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THE WORLD HEAT FLOW DATA COLLECTION—1975

A.M. Jessop, M.A. Hobart and J.G. Sclater

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PREFACE

Periodic revisions of the world compilation of heat flow data take place under the auspices of the International Heat Flow Commission of the International Association of Seismology and Physics of the Earth's Interior. In the current work the compilation of oceanic data has been the responsibility of M.A. Hobart and J.G. Sclater*, and the compilation of continental data and the coordination of the work have been the responsibility of A.M. Jessop**.

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INTRODUCTION

This compilation is the third in the series of compilations under the auspices of the International Heat Flow Commission, and was undertaken as a result of a decision by the Commission at the time of the general assembly of the International Union of Geodesy and Geophysics in Moscow. Previous compilations have been published by Lee and Uyeda (1965) and Simmons and Horai (1968). In addition to this printed edition, the data are available in computer-compatible format from World Data Centre A.

FORMAT AND PHILOSOPHY

Different writers have described their heat flow measurements in many different ways, and individual measurements are based on data of different quality and from areas of different geological and physical environment. For these reasons it is impossible to describe completely each measurement within the limit of one card of 80 characters. The compilers' aim has been to standardize the description as much as possible, and at the same time to mislead the user as little as possible.

Data has been extracted from the original publications with very few exceptions. The only exceptions are in the data from U.S.S.R., and when original publications were not available the list of Lubimova et al (1973) was used. References that could not be consulted are marked with two asterisks (**) in the reference list. Because of some unexplained discrepancies between the list of Lubimova et al (1973) and some original publications, the accuracy of data from these references is not guaranteed.

A principle adopted from the start was that the compilers would avoid recording their opinions regarding the quality of the data, and that as many factual indicators of quality as possible would be included. This principle accounts for the majority of changes to the format that was established by Lee and Uyeda (1965) and followed by Simmons and Horai (1968). Included for this reason are the minimum and maximum depth of usable borehole and the numbers of temperature data and conductivity data that were used to derive the heat flow result.

The onus is on the user of this data list to make his or her own quality judgment, since some of the items listed are less reliable than others. For example, it is possible to reject all continental measurements made in holes less than 200 m deep, or based on fewer than five conductivity or temperature data, according to the needs or opinions of the user.

The facts recorded, the units and the card format are summarized in Table 1, and brief notes on each column follow:

1. Item number.

Each item has been allocated a five-digit number except where sites are close together. Closely spaced sites are grouped under a single item number and individual sites follow and are allocated a letter. Item numbers are purely arbitrary; they do not correspond to any previous list, and will probably not remain the same in future lists. The normal criterion for grouping has been a spacing of less than 10 km and a similar geological environment. It has not always been possible to apply this rigorously, particularly where measurements have been made in lines of more than 10 km, and some arbitrary decisions have been necessary. Oceanic data have not been grouped.

2. Descriptive codes.

The system of descriptive codes developed by Lee and Uyeda (1965) has been continued with some modification. Notes are to be found below and details are presented in Tables 2 - 8.

3. Name of site.

The name is included for ease of recognition. It is not essential to the data, but it is a great help in compilation, verification and reading. Only eight characters are provided, and some abbreviation has been necessary.

4. and 5. Latitude and Longitude.

Although it is pointless to report heat flow results without specifying the position of the sites, it is surprising how many authors have omitted this information. Missing coordinates have been inserted by the compilers whenever possible, but otherwise the data have been omitted. It would be helpful if future writers would avoid using national grid systems or longitude based on anything but Greenwich, since these cannot always be readily translated by compilers or users.

6. Elevation.

Elevation is less important than horizontal coordinates, but it completes the specification of position. The elevation of the solid surface at the measuring point is recorded, whether it be dry land, sea bed or lake bed.

7. and 8. (On land) Depth interval.

The interval of depth from which data were taken and used for calculating heat flow provides an indication of quality.

7. (In lakes) Water Depth.

This column gives the depth of water at the measurement site. It is not needed for oceanic measurements, since depth is the inverse of elevation, which is given in column 6.

8. (In lakes and oceans) Penetration.

Penetration is the equivalent of factor 8 for land measurements, since it gives the maximum depth of temperature measurement.

9. Number of temperature data.

This number shows how many temperature points were used in the calculation of temperature gradient, and is included as a quality indicator.

10. Temperature gradient.

Temperature gradient is only recorded if it is reasonably uniform over the interval of measurement. It is not corrected for climatic change or any other disturbance unless the author has presented it in a corrected form.

11. Number of conductivity measurements.

This number is also a quality indicator. Where conductivity has been estimated by rock type or from previously existing data from adjacent sites this number has been set as zero, whereas a blank signifies lack of information.

12. Average conductivity.

Conductivity has only been recorded if the individual values are reasonably uniform or if the borehole penetrates a single rock-type.

13. Number of heat generation measurements.

This number records the number of samples used for analysis of heat production by radioactive decay. The sample may be from the drill core or from representative samples from surrounding areas that have been associated with the heat flow site by the authors.

14. (On land). Average heat production.

The figure recorded here is the value chosen by the author to represent the upper crust at the heat flow site.

14. (In oceans) Bottom-water temperature.

A few authors have reported the temperature of the water immediately above the ocean floor. This may be regarded as an indicator of the possibility of significant temperature fluctuation. See Code 7, Table 8.

14. (In lakes). Bottom-water temperature.

Bottom-water temperature and its variability is an important factor in lake measurements, but there may also be associated heat generation data. To avoid confusion, column 13 contains the letter W (for water) when bottom water temperature is given in column 14, and column 13 contains a number or is blank when heat generation is given. Since lake measurements are often grouped it is possible to give heat generation data with the group summary and water temperature with the subitems. Only in lake measurements, indicated by K or L in code 3 is this distinction applied.

15. Heat flow.

The compilation of heat flow data is the prime purpose of this work. A few items are included without heat flow data, but these include a bottom-water temperature. Land values are always given to the nearest 1.0 mW/m^2, which permits an uncertainty of 1% of the average value and is always adequate. Ocean values are given to 0.1 mW/m^2, since differences of this order may be significant between measurements made in sequence, with the same equipment, in closely spaced surveys. Measurements where this precision is justified are a small minority, and in no item is the absolute value of heat flow accurate to this level.

The plus sign (+) in front of some heat flow values is substituted for the greater than (>) symbol in order to provide computer-compatibility for formatted data. A negative sign (-) before the heat flow value indicates that the heat flow is negative.

16. Number of individual sites.

This number is one except where grouping has occurred, and it is left blank in sub-items. Some authors have reported results based on several holes, but do not give sufficient data to allow the listing of individual sites. In such situations the sub-items have been omitted, so it must not be assumed that an item having a number greater than one will always be followed by the appropriate number of sub-items.

17. Reference.

This number gives the source of the data according to the bibliography that follows the data list. The lists of Lee and Uyeda (1965), and Simmons and Horai (1968), have been combined with the new references and numbered in alphabetical order.

18. Date of publication.

The last two digits of the year of publication are recorded as an indicator of the age of the data in computer-accessible form. This information is also included in the references.

DESCRIPTIVE CODES

The descriptive codes are an attempt to condense the words written by the authors about their measurements. There are often several pages of information condensed into these six letters, and some loss of detail is inevitable.

1. Geographical setting.

This code divides the data setting by geographical location into the major continental blocks, the major oceans, smaller non-continental land areas and marginal seas. Details are listed in Table 2.

2. Tectonic setting.

This code is intended to denote the last orogenic disturbance to have affected the site, regardless of the age of the present surface rocks. In the oceans this code describes the nature of the sea floor in terms of plate tectonic theory. Many authors have not included this information and the compilers have inserted information based on current tectonic maps. Tectonic setting of some areas is still subject to argument, and some entries in this code are correspondingly tentative. Details are shown in Table 3.

3. Temperature measurement.

This code denotes the physical nature of the site in terms of the acquisition of temperature data. It should be used as the defining indicator of land, ocean floor, and lake-floor sites. Details are shown in Table 4.

4. Conductivity measurement.

This code describes the technique used to determine the thermal conductivity of the rock or sediment. When more than one technique was employed the technique whereby the majority of results was obtained is entered. Details are shown in Table 5.

5. Corrections.

This code summarizes the correction made to the heat flow to remove purely surface effects due to climate, topography etc. as shown in Table 6. In order to avoid misleading the user one exception has been made to the principle of purely objective reporting. Code J denotes those items where climatic correction has been made on the basis of assumptions now regarded as erroneous. All items affected are very early results, and this judgment is based on the paper by Birch (1948) that established the procedure for climatic corrections.

6. Indication of consistency.

Reliability is mostly superseded by factual indicators of quality such as quantity of raw data, depth of borehole, etc., but it has been retained to specify the variation of heat flow with vertical position or probe tilt, as specified in Table 7. This code is not intended to reflect the opinions of the compilers of the data: many of the data credited with an A, the highest rating, may be unreliable due to inadequate measurement, lack of correction, water flow, or other reasons.

7. Water temperature.

Recently, it has become apparent that the temperature profiles in the water near the floor of the ocean that are obtained by several of the different models of oceanic heat-flow devices are of great oceanographic interest. This has led us to include a code showing whether or not such a profile was obtained and published. The data base for this code is not complete, as many authors have not indicated whether they obtained such profiles with their heat flow measurements. This also accounts for the inclusion of several stations for which there is no heat flow value. Details are shown in Table 8.

GEOGRAPHICAL STATISTICS

The average and standard deviation of heat flow, grouped by geographical area, are shown in Table 9. The continental averages are very uniform, except for South America, where the data are too few to constitute an adequate sample, and for 'miscellaneous lands' including New Zealand and Iceland, which are associated with the world rift system and may be expected to be different from the large continental blocks. The oceanic averages show a wide variation. This is not a function of the distribution of results by tectonic area, but of the average heat flow within the tectonic areas. Table 10 shows that the Atlantic and Indian Oceans, the two oceans having the lowest overall heat flow, have significantly lower heat flow in the active spreading centres (code 0) than the other oceanic areas. The Mediterranean area has a particularly high heat flow in active spreading centres, almost entirely due to data from the Red Sea, and this influences the average for the whole area The average heat flow in the Atlantic and Indian Oceans is similar to the continental levels.

Figure 1 shows histograms of all heat flow values, with subdivisions into oceanic and continental areas. Although the means are different the modal values are the same in all these histograms. The oceanic data have a wider distribution than the continental data, as shown by the standard deviations in Table 9 and, although it is not illustrated, the histogram of oceanic data continues to the level of 345 mW/m^2 before a block of $5 mW/m^2$ is found with no entries. This high level of asymmetry of the distribution forces the mean to be well above the mode.

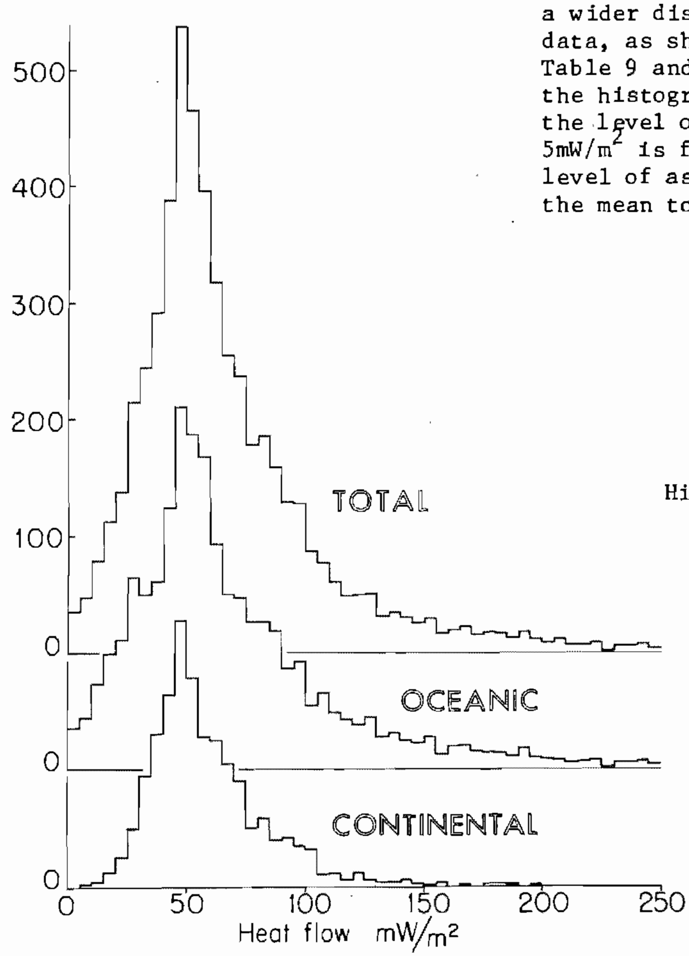

Fig. 1

Histogram of heat flow data.

TABLE 1

Summary of Format

Col.	Description	Units	Characters	Card Cols.
1	Data number		5 digits	1 - 5
2	Descriptive codes		7 letters	6 - 11, 75
3	Names		8 characters	13 - 20
4	Latitude	Deg., Min., Tenths	5 digits & letter	21 - 26
5	Longitude	Deg., Min., Tenths	6 digits & 1 letter	27 - 33
6	Elevation of collar (land) Elevation of sea floor Elevation of lake floor	m m m	Sign & 4 digits	34 - 38
7	Minimum depth used (land) - blank - (sea) Water depth (lake)	m m	4 digits	39 - 42
8	Maximum depth used (land) Penetration (sea) Penetration (lake)	m m m	4 digits	43 - 46
9	No. of temperature meas.		3 digits	47 - 49
10	Temperature gradient	mK/m	3 digits	50 - 52
11	No. of conductivity meas.		3 digits	53 - 55
12	Average conductivity	W/mK	3 digits & decimal	56 - 59
13	No. of heat production meas.		3 digits	61 - 63
14	Av. heat production (land) Bottom water temp. (sea) Bottom water temp. (lake)	W/m^3 ^oC ^oC	3 digits & decimal	64 - 67
15	Heat flow	mW/m^2	3 digits & decimal	68 - 71
16	No. of sites		2 digits	73 - 74
17	Reference		3 digits	76 - 78
18	Year of publication		2 digits	79 - 80

NOTE: Items 10 and 12 are only filled in if the quantities are reasonably uniform and are specifically quoted by the author.

Code 3 provides the means of separation into land, sea, and lake measurements.

The units and conversion factors used are those recommended by the International Heat Flow Commission.

TABLE 2

Explanation of descriptive codes
Code 1 - Geographical area

This code describes the major geographical unit in which the individual site lies.

The convention of using the first half of the alphabet for land sites and the second half for ocean sites is adopted, and is used in all the codes as appropriate.

The continental areas include the continental shelves adjacent to the continents.

A	Africa
B	North America
C	South America
D	Australia
E	Europe and Asia
F	Miscellaneous lands, including New Zealand, Pacific Islands, Iceland, etc.
N	Atlantic Ocean
O	Indian Ocean
P	Pacific Ocean
Q	Arctic Ocean
R	Mediterranean, Red, Black, and Caspian Seas
S	Other marginal seas (Caribbean, Philippine, etc.)

TABLE 3

Explanation of descriptive codes
Code 2 - Tectonic setting

At land and lake sites this code describes the last orogenic disturbance to have affected the site area, even though surface rocks might be of later period. Since Precambrian orogenic periods are less well defined codes A, B, and C describe the surface rocks.

At ocean sites this code describes the tectonic setting at present.

A	Archaean
B	Proterozoic
C	Phanerozoic non-orogenic
D	Early Paleozoic orogeny
E	Late Paleozoic orogeny
F	Mesozoic orogeny
G	Tertiary orogeny or volcanic zone
H	Geothermal area
I	Continental shelf
N	Ocean basin
O	Ocean ridge or rise - active spreading centre
P	Ocean trench
Q	Continental rise
R	Continental slope
S	Aseismic ridge
T	Fracture zone
U	Island arc
Y	Unknown
Z	Not specified.

Explanation of description codes
Code 3 - Temperature measurements

At land and lake sites this code describes the nature of the temperature measurement site, and not the method of measurement.

At ocean sites this code describes the measurement instrument when a sea-bottom probe was used.

A	In borehole - all vertical boreholes
B	In mine - horizontal boreholes only
C	In tunnel - one level
K	In lake bottom by shallow-water techniques
L	In lake bottom by oceanographic techniques
N	Bullard-type probe
O	Ewing-type probe
P	Other probes
Q	Deep sea borehole
Z	Not specified

TABLE 5

Explanation of descriptive codes
Code 4 - Conductivity measurements

This code describes the technique of conductivity measurement.

A	Divided bar
B	Transient method in laboratory
C	Down-hole probe
D	Chips in divided bar
E	Other laboratory method
F	Estimated by correlation with nearby holes
G	Estimated from the literature
N	Needle probe
O	Water content
P	Chlorine content
Q	In situ method
R	Other methods
S	Estimated from nearby sites
T	Estimated from sediment lithology
Z	Not specified

TABLE 6

Explanation of descriptive codes
Code 5 - Corrections

This code describes the corrections that have been made to the measurements.

A	Climatic change
B	Topographic irregularity
C	Sedimentation or erosion on land
D	Nearby bodies of water
E	Water circulation
F	Refraction by conductivity contrast
G	Composite corrections - land
H	None
I	Estimated by author to be zero or small
J	Rejected by compiler - see text
N	Sedimentation
O	Sea-floor topography
P	Water temperature variation
Q	Composite correction - sea - lake
R	None - sea
Z	Not specified

TABLE 7

Explanation of descriptive codes
Code 6 - Consistency

It is desirable that the user of the data should be able to assess its quality. Since the data list includes more data than previous lists, it is possible for the individual user to make his or her own quality judgement. The items listed that can be used for this purpose are:

Cols. 7, 8	Depth interval of measurement
Cols. 9, 11	Amount of data used to calculate heat flow
Cols. 15, 16	Variation of heat flow in small area, where multiple sites are available.

The only important factors not listed are the author's estimation of his own limit of errors and the variation of heat flow with depth. Author's estimates of error are calculated in so many different ways that simple listing is worthless. Variation of heat flow with depth is of importance in ocean measurements as an indicator of non-equilibrium temperatures, and can be classified very simply. This factor is not usually important in continental measurements, but the same classification is applied.

A	Less than 10 per cent, or full probe penetration (at least 2 gradient measurements)
B	Greater than 10 per cent but less than 20 per cent, or probe tilt 15-30 degrees and/or only 1 gradient measurement, or large uncertainty in conductivity
C	Greater than 20 percent or probe tilt 30 degrees or only one sediment temperature measurement
D	Probe tilt not determined
E	Indeterminate

Lamont-Doherty Geological Observatory quality ratings on a scale of 10 were divided in the following manner: 10,9 -A; 8,7,6 - B; 5,4,3,2,1 - C.

TABLE 8

Explanation of descriptive codes
Code 7 - Water temperatures profile code

This code is only relevant to oceanic measurements, and there are many blanks.

N	Profile not obtained
P	Profile obtained and has been published
U	Profile obtained but has not been published.

TABLE 9

Average heat flow

Area	Number	Average	Standard Deviation
Africa	99	58.0	35.1
North America	540	60.6	45.5
South America	20	53.7	10.9
Australia	42	64.9	27.4
Europe and Asia	954	63.1	36.2
Miscellaneous lands	44	71.4	67.7
Total continental	1699	62.3	40.1
Atlantic Ocean	857	64.2	49.4
Indian Ocean	419	63.1	46.1
Pacific Ocean	1427	87.9	90.8
Arctic Ocean	56	70.9	26.1
Mediterranean, Red, Black, Caspian Seas	269	120.7	303.6
Other marginal seas	690	77.5	42.4
Total oceanic	3718	79.8	105.9
Total oceanic, without Mediterranean area	3449	76.6	69.0
Global total	5417	74.3	90.9

TABLE 10

Distribution of oceanic heat flow by tectonic setting

a) number of sites by percentage

	Total	N	O	P	Q	R	S	T	U
Atlantic Ocean	857	45.6	41.5	.5	4.4	2 1	2 7	1.3	1.8
Indian Ocean	419	47.5	43 0	2.1	5.0	0	.7	.7	1.0
Pacific Ocean	1427	48.4	35.3	2.3	4.1	2 5	4 5	2.2	.1
Arctic Ocean	56	26.8	14.3	0	0	0	8 9	0	0
Mediterranean Sea, etc.	269	36.1	26.8	1.1	14.9	14.1	4 8	0	1.1
Other marginal seas	690	61.9	3.9	1.9	5.2	5 5	10.0	1.9	9.7
Total	3718	49.0	30.8	1.7	5.2	3 8	5 5	1.6	2.4

b) average heat flow

	Total	N	O	P	Q	R	S	T	U
Atlantic Ocean	64.2	53.6	71.6	60.1	96 9	75 1	49.9	116.8	53.3
Indian Ocean	63.1	58.8	69.1	45 7	56.7		52 2	53.4	109.9
Pacific Ocean	87.9	60.5	129.1	45.7	88.1	91.8	76.5	83.2	118.6
Arctic Ocean	70.9	61.7	96.8				68 8		
Mediterranean Sea, etc.	120.7	54.2	263.5	35.9	43.8	60.4	31.0		65.2
Other marginal seas	77.5	73.2	137.5	56.8	73 7	85.3	87.3	75.8	72.4
Total	79.8	61.4	110.2	48.5	74.5	75 9	72.7	86.3	71.7

Column Headings:

N	Ocean basin	R	Continental slope
O	Spreading centre	S	Aseismic ridge
P	Ocean trench	T	Fracture zone
Q	Continental rise	U	Island arc

REFERENCES

Birch, F. The effects of Pleistocene climatic variations upon geothermal gradients. Am. J. Sci., 246, 729-760, 1948.

Lee, W.H.K. and Uyeda, S. Review of heat flow data. In - Terrestrial heat flow, Ed. Lee. Am. Geophys. Un. Monograph. 8, 87-190, 1965.

Lubimova, E.A., Polyak, B.G., Smirnov, Y.B., Kutas, R.I., Firsov. F.V., Sergienko, S.I., Liusova, L.N. Heat flow on the USSR territory catalogue of data. Geophys. Committee Acad. Sci., USSR, 1973.

Simmons, G. and Horai, K. Heat flow data 2. J. Geophys. Res., 73, 6608-6629, 1968.