Australian Journal of Earth Sciences
An International Geoscience Journal of the Geological Society of Australia
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t716100753

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Online Publication Date: 01 December 1977

To cite this Article: Lilley, F. E. M., Sloane, Merren N. and Sass, J. H. (1977) 'A compilation of Australian heat-flow measurements', Australian Journal of Earth Sciences, 24:7, 439 — 445

To link to this article: DOI: 10.1080/00167617708729003
URL: http://dx.doi.org/10.1080/00167617708729003

A COMPILATION OF AUSTRALIAN HEAT-FLOW MEASUREMENTS

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(With 1 Table and 3 Figures)

(MS received 26 September 1977)

ABSTRACT

A map is presented based on all known Australian heat-flow estimates, including five new ones. A second map, based on the first, also is presented, but excludes any determinations judged for any reason to be unreliable. The data show that heat flow over large areas of the continent is effectively uniform to within 0.5 heat flow units (*i.e.* to within 20 mW m^{-2}), with perhaps three major regional heat-flow provinces being defined in western, central, and eastern Australia.

INTRODUCTION

A register of heat-flow measurements in Australia recently compiled by the authors contains some 200 entries. Most of these have been made by the Australian National University over the last 25 years since the Department of Geophysics (forerunner of the present Research School of Earth Sciences) was formed in 1952. The thermal state of the Australian upper crust has also been examined by temperature logs run in many thousands of boreholes, (see, for example, Thomas, 1960; Beck, 1976), but these are outside the scope of this paper. A major contribution to the present compilation comes from the work of Sass *et al.* (1967), and also included are five new determinations made recently, which will be described first.

RECENT MEASUREMENTS AT THE AUSTRALIAN NATIONAL UNIVERSITY

Five determinations have been made in holes of opportunity in two previously studied areas: the Tennant Creek region, Northern Territory, and Yorke Peninsula, South Australia. The procedure followed has been the traditional one of logging a borehole for temperature (T) against vertical depth (z), and then computing the heat flow (q) upon the basis of steady-state one-dimensional heat conduction, according to

$$q = -k \frac{dT}{dz}$$

where k denotes thermal conductivity. The negative sign is present because the flow of heat takes place in the direction of decreasing temperature.

The borehole logs were run using a temperature-sensitive thermistor probe and thermal conductivity measurements were made on the A.N.U. divided-bar apparatus, using rock discs 35 mm in diameter and 6 mm thick cut from borehole core. These discs were first saturated with water, and control on absolute thermal conductivity values was obtained using standard discs of fused silica (k = 3.27 mcal°$C^{-1}cm^{-1}sec^{-1}$ = 1.37 $Wm^{-1}K^{-1}$). The procedures followed were essentially as described by Sass *et al.* (1971).

From the temperature profiles, thermal gradients were estimated at particular depths and combined with the thermal conductivity value for each depth to give a set of heat-flow values for each hole. The results of these measurements and calculations for the five holes are presented in Figure 1. A mean heat-flow value was calculated from the set of values for each hole, with error estimated as the standard deviation from the mean. The results are summarized in the Table.

THE COMPILATION

Figure 2 presents a map upon which has been plotted, in code form, the compilation of heat-flow determinations for the Australian continent. All known determinations have been included except that, where several values of the same category have been found close to each other, some will have been omitted simply because of lack of space on the map. Many of the determinations have been extracted from the original references listed in the appended bibliography, though a series of intervening compilations should be acknowledged, especially Lee & Uyeda (1965), Lee & Clark (1966), Jaeger (1970), and Sass *et al.* (1976).

It has been traditional in previous compilations to take into account some estimate of the reliability of each determination. This is inevitably a subjective matter in some instances but

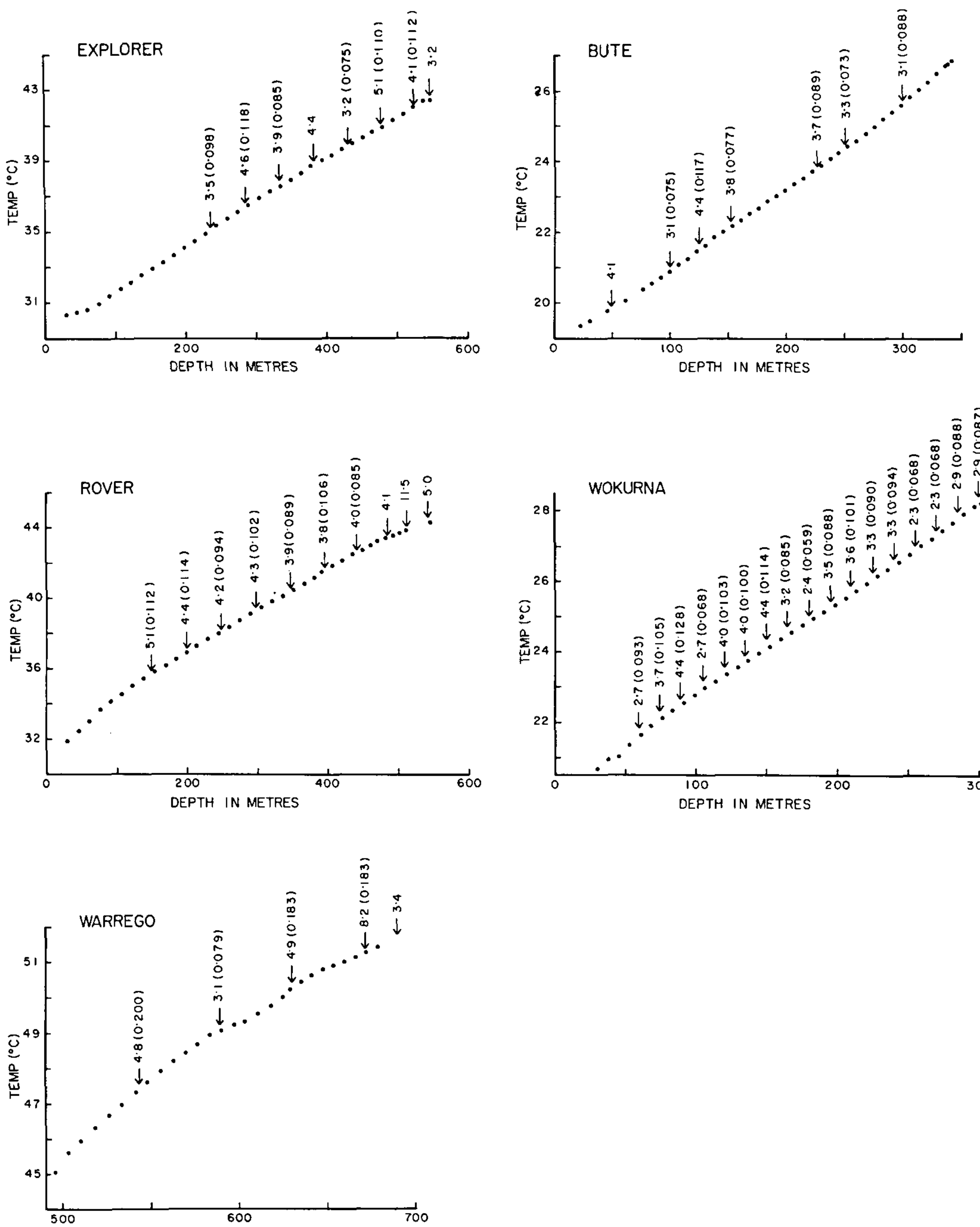
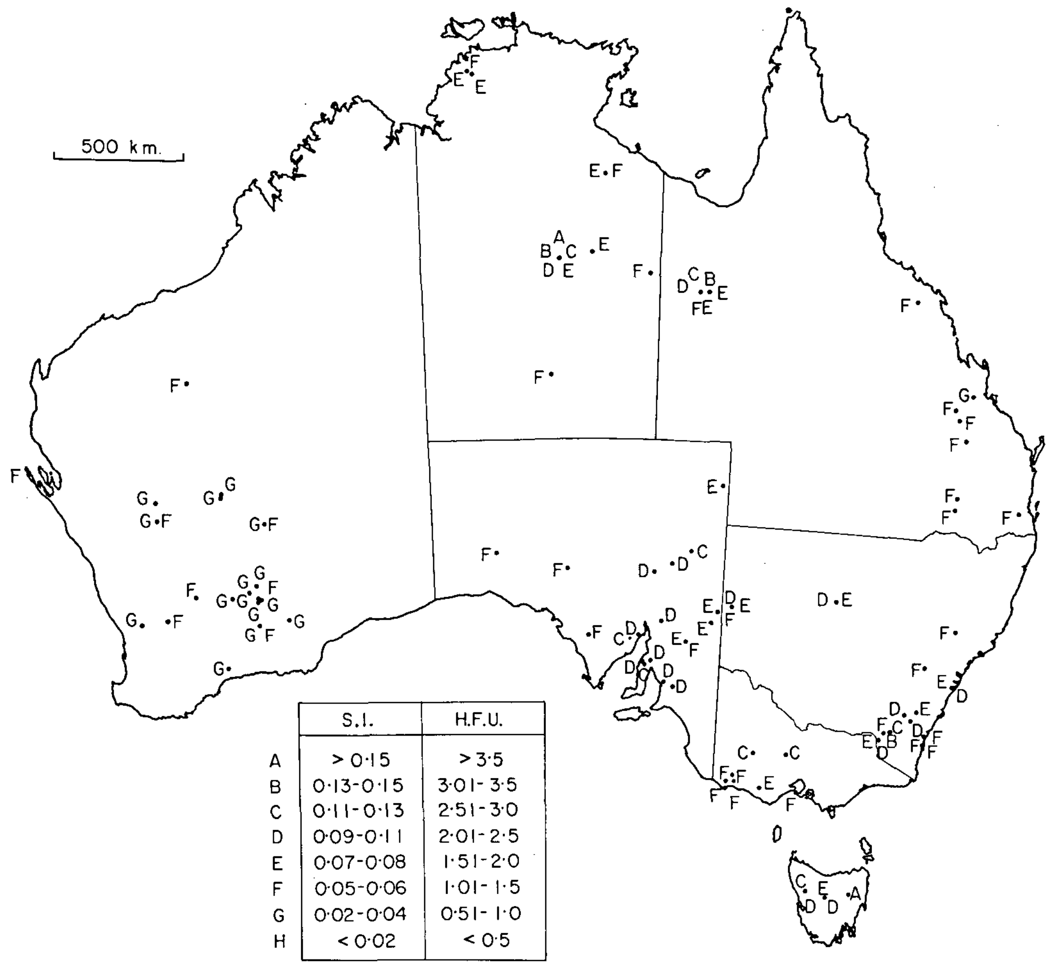


Fig. 1. Heat-flow data for the five boreholes listed in Table. The graphs show the actual temperature measurements down the holes; the numbers beside the arrows give the measurement of thermal conductivity in SI units ($W\,m^{-1}K^{-1}$) of a core sample taken at the depth shown, and the numbers in brackets give the heat flow in SI units ($W\,m^{-2}$) obtained from the conductivity value and the thermal gradient measured at the point shown.
When logged, the Warrego hole, drilled below ground level in a mine, was noted as being 'flowing', and so must be classed as unreliable. This may account for the very high heat-flow value recorded in it.

TABLE

Hole Name	Explorer	Rover	Warrego	Bute	Wokurna
Hole Information	Geopeko	Geopeko	Geopeko	S.A. Dept. Mines	S.A. Dept. Mines
	Explorer 46 DDH 5	Rover 1 DDH 2	Warrego DDH Tex 1A	Bute DDH 6	Wokurna No.3
State	Northern Territory	Northern Territory	Northern Territory	South Australia	South Australia
Geograph.Coords. Lat.	19°41'S	20°05'S	19°27'S	33°56'S	33°43'S
Long.	134°14'E	133°40'E	133°49'E	137°58'E	138°07'E
Date of Logging	May 1974	March 1974	March 1974	December 1973	March 1977
Static or Flowing	Static	Static	Flowing	Static	Static
Extrapolated Surface Temp.	29.1°C	31.5°C	-	18.9°C	19.9°C
Heat Flow Value SI units ($W\ m^{-2}$)	0.100±0.008	0.100±0.004	0.161±0.028	0.087±0.008	0.091±0.004
($mW\ m^{-2}$)	100 ± 8	100 ± 4	161 ± 28	87 ± 8	91 ± 4
HFU ($\mu cal\ cm^{-2} s^{-1}$)	2.39±0.17	2.39±0.10	3.86±0.66	2.07±0.16	2.17±0.10



	S.I.	H.F.U.
A	> 0·15	> 3·5
B	0·13–0·15	3·01–3·5
C	0·11–0·13	2·51–3·0
D	0·09–0·11	2·01–2·5
E	0·07–0·08	1·51–2·0
F	0·05–0·06	1·01–1·5
G	0·02–0·04	0·51–1·0
H	< 0·02	< 0·5

Fig. 2. Map of all heat-flow determinations, except that, where many values of the same category have been found in close proximity to each other, some have been omitted from the map simply because of lack of space. An extreme case of this is the Mt Isa locality, where 14 *D*-values and 17 *E*-values have been determined. The code letters thus do not all carry equal weight.
SI numbers in the code legend are in units of W m^{-2} and HFU numbers are in heat-flow units of μcal $cm^{-2}s^{-1}$.
Note: Additional values of *D* (87 mW m^{-2}) and *F* (57 mW m^{-2}) for southern Tasmania have recently been obtained by Wronski (1977).

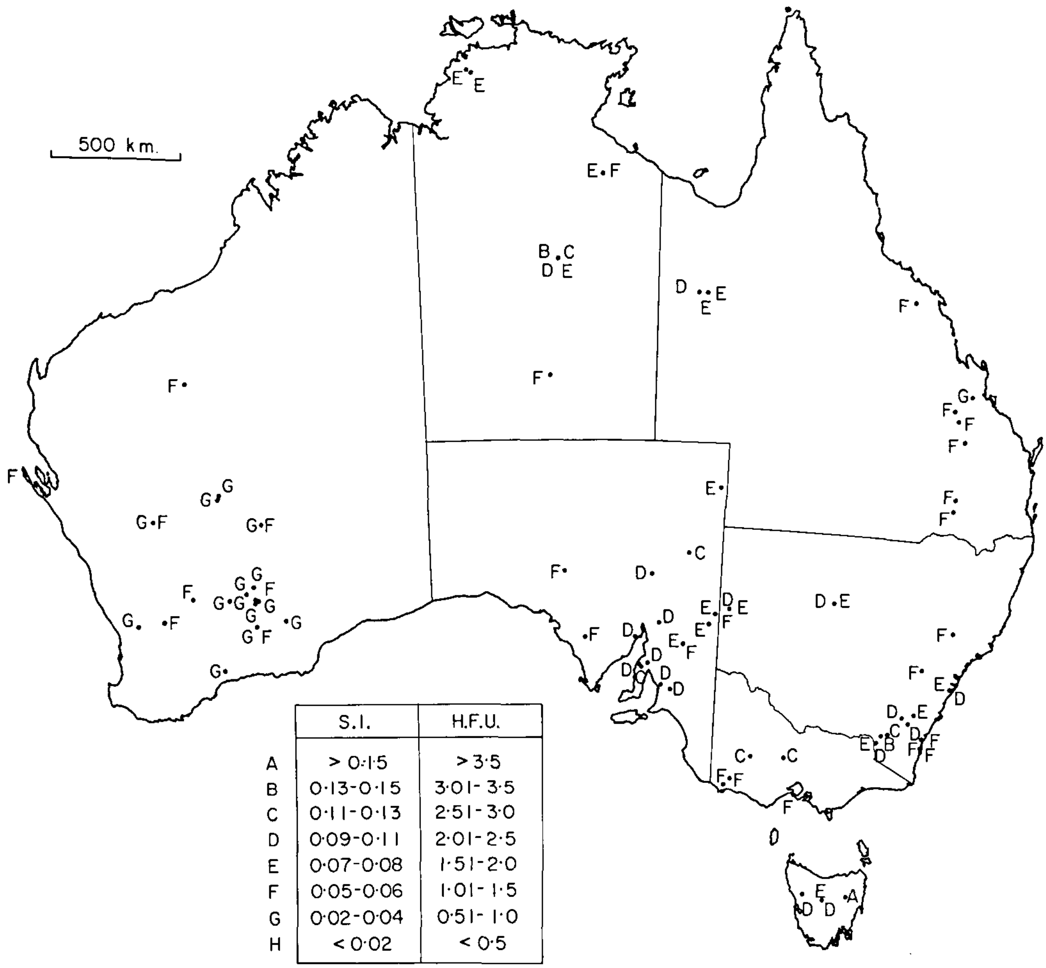
a decision for unreliability may be clear if, for example, the bore-hole logged was actually flowing (thus contravening the theoretical assumption of steady-state conduction), or if some doubt pertains to the thermal conductivity measurements. In some cases such qualifications concerning reliability are made by the authors of the original references themselves.

Another indication of possible unreliability is whether a determination is consistent with others nearby, or appears anomalously different from them. The authors of this review have therefore been careful to check the source references of such apparently anomalous heat-flow values: in many cases they do appear to be suspect, and so have been classed as unreliable. Where there has been no other reason to doubt them, except upon the basis of their inconsistency, these anomalous values have been retained, and the more prominent of them are discussed in section 4 (ii) below.

When values thus judged unreliable are deleted from the map in Figure 2, the map of Australian heat-flow shown in Figure 3 is obtained.

DISCUSSION

It is not a purpose of this paper to analyse in detail the geological significance of the Australian heat-flow pattern: a discussion of the



	S.I.	H.F.U.
A	> 0·15	> 3·5
B	0·13-0·15	3·01-3·5
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D	0·09-0·11	2·01-2·5
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F	0·05-0·06	1·01-1·5
G	0·02-0·04	0·51-1·0
H	< 0·02	< 0·5

Fig. 3. Map of the heat-flow determinations remaining when those judged unreliable have been omitted. As for Fig. 2, not all values of the same category have been plotted when they occur in close proximity to each other.
Note: An additional *D* value (87 mW m^{-2}) has recently been obtained by Wronski (1977).

relations among heat-flow, near-surface radioactivity, Cainozoic tectonic activity and major geologic provinces may be found in the report by Sass *et al.* (1976), reprints of which are available from the present authors.

However, some remarks may be made upon inspection of Figure 3.

(i) With several exceptions (see (ii) below), the heat-flow distribution over the Australian continent appears smooth. The uniformity of low heat-flow in the west (which has been well discussed before) is remarkable, as is the high heat-flow in the Adelaide Geosyncline area of central southern Australia. In eastern Australia, on earlier indications also generally a high heat-flow area, there is now increasing evidence of moderate heat-flows, restricting the high heat-flow region perhaps to an area from the Snowy Mountains northeastwards to the Sydney Basin.

(ii) The exceptions to the smooth pattern evident in Figure 3 are few enough to be listed individually. They are:

(a) The *B* and *C* values in the Tennant Creek area (in fact at the Warrego Mine), where the cause of such high values is not understood, but may be due to uneven stratification in the thermal conductivity of mineralized zones.

(b) The two *C* values in Victoria, originally appearing consistent between themselves but not now gaining support from several determinations made in the Otway Basin near the coast to the south. High values occur again in Tasmania, however, and the area is one in which an asthenospheric 'hot spot' has been postulated on the basis of recent volcanism (Vogt & Conolly, 1971), and an electrical conductivity anomaly found by Lilley (1976). Thus the pattern of low-to-normal heat flow in the Otway Basin may not reflect the thermal regime at depth but could result from hydrologic conditions of the type described by Sass *et al.* (1971) and Lachenbruch & Sass (*in press*) for the 'Eureka Low', a large region of low heat-flow in the Basin and Range Province of the western United States.

(c) The *A* value in eastern Tasmania, which may also be due to uneven thermal conductivity in a mineralized zone.

(d) The *B* and *C* values in the Snowy Mountains, which are, however, heavily outweighed numerically by the *D* and *E* value determinations for the same area (six *B* and *C* values against fifteen *D* and *E* values). Thus representative codes for the area are *D* and *E*.

CONCLUSIONS

Heat-flow values measured for the Australian continent are continuing to define regional heat-flow provinces. The work of surveying the continent for heat-flow may receive an impetus from interest in the subject now being taken by the Bureau of Mineral Resources (*e.g.* Cull, 1977).

ACKNOWLEDGMENTS

Four of the recent holes were logged by J. Kras, and D. V. Woods assisted with the fifth. We especially thank Geopeko Limited and the South Australian Department of Mines for their help in the process of logging the holes, and for supplying core samples for conductivity measurements.

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