observed and relatively low values would then be calculated for the heat flow. One of the objectives of this study was to determine the accuracy of geothermal gradients obtained from such data.

Two approaches can be adopted. First, if sufficient core is available, the thermal resistivity can be determined for any given oil well and the temperature data (as measured) can be used in a Bullard reduction. Heat flow determined in this manner should then approximate values reported in the previous section for holes which have returned to thermal equilibrium. The second approach is to use the previously determined regional heat flow data to predict temperatures at greater depth. Oil-well data can then be compared with predicted values.

Z	ΔZ	λ(-20%)	$\frac{\Delta Z}{\lambda}$	$\Sigma\left(\frac{\Delta Z}{\lambda}\right)$	T
(m)	(m)	($Wm^{-1}K^{-1}$)			(K)
90	90	2·8	31·91	31·91	29·75
190	100	4	25	56·41	31·12
220	30	2·2	13·39	70·30	31·94
				Surface	28·00

BULLARD PLOT YUENDUMU (# 6)

$$T = T_0 + Q\,\Sigma_i \frac{Z_i}{\lambda_i}$$



Bullard plot – Yuendumu data

Fig. 11

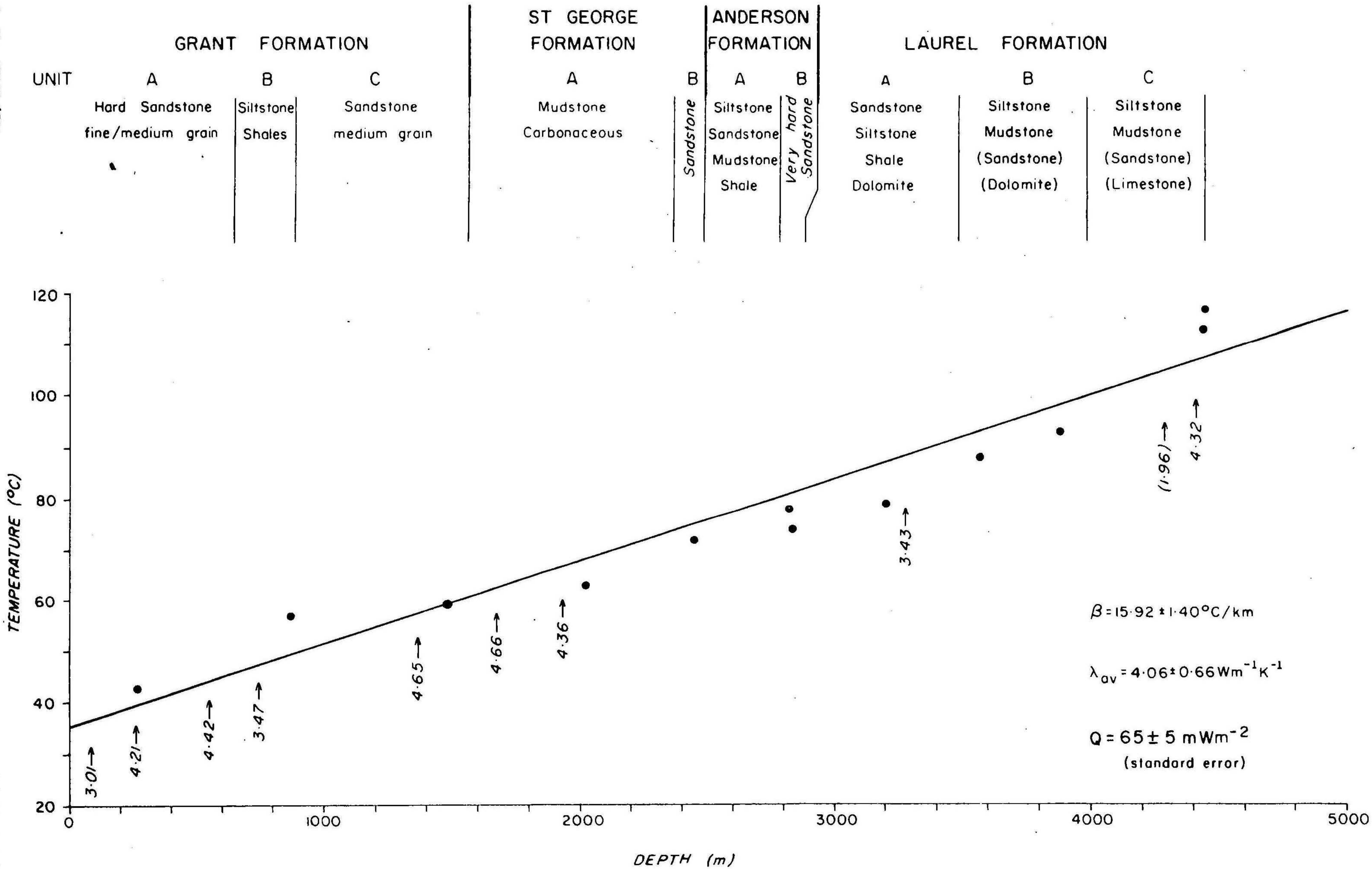
Data were obtained for the St George Range No. 1 well in the Fitzroy Trough. The temperature data obtained during drilling are plotted in Figure 12. Ten core samples were available, representing major formations. Thermal conductivities were determined on the divided bar apparatus and are noted at the appropriate depths in Figure 12. If the thermal conductivities are averaged and combined with the apparent geothermal gradient (from a least-squares fit to the temperature data) the heat flow is calculated to be 65 $\pm$ 5mW m^{-2} (standard error, one extreme conductivity value removed).

The stratigraphy of the St George Range well is noted in Figure 12. In general there is at least one conductivity determination for each unit. No core was available for the Anderson formation or for unit B in the Laurel formation. An approximate conductivity based on rock type was assumed for these intervals in the Bullard reduction shown in Figure 13. If the interval conductivities are well determined, all points in Figure 13 should lie on one straight line; deviations would then reflect errors in temperature measurements. In view of the coarse sampling rate used for the conductivity determinations the scatter is considered reasonable and a value of 64 $\pm$ 4 mW m^{-2} (with least-squares fit) is obtained for the heat flow. Again the estimate of error depends upon the sampling rate in each stratigraphic unit. Conductivities may vary by 100 percent between units but the stratigraphy is well known. The conductivity of each unit is determined independently and errors may cancel in part. Calculations of heat flow are consequently estimated to be correct to 20 percent.

Heat flow in the Noonkanbah bores was calculated in the previous section. A value of 67 $\pm$ 3 mW m^{-2} was obtained with good control on thermal conductivities. Similar values are obtained for the St George Range well (65 and 64 mW m^{-2}) suggesting that the measured temperatures are a reasonable approximation to true formation temperature.

CONCLUSIONS

This study appears to confirm that the Canning Basin is located in a region of low heat flow. Values determined in this study (Table 4) are generally less than the world average, which is about 62 mW m^{-2}. However, there may be a systematic increase in heat flow towards the centre of the basin. Along the margins most values are near 40 mW m^{-2}, consistent with previous results reported for Precambrian basement regions (Sass & others,



Temperature gradient - St George Range No.1

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Fig. 12

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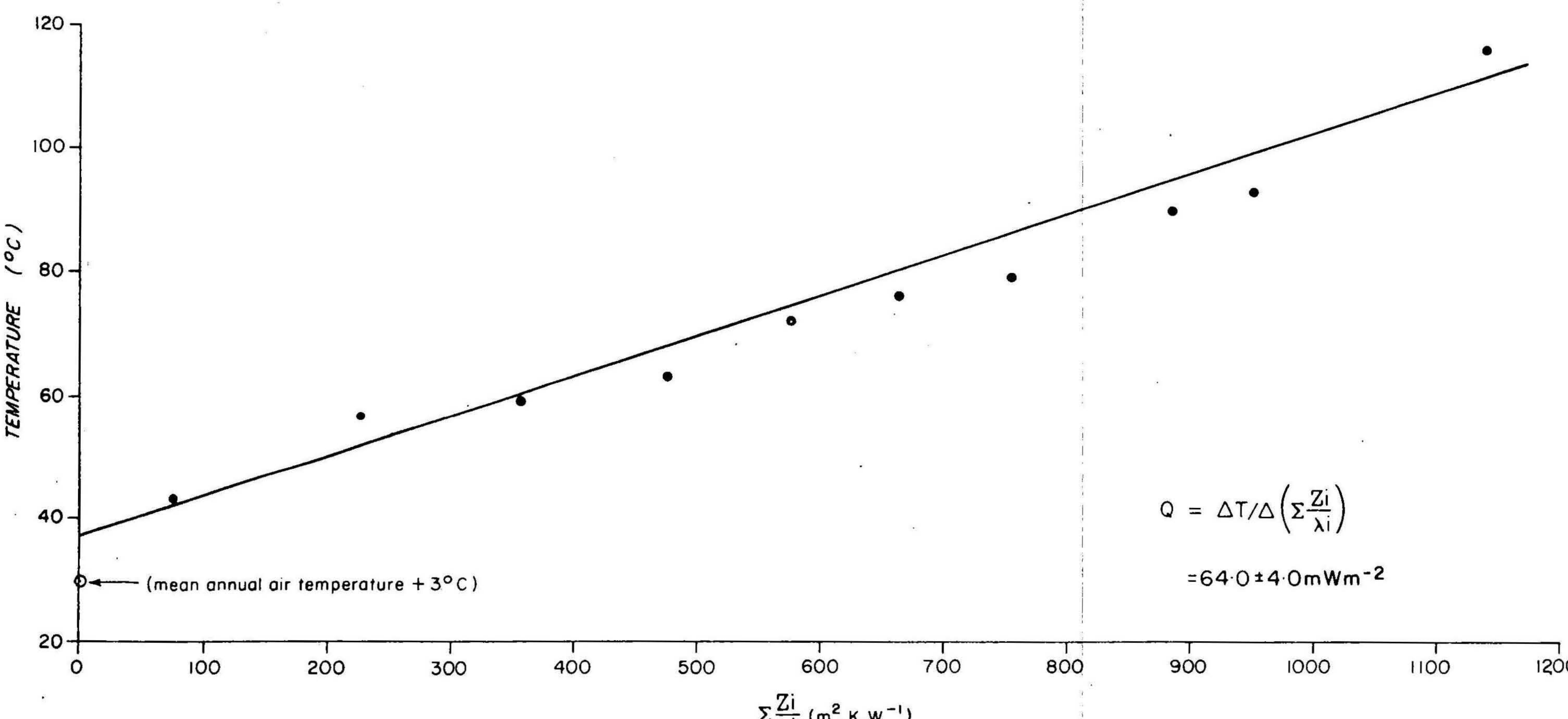
Z (m)	T (^{o}c)	ΔZ (m)	λ ($Wm^{-1} K^{-1}$)	$\frac{\Delta Z}{\lambda}$	Σ
260	43	260	3·61	72·0	72·0
860	57	600	3·95	151·9	223·9
1472	59	610	4·65	131·2	355·1
2013	63	540	4·51	119·7	474·8
2444	72	430	4·51	95·3	570·1
2808	76	360	4·0	90·0	660·1
3192	79	380	3·43	110·8	770·9
3561	89	370	3·43	107·9	878·8
3872	93	310	4·0	77·5	956·3
4434	115	560	3·14	178·3	1134·6



Bullard plot – St George Range No. 1

A/B 10-55A

Fig. 13

1976). The highest values of heat flow (excluding data from Yuendumu) were obtained in the Fitzroy Trough. The reason for this trend is not obvious. Shvetsov (1976) suggests that adiabatic compression of sediments (diagenesis) together with particle friction may give rise to exothermic reactions. In a continuing process, heat liberated would depend on the thickness of sediments involved. Clearly sediment thickness is a maximum near the depocentre. An alternative explanation is that basement rocks under the Canning Basin are younger than the rocks comprising both the Pilbara and Kimberley blocks. Generally it is found that younger rocks contain a greater concentration of radioactive elements, resulting in greater rates of heat generation. Basement age can be correlated inversely with surface heat flow (Polyak & Smirnov, 1968)

Temperatures measured during pauses in drilling of the St George Range oil exploration well appear to give results which do approximate true formation temperatures; values derived for heat flow are in close agreement with near-surface determinations in neighbouring bores.

Sediments in the Canning Basin date from the Ordovician and an effective heating time equal to burial time is assumed for present LOM studies. Consequently in Figure 3 it can be seen that oil-mature sediments are those with a temperature greater than 50°C but less than 110°C (LOM 9-10). In the St George Range well (in which oil stains have been noted on cuttings at 3400 m) the temperature exceeds 110°C below about 4000 m. Therefore drilling for oil at substantially greater depths in this region is not justified. Sediments at depths less than 2000 m are in contrast considered immature since formation temperatures do not exceed 50°C.

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TABLE 1

Borehole Locations and nature of Data Obtained

Sheet 1:250 000	Name	Lat (^oS)	Long (^oE)	Type	Measurements β	λ
Noonkanbah	Peglars	18.08	124.53	w. bore	x	
	Mochelles	18.40	124.69	w. bore	x	
	Boundary	18.11	124.90	w. bore	x	
	Esso 15	18.10	124.79	Explor.	x	
	Noon 1	18.57	125.97	Strat		x
	Noon 2	18.12	125.33	Strat		x
	St George Range	18.69	125.14	Oil well	x	x
Billiluna	Bil 3	19.51	127.64	Strat	x	x
	Ban 1	19.95	127.23	Strat	x	x
	Cornish 3	20.18	127.40	Strat		x
Tanami	Govt. Bore	19.98	129.71	w. bore	x	
	1488	19.62	129.60	Strat		x
	63	19.85	130.16	Strat		x
Gordon Downs (Halls Ck)	7/75	18.24	127.69	w. bore	x	
	9/75	18.24	127.69	w. bore	x	
	76/1	18.24	127.69	w. bore	x	x
	PDH 8	18.09	127.86	Explor	x	
Mt Doreen (Yuendumu)	10556/4	22.33	131.75	w. bore	x	x
	10660/6	22.33	131.75	w. bore	x	x
	10947/7	22.33	131.75	w. bore	x	x

β : Thermal gradient
λ : Thermal conductivity

TABLE 2

Borehole temperatures

Area	Borehole Location	Depth (m)	Temp (^oC)
NOONKANBAH	$18^o4.5'$ $124^o31.7'$	21.4	32.67
	(Peglars)	22.9	32.69
		24.4	32.73
		25.6	32.74
	$18^o24.1'$ $124^o41.6'$	32.0	33.16
	(Machells)	33.6	33.18
		35.1	33.20
		36.6	33.24
	$18^o6.3'$ $124^o53.9'$	24.8	33.68
	(Boundary)	30.9	33.81
		37.0	33.99
		43.1	34.22
		49.2	34.56
		50.7	34.61
		52.2	34.66
		53.8	34.72
		55.3	35.01
		56.8	35.21
		58.3	35.22
	$18^o5.9'$ $124^o47.3'$	23.8	33.05
	(ESSO 15)	32.9	33.24
		42.1	33.45
		51.2	33.72
		60.4	33.98
		69.5	34.25
		78.7	34.55
		87.8	34.92
		97.0	35.22
		106.1	35.54
		115.3	35.75

Table 2 (Continued)

Area	Borehole Location	Depth (m)	Temp (^oC)
NOONKANBAH	$18^o6.4'$ $124^o49.1'$	24.2	32.40
	(22)	33.3	33.06
		42.5	33.54
		51.6	33.90
		61.0	34.30
		69.9	34.49
		79.1	34.65
		88.2	35.06
		97.4	35.36
		106.5	35.56
		115.7	35.89
		124.8	36.15
		137.0	36.54
BILILUNA	19.51^o 127.64^o	24.5	30.75
	(Bil 3)	33.6	30.99
		42.8	31.18
		51.9	31.29
		61.1	31.45
		70.3	31.56
	19.95^o 127·23o	26.9	31.16
	(Ban 1)	33.6	31.52
		45.2	31.92
		54.4	32.34
		63.5	32.70
TANAMI	$19^o58.8'$ $129^o42.6'$	29.6	29.88
		38.7	30.26
		47.9	30.60
		57.0	30.82
		66.2	31.00
		75.3	31.19

Table 2 (Continued)

Area	Borehole Location	Depth (m)	Temp (^oC)
TANAMI	$19^o58.8'$ $129^o42.6'$	84.5	31.29
		93.6	31.47
HALLS CK	$18^o14.3'$ $127^o41.2'$	24.9	30.57
	(7/75)	34.0	30.55
		43.2	30.59
		52.3	30.63
		61.5	30.68
		70.6	30.77
		79.8	30.85
	$18^o14.5'$ $127^o41.5'$	18.6	29.55
	(9/75)	27.8	30.57
		36.9	30.92
		46.1	31.05
		55.2	31.09
		64.4	31.13
		73.5	31.32
		82.7	31.43
		91.8	31.51
	$18^o14.1'$ $127^o41.6'$	56.4	31.08
	(76/1)	65.6	31.26
		74.7	31.38
		78.8	31.39
HALLS CK	$18^o5.2'$ $127^o51.4'$	32.0	31.39
	(PDH 8)	42.7	31.49
		51.9	31.54
		61.0	31.57
		64.4	31.59
YUENDUMU	$22^o19.6'$ $131^o44.7'$	28.9	26.96
	(10556 4)	38.0	27.75
		47.2	27.96
		56.3	28.27

Table 2 (Continued)

Area	Borehole Location	Depth (m)	Temp (^{o}C)
YUENDUMU	22°19.6' 131°44.7'	65.5	28.51
		74.6	28.83
		83.8	29.55
		92.9	30.09
		102.1	30.19
		111.2	30.23
		120.4	30.29
		129.5	30.32
		138.7	30.37
		147.8	30.45
		157.0	30.61
		166.1	30.68
		175.3	30.79
		184.4	30.91
		193.6	30.96
		202.7	31.03
		211.9	31.07
		221.0	31.51
YUENDUMU	22°18.9' 131°44.9'	29.8	27.35
	(10660 6)	39.0	27.92
		48.1	28.07
		57.3	28.36
		66.4	28.59
		75.6	28.89
		84.7	29.36
		93.9	30.04
		103.0	30.43
		112.2	30.44
		121.3	30.45
		130.5	30.47
		139.6	30.49
		148.8	30.50

Table 2 (Continued)

Area	Borehole Location	Depth (m)	Temp (^{o}C)
YUENDUMU	$22^{o}18.9'$ $131^{o}44.9'$	157.9	30.53
		167.1	30.55
		176.2	30.57
		185.4	30.78
		194.5	31.45
		203.7	31.56
		212.8	31.62
		222.0	31.98
	$22^{o}19.3'$ $131^{o}44.8'$	24.7	27.14
	(10945 7)	33.9	27.45
		43.0	27.76
		52.2	27.98
		61.3	28.27
		70.5	28.49
		79.6	28.84
		88.8	29.37
		97.9	29.60
		107.1	29.72
		116.2	29.81
		125.4	29.86
		134.5	29.90
		143.7	29.96
		152.8	29.98
		162.0	30.00
		171.1	30.01
		180.3	30.88
ST GEORGE RANGE	$18^{o}41.5'$ $125^{o}8.2'$	261	43
		862	57
		1472	59
		2013	63
		2444	72
		2808	78

Table 2 (Continued)

Area	Borehole Location		Depth (m)	Temp (^{o}C)
ST GEORGE RANGE	18^{o}41.5'	125^{o}8.2'	2809	74
			3192	79
			3561	89
			3872	93
			4431	113
			4436	117

TABLE 3

Thermal conductivity results

Area	Borehole	Depth (m)	$(W.m^{-1}.K^{-1})$	Technique
NOONKANBAH	NOON 1	39.6	2.66	Cell
		50.3	2.62	
		64.0	2.60	
		74.7	2.53	
		89.9	2.65	
		118.9	2.86	
		149.4	2.91	
	NOON 2	46.0	3.82	Cell
		48.8	3.25	
		76.2	2.16	
		79.3	1.9	
		106.7	2.4	
		137.5	2.14	
	NOON 2	167.6	2.11	Core
		198.1	2.97	
		274.3	1.88	
		305.1	2.23, 2.39	
BILILUNA	BIL 3	9.1	4.15	Cell
		15.2	4.17	
		42.7	4.01	
		54.9	4.13	
		64.0	3.68	
		73.2	4.11	
		82.3	3.22	
		91.4	4.31	
		106.7	3.46	
		122.0	3.98	
		137.2	3.33	
		155.4	2.55	

Table 3 (Continued)

Area	Borehole	Depth (m)	$(W.m^{-1}.K^{-1})$	Technique
BILLILUNA	BIL 3	64.3	3.27	Core
		88.4	2.68	
		113.4	3.70	
		146.0	3.42	
		161.2	3.45	
	BAN 1	6.1	3.27	Cell
		15.2	2.51	
		79.3	2.10	
		109.7	3.13	
	CORNISH 3	50	2.01	Cell
	(Lake Gre-	54	1.82	
	gory Beds)	56	1.70	
HALLS CK	76/1A	10.0	3.41	Cell
		60.0	3.40	
TANAMI	1488	59.4	2.68	Cell
		68.6	2.30	
		79.3	2.55	
	63	53.6	1.74	
YUENDUMU	6	90	3.76	Cell
		92	3.44	
		94	3.37	
		214	2.69	
		216	2.91	
		218	2.79	
	7	82	2.76	Cell
		85	(4.8)	
		88	3.15	

Table 3 (Continued)

Area	Borehole	Depth (m)	$(W.m^{-1}.K^{-1})$	Technique
YUENDUMU	7	172	3.72	Cell
		175	3.07	
		178	3.48	
	4	74	2.72	Cell
		76	3.49	
		78	3.84	
		220	3.00	
		222	2.21	
		224	2.75	
		226	2.43	
		228	2.85	
		230	3.00	
NOONKANBAH	St George Range	94.2	3.01	Core
		260.0	4.21	
		546.0	4.42	
		740.7	3.47	
		1360.9	4.65	
		1670.3	4.66	
		1925.7	4.36	
		3274.8	3.43	
		4286.1	1.96	
		4406.2	4.32	

TABLE 4

SUMMARY OF HEAT-FLOW VALUES

Bore	Lat.	Long.	Elev.(m)	D	G	λ	N	Q
Esso 15	18.10	124.79	120	40-115	32.9 ± 0.7	2.65 ± 0.40	13(2)	70 ± 3
" 22	18.11	124.82	120	50-137	30.5 ± 0.7	2.65 ± 0.40	13(2)	65 ± 3
BIL 3	19.51	127.64	450	40-70	14.2 ± 0.7	3.92 ± 0.32	8	46 ± 3
						3.27(1)	1	46 ± 2
BAN 1	19.95	127.23	450	35-65	39.9 ± 1.6	1.84 ± 0.16	3(2)	59 ± 7
Tanami	19.98	129.71	450	40-80	17.4 ± 0.9	2.32 ± 0.35	4	32 ± 7
Halls Ck	18.24	127.69	510	45-95	10.8 ± 0.9	3.41	2	29
Yuendumu	22.33	131.75	730	0-220	B	B	6	56 ± 3
St George R.	18.69	125.14	210	0-4400	15.92 ± 1.4	3.96 ± 0.66	10	65 ± 5
St George R.					B	B	10	64 ± 4

Legend : D depth interval examined (m)

G thermal gradient (°C) [B denotes Bullard reduction]

λ average thermal conductivity ($W\ m^{-1}\ K^{-1}$)

[(1): data from solid core, other data from chips]

N number of samples measured for conductivity

[(2): data obtained from neighbouring holes in similar rock types]

Q corrected heat flow ($mW\ m^{-2}$)