



Keywords

IHFC,
History,
Accomplishments,
Five Decades.

Received: January 28, 2018

Accepted: April 10, 2018

Published: April 26, 2018

International Heat Flow Commission: History and Accomplishments over the last fifty-five years

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Abstract

The study of the earth's internal heat plays an important role in understanding the Earth's origin, internal constitution, and plate tectonics. The outflow of heat from the Earth's interior is, energy-wise, the most impressive terrestrial phenomenon. The present rate of heat loss is estimated to be about 1021 joules per year, which is orders of magnitude greater than the energy dissipation of earthquakes or heat loss from volcanic eruptions. Knowledge of terrestrial heat flow is essential in investigating the internal thermal field of the Earth. Initially focus has been on measurements of underground temperatures and thermal properties of geologic materials, assessment of sources and sinks of heat, institution of global data base, development of thermal models of crust and qualification of geothermal energy resources. During later stages, other implications of heat flow studies has also been recognized in fields such as paleoclimatology, global warming, exploration geophysics and hydrogeology. The International Heat Flow Commission – IHFC plays a guiding role in development of such investigations.

1. Introduction

The study of the thermal structure of the Earth, generally referred as the geothermics or also as the (terrestrial) heat flow, has a long history. However, the modern geothermics, one of the fundamental geophysical disciplines, is relatively young. The International Heat Flow Commission (IHFC), under which the academic geothermal research on the international scale is organized, was created only in 1963. The IHFC, operating under the International Association of Seismology and Physics of the Earth's Interior (IASPEI), covers a broad scope of geophysical studies and links the activities of other associations of the International Union of Geodesy and Geophysics (IUGG), namely, the International Association of the Physical Sciences of the Ocean (IAPSO), the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI), and the International Association of the Hydrological Sciences (IAHS). Geothermal research is further related to a number of geological, hydrogeological and geochemical investigations covered by the International Union of Geological Sciences (IUGS), and in their practical applications the heat flow studies are related to the mission of the International Geothermal Association (IGA). Most of the knowledge of the contemporary geothermics was formulated

only in the last half of the 20th century. The basic ideas on the thermal structure and thermal history of the Earth, based on routine measurements of borehole temperature on land and measurements of heat flow through the ocean floor, together with determinations of the thermal properties of the rock material were enabled by the rapid development of measurement techniques in the 1950s.

Geothermal modeling, the assessments of the deep lithosphere temperature, evaluation of the thermal regimes of geological processes on local, regional and global scales were made possible by the recent advancement of computer techniques.

2. The Birth of the IHFC

The year 1963 represented an important milestone in the development of the international co-operation in the geothermal research. At the thirteenth IUGG General Assembly at Berkeley, California, 19-31, August, 1963, Sir Edward Bullard (Figure 1) of Cambridge University, England, called an informal meeting to organize a heat flow committee to promote geothermal research, especially in areas where there were no heat flow measurements.

Bullard's agenda included organizing symposia and field trips, comparing techniques, maintaining a database, and publishing a monograph, and they were well received. Sir Edward said that a committee secretary would be needed to coordinate its activities and asked for nominations from the floor. After a few minutes of silence, Bullard nominated W. H. K. Lee to be the secretary, and his motion was seconded by John Jaeger of Australia. Since there were no other nominations, Lee became the proposed secretary. Sir Edward then instructed Lee to find a deputy secretary who would succeed him three years later. Gene Simmons who was at the IUGG General Assembly kindly accepted the invitation. Bullard would chair the Committee, and Elena Lubimova of the Soviet Union would be the vice-chair. The proposed officers and Committee members would be appointed by three IUGG Associations: Seismology, Volcanology, and Oceanography at the end of the General Assembly.



Figure 1 - Sir Edward Bullard (1907-1980) [photo taken by Seiya Uyeda in 1958].

A few days later, Bullard withdrew as the proposed chairman of the Heat Flow Committee in order to run for the IUGG presidency. He then persuaded Francis Birch, a heat flow pioneer at Harvard University, to be the proposed chair of the Heat Flow Committee. At the end of the IUGG General Assembly, the International Heat Flow Committee (later Commission) was established under the following resolution (IASPEI, 1964): "... that the IASPEI should establish a working group on geothermal problems which should arrange comparisons of the techniques of different experimenters, particularly in the measurement of thermal conductivity, organize a symposium at the next General Assembly, and collect and summarize the observational data. The committee should arrange for adequate liaison with the International Association of Volcanology ..."

The first International Heat Flow Committee consisted of: Francis Birch, chairman, Elena A. Lubimova, vice-chairman, William H. K. Lee, secretary, and Gene Simmons, deputy secretary; and members were: C.J. Banwell, A.E. Beck, T. Boldizar, E.C. Bullard, J.C. Jaeger, A.M. Jessop, M.G. Langseth, C. Lomnitz, V.A. Magnitsky, L. Stegena, S. Uyeda, and R.P. Von Herzen. The International Association of Volcanology appointed the following liaison members: G. Facca, J. Healy, J. McNitt, and P. Evrard.

3. First Heat Flow Symposium and Monograph

In March 5-6, 1964, F. Birch hosted the first Heat Flow Committee meeting/symposium at Harvard. All the officers and about half of the Committee members attended. About a dozen guest participants also presented their results. Birch appointed a working group, consisting of A. Beck, G. Garland, A. Jessop, M. Langseth, W. Lee, E. Lubimova, and R. P Von Herzen, to work out the details so that the manuscripts of a heat flow monograph could be submitted to Lee as the editor within six months (IUGG, 1964).

The American Geophysical Union (AGU) had started its geophysical monograph series at that time. Jack Jacobs of Canada, who was a member of the AGU Committee overseeing the geophysical monographs persuaded his Committee to approve the publication of the heat flow monograph. Carrying a briefcase-full of manuscripts that had been reviewed and revised, Lee went to the Headquarters of the American Geophysical Union in Washington D.C. in January, 1965. With the timely support of Mr. Waldo E. Smith, the then AGU Executive Director, and Ms Judy Holoviak, the efficient copy editor, the heat flow monograph was published in August 1965 as AGU Geophysical Monograph No. 8, about 10 months after the manuscripts were received.

This monograph is subdivided in nine chapters, well characterizing all aspects covered by the IHFC for the following decades: (1) Historical introduction to terrestrial heat flow (E.C. Bullard), (2) Application of the theory of heat conduction to geothermal measurements (J.C. Jaeger), (3) Techniques of measuring heat flow on land (A.E. Beck), (4) Techniques of measuring heat flow through the ocean floor (M.G. Langseth), (5) On heat transfer through the ocean floor (E.A. Lubimova, R.P. Von Herzen and G.B. Udintsev), (6) Review of heat flow data (W.H.K. Lee and S. Uyeda), (7) Geophysical deduction from observations of heat flow (G.J.F. MacDonald), (8) Physical processes in geothermal areas (J.W. Elder), and (9) Review of geothermal resources (J.R. McNitt).

4. Status of IHFC

The International Heat Flow Commission (IHFC) is a commission of, and operates generally under guideline set by, the International Association of Seismology and Physics of the Earth's Interior (IASPEI). The IHFC is co-sponsored also by the International Association of the Physical Sciences of the Ocean (IAPSO) and the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI). The IHFC promotes, on its own or in co-operation with other organisations, all aspects of geothermal investigations. The main activities of the IHFC include: (1) Developing and recommending standards and techniques for the determination of all parameters necessary to geothermal research, such as:

thermophysical properties of rocks and other Earth's materials, underground temperatures, qualification of geothermal energy resources, etc; (2) Gathering, estimating quality and publishing of heat flow density data as well as other geothermal data of interest; (3) Organising or co-sponsoring international scientific meetings and expeditions as necessary; (4) Initiating or co-sponsoring the publication of monographs about scientific aspects of geothermal problems; and (5) Creating Working groups as necessary for investigating and reporting on specific geothermal problems.

The list of the officers of IHFC for the period 1963 – 2019 are as follows:

Chair: F. Birch (1963-67), E.A. Lubimova (1967-79), L. Stegena (1979-83), A.E. Beck (1983-87), S. Uyeda (1987-91), H.N. Pollack (1991-95), V. Cermak (1995-99), I.T. Kukkonen (1999-2003), D.S. Chapman (2003-07), C. Clauser (2007-2011), Y. Popov (2011-2015) and S. Huang (2015-2019)

Vice-Chair: E.A. Lubimova (1963-67), S. Uyeda (1967-75), L. Stegena (1975-79), A.E. Beck (1979-83), S. Uyeda (1983-87), H.N. Pollack (1987-91), V. Cermak (1991-95), I.T. Kukkonen (1995-99), D.S. Chapman (1999-2003), C. Clauser (2003-07), Y. Popov (2007-2011), S. Huang (2011-2015) and M. Verdoya (2015-2019).

Secretary: W.H.K. Lee (1963-67), G. Simmons (1967-71), A.M. Jessop (1971-79), M.L. Gupta (1979-83), L. Rybach (1983-87), V. Cermak (1987-91), V.M. Hamza (1991-95), T.J. Lewis (1995-99), C. Clauser (1999-2003), J. Safanda (2003-07), M. Taniguchi (2007-2011), S. Roy (2011-2015) and H. Villinger (2015-2019).

Vice-Secretary: G. Simmons (1963-67), A.M. Jessop (1967-71), R.P. Von Herzen (1971-75), M.L. Gupta (1975-79), L. Rybach (1979-83), V. Cermak (1983-87), V.M. Hamza (1987-91), T.J. Lewis (1991-95), C. Clauser (1995-99), J. Safanda (1999-2003), M. Taniguchi (2003-07), S. Roy (2007-2011), H. Villinger (2011-2015) and G. Beardsmore (2015-2019).

5. IHFC Publications

It has been a tradition for the International Heat Flow Commission to organize meetings and published the proceedings. The following list contains books, monographs and special issues summarizing the major contributions presented on symposia and workshops organized or co-organized by the International Heat Flow Commission during the past 40 years. It is presented below in chronological order:

- Lee, W.H.K. (Ed.) (1965). "Terrestrial Heat Flow". Geophys. Monogr. Ser. 8, Am. Geophys. Union, Washington, D.C., 276 pp.
- Kappelmeyer, O. and R. Haenel (1974). "Geothermics with Special Reference to Application", Gebruder Borntrager, Berlin, Stuttgart, 238 pp.
- Rybach, L. and L. Stegena (Eds.) (1978/1979). "Geothermics and Geothermal Energy", *Pageoph*, 117, 1-341 pp.
- Cermak, V. and L. Rybach (Eds.) (1979). "Terrestrial Heat Flow in Europe". Springer-Verlag, Berlin, Heidelberg and New York, 328 pp.
- Rybach, L. and L.J.P. Muffler (Eds.) (1980). "Geothermal Systems: Principles and Case Histories". J. Wiley, Chichester, 336 pp.

- Cermak, V. and R. Haenel (Eds.) (1982). "Geothermics and Geothermal Energy". Schweizerbart'sche Verlagsbuchhandlung, Stuttgart 299 pp.
- Gupta, M.L. (Ed) (1982) Terrestrial Heat Flow. Tectonophysics (Special Issue) Volume 83, pp, 1-149 (Papers presented at an IHFC Workshop on "Terrestrial Heat Flow " held during XVII General Assembly of the IUGG at Canberra A.C.T December 1979.
- Haenel, R. and Gupta, M. (Eds) (1983). Results of the First Workshop on Standards in Geothermics E. Schweizbart'sche Verlagsbuchhandlung (Nagele u. Obermiller), Stuttgart (it is a special volume devoted to the publication of seventeen papers contributed to a workshop on "Standards in Geothermics" organized by the IHFC during the 21 ST General Assembly in London, Ontario (Canada) on 24th July 1981.
- Cermak, V., L. Rybach and D.S. Chapman (Eds.) (1984). "Terrestrial Heat Flow Studies and the Structure of the Lithosphere", *Tectonophysics*, 103, Nos.1-4, 1-356.
- Rybach, L. (Ed.) (1985). "Heat Flow and Geothermal Processes", *J. Geodynamics*, 4, Nos.1-4, 1-352
- Cermak, V. (Ed.) (1986). "Geophysical Fields, Their Nature and Geological Interpretation", *J. Geodynamics*, 5, No.2, 111-256.
- Buntebarth, G. and L. Stegena (Eds.) (1986). "Paleogeothermics", Springer-Verlag, Berlin, 234 pp.
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- Haenel, R., L. Rybach and L. Stegena (Eds.) (1988). "Handbook of Terrestrial Heat-Flow Density Determination". Kluwer Acad. Publishers, Dordrecht, Boston, London, 486 pp.
- Beck, A. E., G. Garven and L. Stegena (Eds.) (1989). "Hydrogeological Regimes and Their Subsurface Thermal Effects". *Geophys. Monogr.* 47, IUGG Vol. 2, Am. Geophys. Union, Washington, D.C., 158 pp.
- Cermak, V., L. Rybach and E.R. Decker (Eds.) (1989). "Heat Flow and Lithosphere Structure". *Tectonophysics*, 164, Nos. 2-4, 83-376.
- Jessop, A. M. (1990). "Thermal Geophysics". Elsevier, Amsterdam, 306 pp.
- Hurtig, E., V. Cermak, R. Haenel, V. I. Zui (Eds.) (1991). "Geothermal Atlas of Europe". Hermann Haack Verlagsgesellschaft, Gotha, 36 maps, 156 pp.
- Cermak, V. and J. H. Sass (Eds.) (1991). "Forward and Inverse Techniques in Geothermal Modeling", *Tectonophysics*, 194, No.4, 307-428.
- Cermak, V. and L. Rybach (Eds.) (1991). "Terrestrial Heat Flow and the Lithosphere Structure". Springer-Verlag, Berlin and Heidelberg, 507 pp.
- Lewis, T. (Ed.) (1992). "Climatic Changes Inferred from Underground Temperatures", *Global Planet. Change*, 6, Nos.2-4, 71-281.
- Cermak, V. (Ed.) (1993). "Heat Flow and the Structure of the Lithosphere", *Stud. Geophy. Geod.*, 37, No.3, 233-348.
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- Balling, N. and E.R. Decker (Eds.) (1995). "Heat Flow and Thermal Regimes of Continental Lithosphere", *Tectonophysics*, 244, Nos.1-3, 1-196.

- Gupta, M.L. and M. Yamano (Eds.) (1995). “Terrestrial Heat Flow and Geothermal Energy in Asia”. A. A. Balkema, Rotterdam, 516 pp.
- Cermak, V. and L. Rybach (Eds.) (1996). “Geothermal Aspects of Lower Crustal Structure, Heat Flow and Hydrothermal Circulation”, *Tectonophysics*, 257, No.1, 1-109.
- Cermak, V. (Ed.) (1998). “Heat Flow and the Structure of the Lithosphere - IV”, *Tectonophysics*, 291 Nos.1-4, 1-298.
- Buntebarth, G. (Ed.) (1998). “Microtemperature Signals of the Earth Crust”, *Technische Uni., Clausthal-Zellerfeld*, 189 pp.
- Clauser, C., T. Lewis and L. Rybach (Eds.) (1999). “Thermal Regimes in the Continental and Oceanic Lithosphere”, *Tectonophysics*, 306, Nos.3-4, 259-470.
- Clauser, C. (1999). “Thermal Signatures of Heat Transfer Processes in the Earth’s Crust”, *Lecture Notes in Earth Sciences*, Vol. 85, 111 pp., ISBN 3-540-65604-9, Springer Verlag, Heidelberg-Berlin.
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- Special Issue of Physics of the Earth and Planetary Interiors (PEPI), 2001, vol. 26, No. 3-4, “Thermal Studies of the Earth’s Structure and Geodynamics”, edited by I.T. Kukkonen, V. Čermák and B. Kennett
- Special Issue of Physics and Chemistry of the Earth. Volume 28, Issues 9-11, Pages 345-519 (2003), “Heat Flow and the Structure of the Lithosphere”, edited by Vladimír Čermák and Ilmo T. Kukkonen, *IASPEI Handbook*, W. H. Lee (ed), Elsevier,
- Bodri, L., Cermak, V., 2007. *Borehole Climatology*. Elsevier, Amsterdam. 335 pp.
- Cermak, V. and Hamza, V.M. (2008) “Terrestrial heat flow: Recent advances in modeling and interpretation”, *International J. of Earth Sciences*, Volume 97, Issue 2.
- Jaupart, C. and Mareschal, J.-C., 2010. *Heat Generation and Transport in the Earth*. Cambridge Univ. Press, Cambridge, U. K.
- Hasan, Nordin M. and Roy, Sukanta (Eds.), 2010. *Sustainable Energy in Asia and the Pacific: Emerging Technologies and Research Priorities*. Malaysian Academy of Sciences / ICSU-ROAP, 145 p.
- Jaupart, C., Labrosse, S., Mareschal, J.-C., 2007. Temperatures, Heat and Energy in the Mantle of the Earth, In: D. Bercovici (Ed), *Treatise on Geophysics*, vol. 7, Elsevier, Amsterdam, pp. 253-303.
- Jaupart, C., Mareschal, J.-C., 2007. Heat Flow and Thermal Structure of the Lithosphere, In: D. Bercovici (Ed), *Treatise on Geophysics*, vol. 7, Elsevier, Amsterdam, pp. 217-251.
- Gupta H.K. (Ed.) 2011, *Encyclopedia of Solid Earth Geophysics Vol. 1 and Vol 2* (1539 pp). Springer, Dordrecht. The Encyclopedia includes a set of 13 chapters on various aspects of Thermal Geophysics, of which the following articles were contributed by the Commission members. Sukanta Roy served on the Editorial Board as the Field Editor for Thermal Geophysics.
- Chapman, D. S., Hasterok, D. 2011. Thermal Isostasy In: H. Gupta (Ed), *Encyclopedia of Solid Earth Geophysics*, 2nd ed., Springer, Dordrecht.
- Clauser, C., 2011. Thermal Storage and Transport Properties of Rocks, I: Heat Capacity and Latent Heat. In: H. Gupta (Ed), *Encyclopedia of Solid Earth Geophysics*, 2nd ed., Springer, Dordrecht.
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- Mareschal, J.-C., Jaupart, C., 2011. Energy budget of the Earth. In: H. Gupta (Ed), *Encyclopedia of Solid Earth Geophysics*, 2nd ed., Springer, Dordrecht.
- Davis, M.G., Chapman, D.S. and Harris, R.N., 2011. Geothermal Record of Climate Change. In: H. Gupta (Ed), *Encyclopedia of Solid Earth Geophysics*, 2nd ed., Springer, Dordrecht.
- Davis, E.E. and Chapman, D.S., 2011. Lithosphere, Oceanic: Thermal Structure. *Encyclopedia of Solid Earth Geophysics*, 2nd ed., Springer, Dordrecht.
- Jaupart, C. and Mareschal, J.-C., 2011. Lithosphere, Continental: Thermal Structure. *Encyclopedia of Solid Earth Geophysics*, 2nd ed., Springer, Dordrecht.

6. Global Heat Flow Data Compilation

The most recent published global heat flow compilation was prepared by H.N. Pollack, S.J. Hurter and J.R. Johnson (Rev. Geophys., 31, 267-280, 1993) based on aid of other IHFC members who compiled regional subsets, such as marine heat flow data (K. Loudon), Europe (V. Cermak), China (J.Y. Wang and S. Huang), Japan (S. Uyeda), India (M.L. Gupta), South Africa (M. Jones), USSR (Y.B. Smirnov), Canada (A.M. Jessop) and USA (D. Blackwell and J. Sass). The authors from various publications and national catalogues also compiled additional data, such as from Africa and Australia. All data were carefully evaluated by cross-referencing and duplicate checking, original format was slightly modified, and all data were made available through the World Data Center at Boulder on floppy discs. The compilation includes 24,776 lines of data, after closely spaced boreholes were averaged into one site, the set comprised 20,511 data points.

Since the mid-1990s the process of adding new information to the heat flow database has been kept up-to-date on the Web. The present custodian of the IHFC taking care for systematically reviewing heat flow literature is William D. Gosnold, presently at the Department of Geology and Geological Engineering, University of North Dakota, in Grand Forks, USA. The database can be visited on the website at: <http://www.heatflow.und.edu>.

7. 40th Anniversary and Commemorative CD

At the 23rd General Assembly of the International Union of Geodesy and Geophysics at Sapporo, Japan, the International Heat Flow Commission celebrated its 40th anniversary (Figure 2).

The celebration party took place at the hotel Royton Sapporo, the venue of the IUGG Assembly, in the evening of July 4, 2003. The party started by an informal reception where about 100 participants met together in a friendly atmosphere. It was followed by short speeches, violin music, dinner, and honoring Seiya Uyeda (Figure 3).

Details will be presented in a Commemorative CD-ROM, which is now being prepared. This CD will document the highlights of IHFC in the past 40 years, including photos taken and speeches given at the 40th anniversary party, and the current version of the IHFC heat flow database. Any interested person may request a free copy of this Commemorative CD-ROM by sending an e-mail to W. H. K. Lee <lee@usgs.gov> with his or her mailing address.



Figure 2 - A group photo of the present and past IHFC members who participated at its 40th anniversary party. From left to right: Makoto Yamano, Makoto Taniguchi, Christoph Clauser, Ilmo Kukkonen, William H.K. Lee, Sukanta Roy, Seiya Uyeda, Vladimir Cermak, David S. Chapman, Valiya M. Hamza, Ki-iti Horai, and Massimo Verdoya.

Present Heat Flow Commission

Chair	Huang, Shaopeng (USA/China)
Vice chair	Verdoya, Massimo (Italy)
Past chair	Popov, Yuri (Russia)
Secretary	Roy, Sukanta (India)
Vice secretary	Beardsmore Graeme (Australia)

The members of the present IHFC

Name	Country
Demetrescu, Crisan	Romania
Demezhko, Dmitry	Russia
Foerster, Andrea	Germany
Gosnold, William	USA
Hamza, Valiya	Brazil
Harris, Robert	USA
He, Lijuan	China
Joeleth, Argo	Estonia
Jones, Michael	South Africa
Kohl, Thomas	Germany
Majorovicz, Jacek	Canada
Manzella, Adele	Italy
Regenauer-Lieb, Klaus	Australia
Saar, Martin	Switzerland
Schill, Eva	Switzerland
Williams, Colin	USA



Figure 3 - Ilmo Kukkonen presenting a plaque to Seiya Uyeda.

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- IASPEI. 1964. Resolution on heat flow, Comptes Rendus No. 14, International Association of Seismology and Physics of the Earth's Interior, p. 78-79.
- IUGG. 1964. International Heat Flow Committee meeting, Chronicle No. 54, International Union of Geodesy and Geophysics, p. 90-92.