International Heat Flow Commission 2015-2019 Report

Dr. Shaopeng Huang IHFC Chairman 2015-2019

16 July 2019

Dear Dr. Johannes Schweitzer, IASPEI Secretary General, Dear Dr. Roberto Sulpizio, IAVCEI Secretary General,

On behalf of the International Heat Flow Commission (IHFC), hereby I am summiting the IHFC report for 2015-2019 for your review and record. Please find Attached below the regional reports from individual IHFC members. The highlights of the IHFC organized activities and community achievements during the 2015-2019 period include the followings.

- At this 27th IUGG General Assembly, the IHFC organized three join symposia and one IASPEI symposium.
 - JS08 Climate modeling, climate change and subsurface temperature field (IASPEI, IAHS). *Conveners: Vladimir Cermak, Makoto Taniguchi*
 - JS09 Tectonophysics of the continental lithosphere: integrating the thermal field with thermo-barometric, seismological, electromagnetic and seismicity data (IASPEI, IAVCEI, IAGA). *Conveners: Andrea Förster, Rainer Kind, Alan Jones, Gianluca Gola*
 - JV04 Advances in terrestrial heat flow measurement and interpretation (IAVCEI, IASPEI). *Conveners: Shaopeng Huang, Massimo Verdoya, Jacek Majorowicz, Guangzheng Jiang*
 - S26 Age dependences of terrestrial heat flow in continental and oceanic settings (IASPEI). *Conveners: Valiya Hamza, Mohan Lal Gupta, Shaowen Liu*
- At the IAG-IASPEI Joint Assembly in Kobe 2017, the IHFC organized four IASPEI symposia S24-S27.
 - S24: Methods and instruments of experimental geothermics application and recent evolution. *Conveners: Yuri Popov and Andrea Förster*

- S25: Development and application of geothermal databases. Conveners: *Shaopeng Huang and Will Gosnold*
- S26: Exploring connections between heat flow and tectonics. *Conveners: Valiya M. Hamza and Makoto Yamano*
- S27: Geothermal Energy: Ground source heat pump, hydrothermal system, and hot dry rocks. *Conveners: Makoto Taniguchi and Philipp Blum*

The four IHFC symposia featured a total of 49 papers distributed over 6 oral sessions and 4 poster sessions at the IAG-IASPEI 2017.

- The IHFC Global Heat Flow Database remains hosted at the University of North Dakota under the custodianship of Professor William Gosnold. The global heat flow data compilation consists 35,523 terrestrial data points and 23,013 marine data points. The data may be downloaded in Excel csv format. The database at this moment can be accessed at https://engineering.und.edu/research/global-heat-flow-database/.
- Under the support from the IHFC community and a grant from US NSF to Shaopeng Huang (IHFC Chair), the Global Database of Borehole Temperatures for Climate Reconstruction currently has over 1000 sites. In addition to extending the spatial coverage, efforts have been made to work on the improvement of the accessibility and functionalities of the database. Both the University of Michigan and NCEI/NOAA data outlets have been updated with the addition of the recently acquired borehole data and reconstructions. The colleagues at the NCEI/NOAA have empowered the database with capabilities of Interactive Map, Google Earth Map, Catalog Service, Text Search, and FTP for data sharing at <u>https://www.ncdc.noaa.gov/data-access/paleoclimatologydata/datasets/borehole</u>.
- With Drs. Vladimir Cermak (IHFC Chair 1995-1999), Shaopeng Huang (IHFC Chair), Dhananjay Ravat and Massimo Verdoya (IHFC Vice Chair) as guest editors, a Special Issue entitled "Heat Flow: Recent Advances" of International Journal of Earth Sciences (IJES) was published. The Special Issue includes 12 papers selected from the 24 oral and 28 poster presentations presented at the 26th IUGG General Assembly Symposium S13 "*Terrestrial Heat Flow*".
- A new online journal International Journal of Terrestrial Heat Flow and Applied Geothermics (IJTHFA). Two issues have so far been published. Dr. Valiya Hamza (IHFC Member) is the Editorial Manager and Editor-in-Chief of the IJTHFA. The journal is intended to be a forum for publication of results of high-quality research work dealing with recent advances in field measurement of terrestrial heat flow, regional and global geothermal data analysis, model studies of heat transfer in the Earth's interior and practical applications of geothermal studies.
- A two-day Workshop on Thermal Conductivity of Rocks was successfully held in Chengdu University of Technology, Chengdu, China, October 12-13, 2018. The workshop

featured three lectures and one hand-on session instructed by Professor Yuri Popov (IHFC Chair 2011-2015): 1) New role of thermal petrophysics and geothermics in prospecting, exploration and development of unconventional and traditional hydrocarbon fields; 2) Methodology and results of experimental geothermic investigations of scientific deep and industrial wells (1990-2018); 3) Peculiarities of application of optical scanning techniques in geothermic and petrophysical experiments; and 4) Hands-on exercise and best practice with the Lippmann and Rauen GbR Thermal Conductivity Scanner. Professor Shaopeng Huang (IHFC Chair) is the organizer of the workshop, which attracted more than 60 participants.

- Monographs published over the 2015-2019 period include:
 - Clauser, C., 2018. *Grundlagen der angewandten Geophysik Seismik, Gravimetrie*, Springer Spektrum, Heidelberg–Berlin
 - PASQUALE, V., VERDOYA, M., CHIOZZI, P., 2017. Geothermics, Heat Flow in the Lithosphere (2nd Edition). <u>SpringerBriefs in Earth Sciences</u>, Springer International Publishing, pp. 139.
 - Harvey, C., Beardsmore, G.R., Rueter, H. and Moeck, I., 2016. *Geothermal Exploration: Global Strategies and Applications*. IGA Academic Books. 198pp. ISBN 978-3-9818045-0-8
 - Clauser, C., 2016. *Einführung in die Geophysik Globale physikalische Felder und* Prozesse in der Erde, 2nd ed., Springer Spektrum, Heidelberg–Berlin.
 - Wang, J., et al., 2016. 地热学及其应用(Geothermics and Its Applications). Science Press, Beijing, pp573.
- Yuri Popov (IHFC Chair 2011-2015) led the effort to finish a contribution to The International Society for Rock Mechanics and Rock Engineering (ISRM) Suggested Methods. *ISRM Suggested Methods for Determining Thermal Properties of Rocks from Laboratory Tests at Atmospheric Pressure* (Rock Mech Rock Eng, v. 49, pp. 4179–4207, DOI 10.1007/s00603-016-1070-5) was published in 2016. The coauthors of this important paper are Yuri Popov, Graeme Beardsmore (IHFC Vice Secretary), Christoph Clauser (IHFC Chair 2007-2011) and Sukanta Roy (IHFC Secretary).

At its latest Business Meeting held on July 15, 2019, a new IHFC 2019-2023 team has been elected. It is my great pleasure and hornor to inform you that Professor Massimo Verdoya from the University of Genoa, Italy is the new IHFC Chairman.

I would like to take this opportunity to thank you for the supports you have given to me and to the International Heat Flow Commission over my term as the IHFC Chairman.

Sincerely,

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Shaopeng Huang IHFC Chairman 2015-2019

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Inst. Deep Earth Sciences and Green Energy Shenzhen University 3688 Nanhai Avenue Shenzhen, Guangdong 518060 shaopeng@szu.edu.cn Attachment:

Regional Reports from Individual IHFC Members

Dr. Graeme Beardsmore, Australia

Report to the International Heat Flow Commission 2015–2019

- 1. Titles of your and your teams projects during 2015-2019 in basic and applied (geothermal energy and oil\gas production) geothermics.
 - a. Developing a digital 'portable electronic divided bar' (PEDB) apparatus
 - b. Developing a shallow (1 m) heat flow probe ('Heat Needle')
 - c. Applied geothermics for mineral exploration, climate history reconstructions and geothermal energy exploration
- 2. Main results of the projects mentioned above described very shortly.
 - Designed, manufactured and successfully tested a prototype digital PEDB (<u>https://www.hotdryrocks.com/portable-electronic-divided-bar</u>); currently developing a graphical user interface prior to commercialisation.
 - Ongoing field trial of Heat Needles for groundwater research
 - Data processing algorithm development for Heat Needle, especially development of new technique for quantifying ground thermal diffusivity (see Item 8 below)
 - Conference paper on Heat Needle development:
 - Beardsmore, G., Gutiérrez-Negrín, L., Garduño-Monroy, V., Espinoza-Ojeda, O.M., Almanza-Álvarez, S., Antriasian, A. and Egan, S., 2017—Trial deployment of a surface heat flow probe over the Los Azufres geothermal region, Mexico. Proceedings, Forty-First Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, February 13–15, 2017.
 - Conference papers on applied geothermics:

Beardsmore, G., Sandiford, M. and Egan, S., 2018—Surface heat flow measurements: A new window on the subsurface (Abs.) *Proceedings, Australian Geoscience Council Convention*, Adelaide, Australia, 15–18 October 2018.

Haynes, M., Horowitz, F., Sambridge, M., Gerner, E. and Beardsmore, G., 2017— Mapping the continental surface temperature of Australia: the surface boundary condition for conductive thermal models (Abs.) Proceedings, IAG-IASPEI General Assembly, Kobe, Japan, July 30–August 4, 2017.

Haynes, M., Hawkins, R., Sambridge, M. and Beardsmore, G., 2017—Shallow crustal heat flow and heat production inversion (Abs.) Proceedings, IAG-IASPEI General Assembly, Kobe, Japan, July 30–August 4, 2017.

Beardsmore, G.R., 2016—Heat flow: The neglected potential field for mineral exploration (invited keynote address, extended abstract.) Proceedings ASEG-PESA 2016 Conference, Adelaide, Australia, 21–24 August 2016. 6pp.

3. Titles and main goals of your and your teams projects in 2019 – in basic and applied (geothermal energy and oil\gas production) geothermics.

Continuation of 1a,b,c above

- 4. Total amount of researchers and students involved in the projects.
 - a. 4 researchers for 1a
 - b. 4 researchers for 1b
 - c. 2 researchers, 1 student for 1c
- 5. Your vision of the evolution and tendencies in basic and applied geothermics and the application of results during the last decade. Your vision of changes in the role of geothermics in global science and industry.

The past decade has seen an increase in the relevance and application of geothermics to 'environmental' studies. These include climate studies, geothermal energy exploration, and groundwater research. I believe that trend will continue. There is increasing awareness in Australia of the value of fundamental heat flow research and measurements across a broad range of earth science disciplines including mineral and energy exploration, lithospheric modelling, Antarctic research including glaciology, groundwater research, climate modelling and many others. A multimillion dollar expansion of national capacity for heat flow measurements has been proposed for Australia for the coming decade. The outcome of the proposal will be known by the end of 2019.

6. General and special courses for basic and geothermics in education system (universities, colleges, etc.).

Nothing to report

7. Whole monographs and/or separate chapters in monographs published in 2015-2019 and accepted to the publication.

Harvey, C., Beardsmore, G.R., Rueter, H. and Moeck, I., 2016—*Geothermal Exploration: Global Strategies and Applications*. IGA Academic Books. 198pp. ISBN 978-3-9818045-0-8

8. 3-5 articles with principal results published in journals in 2015-2019 or accepted to the publication.

Popov, Y., Beardsmore, G., Clauser, C. and Roy, S., 2016—ISRM Suggested Methods for Determining Thermal Properties of Rocks from Laboratory Tests at Atmospheric Pressure. *Rock Mechanics and Rock Engineering*, 49(10), 4179–4207. DOI: 10.1007/s00603-016-1070-5.

Beardsmore, G., Egan, S. and Sandiford, M., 2019—A Fourier spectral method to measure the thermal diffusivity of soil. *ASTM Geotechnical Testing Journal* (in press).

Haynes, M.W., Horowitz, F.G., Gerner, E.J. and Beardsmore, G.R., 2018—Australian mean annual land-surface temperature. *Geothermics*, 72, 156–162. DOI: 10.1016/j.geothermics.2017.10.008.

Beardsmore, G., Sandiford, M., Gordon, K., McLean, M., Egan, S. and McLaren, S., 2017— Heat flow and inferred ground surface temperature history at Tynong North, southeastern Australia. *Australian Journal of Earth Sciences*, 64(6), 753–767. DOI: 10.1080/08120099.2017.1362663.

9. Patents or patent applications in 2015-1019.

Australian provisional patent 2018900262 Title: METHOD OF MEASURING CONDUCTIVE GEOPHYSICAL HEAT FLOW

Inventor: Graeme Beardsmore

10. Participation and election in National Academies, Committees, Boards etc.

- Chairman of the Resources and Reserves Committee of the International Geothermal Association
- Director of Australian Geothermal Association
- Australian Industry Representative to International Partnership for Geothermal Technology

11. Anything more that you consider as important factors and results in basic and applied geothermics during 2015-2019

A paper accepted to the World Geothermal Congress 2020 describing successful measurement of surface heat flow to \pm 50 mW/m² precision using the 'Heat Needle' surface tool, plus outlining the steps required to improve precision to \pm 10 mW/m².

Beardsmore, G.R., 2020—Developing the 'Heat Needle': a tool for cost effective heat flow mapping. *Proceedings of World Geothermal Congress 2020*, Reykjavik, Iceland, 26 April – 2 May 2020. 10pp. (in press)

Dr. Valiya Hamza, Brazil

Report of research activity in basic and applied geothermics for the period 2015-2019 National Observatory, Rio de Janeiro, Brazil

The main focus of activities at the Geothermal Laboratory of National Observatory, Rio de Janeiro, Brazil has been on publication of the "International Journal of Terrestrial Heat Flow and Applied Geothermics- IJTHFA". Two issues have so far been published, the first one in 2018 and the second one in 2019. Given below are details of the publications.

Contents of Volume 1 of IJTHFA

Editorial to the inaugural issue of "International Journal of Terrestrial Heat Flow and Applied Geothermics". Valiya Hamza, Shaopeng Huang, Massimo Verdoya, p. III

International Heat Flow Commission: History and Accomplishments over the last fifty-five years. Vladimir Cermak, Alan Beck and Valiya Hamza, p. 1-5.

Global Heat Flow: New Estimates Using Digital Maps and GIS Techniques. Fabio Vieira and Valiya Hamza, p. 6-13.

Temperature Gradient Measurements in Hydrothermal Areas of Georgia. Sepehr Sangin, Günter Buntebarth, Andreas Weller and George Melikadze. p 14-17.

Heat Flow, Geotherms, Density and Lithosphere Thickness in SW of Iberia (South of Portugal). Maria Rosa Duque, p. 18-22.

Shallow and Deep Temperatures in the South-Caspian Basin. Abdulvahab Mukhtarov, p. 23-29.

Heat flow in Rajasthan Craton, North–Western Indian Shield and its Implications. Mohan L. Gupta and S.R. Sharma, p. 30-34.

Geothermal Regime and Deep Temperatures of the Siberian Platform. Raisa Dorofeeva, p. 35-40

Subsurface temperature measurements for detecting tectonic dislocations. Diego Barbero, Arianna Bucci, Paolo Chiozzi, Domenico A. Luca, Maria G. Forno, Marco, Manuela L. and Massimo Verdoya, p. 41-45.

Terrestrial Heat Flow in Non-Thermal Ground Water Circulation Settings of Brazil. Carlos Alexandrino and Valiya Hamza, p. 46-51.

Deep-seated Geothermal Resources of the Parana Basin. Antonio J. L. Gomes and Jorge L. S. Gomes, 52-58.

Contents of Volume 2 of IJTHFA

Editorial to the second issue of "International Journal of Terrestrial Heat Flow and Applied Geothermics". Valiya Hamza and Jorge Gomes, p. III

About the penetration of the diurnal and annual temperature variation into the Subsurface, Günter Buntebarth, Maria Pinheiro and Martin Sauter, p. 1-5.

The history of the surface temperature at Ajameti/Georgia as extracted from long-term temperature records in the subsurface. Tamara Jimsheladze, Günter Buntebarth and George Melikadze, p. 6-10.

Paleo heat flow in areas of Sedimentary Exhalative (SEDEX) deposits of Eastern Brazil. Sundaram Iyer and Valiya Hamza, p. 11-16.

Terrestrial heat flow versus crustal thickness and topography – European continental study. Jacek Majorowicz, Marek Grad and Marcin Polkowski, p. 17-21.

Thermomagnetic features of Pirapora region, central Brazil. Suze Guimarães and Valiya Hamza, p. 22-29.

Regions of anomalous geothermal fields in the State of Tocantins, Central Brazil. Patricia Descovi and Fábio Vieira, p. 30-37.

Conductive heat flow pattern of the central-northern Apennines, Italy. Massimo Verdoya, Paolo Chiozzi, Gianluca Gola and Elie El Jbeily. p. 37-45.

Assessment of Geothermal Resources of South America - A New Look. Fabio Vieira and Valiya Hamza, p. 46-57.

Selected list of other publications

- Gomes, J.L.S., Vieira, F.P., Hamza, V.M., 2018, Use of electrical resistivity tomography in selection of sites for underground dams in a semiarid region in southeastern Brazil. Groundwater for Sustainable Development, 7, 232–238.
- Gomes, J.L.S., Vieira, F.P., Hamza, V.M., 2018, Thermal Perturbations by Seepage of Meteoric Waters: Implications for Climate History Deduced from Geothermal Profiles of Shallow Boreholes in Arid and Semi-Arid Regions. International Journal of Geophysics and Geochemistry, 5(1): 19-26.
- Hamza, V.M., Fabio, F.P., Silva, R.T.A., 2017, Anomalous heat flow belt along continental margin of Brazil, Int J Earth Sci (Geol Rundsch), DOI 10.1007/s00531-017-1503-8.
- Gomes, J.L.S., Vieira, F.P., Hamza, V.M., 2017, Underground dams for capture of groundwater resources in the municipality of Jenipapo de Minas (Minas Gerais), Brazil. Revista Vozes dos Vales, 12, 1-25.
- Alexandrino C. H., Hamza V. M., 2016, An Improved Method for Crustal Temperatures: Implications for a Global Framework of Geotherms. International Journal of Geophysics and Geochemistry, 3(6): 61-72.
- Vieira, F.P. 2015. Medium and high enthalpy geothermal resources of Brazil: Assessment of resources and perspectives for utilization (in Portuguese), Unpublished Ph.D. Thesis. National Observatory, Rio de Janeiro (Brazil).

Dr. Jacek A Majorowicz, Canada

Canadian Geothermal Studies 2015-2019

1. Paleoclimatic reconstruction from deep well temperature logs into Precambrian granitic basement in the Canadian craton- the Impact of the last glacial cycle on recent borehole temperature profiles

Demezhko D, Gornostaeva A, Majorowicz J, Šafanda J (2017) Temperature and heat flux changes at the base of Laurentide ice sheet inferred from geothermal data (evidence from province of Alberta, Canada) *Int J Earth Sci (Geol Rundsch)* DOI 10.1007/s00531-017-1464-y

Majorowicz J, Šafanda J (2015) Effect of postglacial warming seen in high precision temperature log deep into the granites in NE Alberta. *Int J Earth Sci (Geol Rundsch)* 104(6):1563–1571

Pickler C, Beltrami H, Mareschal J-C, (2016) Climate trends in northern Ontario and Québec from borehole temperature profiles. *Climate of the Past* 12(12):2215-2227 DOI: 10.5194/cp-12-2215-2016

Pickler C, Beltrami H, Mareschal J-C, (2016) Laurentide Ice Sheet basal temperatures during the last glacial cycle as inferred from borehole data. *Climate of the Past*

Santero FJ, Pickler C, Beltrami H, Mareschal J-C (2016) North American regional climate reconstruction from groundsurface temperature histories. *Clim. Past*, 12, 2181–2194, 2016. <u>www.clim-past.net/12/2181/2016/</u> doi:10.5194/cp-12-2181-2016

2. Variability of recent climatic warming derived from Canadian well temperature logs

Majorowicz J, Safanda J (2017) Large regional variability of recent climatic change driven subsurface temperature changes as derived from temperature logs central Canada example. *Int J Earth Sci (Geol Rundsch)* DOI 10.1007/s00531-017-1453-1

Mareschal J-C, Armitage JJ, Bouquerel, (2017) The Sudbury Huronian Heat Flow Anomaly, Ontario, Canada. Precambrian Research 295. DOI: 10.1016/j.precamres.2017.04.024 Witter J,Miller C A,Friend M, Colpron M (2018) Curie Point Depths and Heat Production in Yukon, Canada. *PROCEEDINGS 43rd Stanford Geothermal Workshop*, Stanford University

3. Permafrost , glacial and gas hydrate thermal modeling – Northern Canada Beaufort-Mackenzie basin study

Hermoso de Mendoza I, Navaljean I, Mareschal J-C, Beltrami H (2016), Constraints on glacier flow from temperature-depth profiles in the ice. Application to EPICA Dome C. *Climate of the Past Discussions* DOI: 10.5194/cp-2016-116

Hermoso de Mendoza I, Beltrami H , MacDougall A, Mareschal J-C (2018) Lower boundary conditions in Land Surface Models. Effects on the permafrost and the carbon pools. Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2018-233

Majorowicz J, Osadetz K, Safanda J (2015) Models of Talik, Permafrost and Gas Hydrate Histories Beaufort Mackenzie Basin, Canada *Energies* 2015, *8*, 6738-6764; doi:10.3390/en8076738

4. Heat flow vs. heat generation study in western Canada sedimentary basins and crystalline basement

Jaupart C. Mareschal J-C (2015) Post-orogenic thermal evolution of newborn Archean continents. November 2015Earth and Planetary Science Letters 432:36-45 DOI: 10.1016/j.epsl.2015.09.047

Liu H, Giroux B, B.Harris L, M.Quenette S, Mansour J (2018) Numerical analysis of the role of radiogenic basement on temperature distribution in the St. Lawrence Lowlands, Québec. *Geothermal Energy* 6:26 <u>https://doi.org/10.1186/s40517-018-0115-2</u>

Majorowicz J (2016) Heat flow-heat production relationship not found: what drives heat flow variability of the Western Canadian foreland basin? *Int J Earth Sci (Geol Rundsch)* DOI 10.1007/s00531-016-1352-x

5. Geothermal energy study in W. Canada and Quebec

Banks, J., Harris, N., B., 2018. Geothermal potential of Foreland Basins: A case study from the Western Canadian Sedimentary Basin. *Geothermics* 76, 74-92.

Bédard K, Comeau F-A, Raymond J, Malo M, Nasr M (2017) Geothermal Characterization of the St. Lawrence Lowlands Sedimentary Basin, Québec, Canada. *Natural Resources Research*. <u>https://doi.org/10.1007/s11053-017-9363-2</u>

Majorowicz J, Minea V. (2015) Shallow and deep geothermal energy potential in low heat flow/cold climate environment: northern Quebec, Canada, case study. *Environ Earth Sci* (2015) 74:5233–5244. DOI 10.1007/s12665-015-4533-1

Majorowicz J, Minea V. (2015) Geothermal Energy Potential in Low Enthalpy Areas as a Future Energy Resource: Identifying Feasible Targets, Quebec, Canada, Study Case. *Resources* 2015, *4*, 524-547; doi:10.3390/resources4030524

Majorowicz J, Grasby S (2019) Deep geothermal energy in Canadian sedimentary basins VS. Fossils based energy we try to replace e Exergy [KJ/KG] compared. *Renewable Energy* 141 (2019) 259e277

Nasr M, Raymond J, Malo M, Gloaguen E (2018) Geothermal potential of the St. Lawrence Lowlands sedimentary basin from well log analysis. *Geothermics* 75:68-80 https://doi.org/10.1016/j.geothermics.2018.04.004

Drs. Lijuan He and Shaowen Liu, China

IHFC report from China

1. Compilation of heat flow data in the continental area of China

In this update heat flow data set, the total number of data has reached 1230. Excluding the local anomalies related to hydrothermal activities, the background heat flow values display a range from 30 to 140 mWm⁻² with a mean of 60.4±12.3 mWm⁻². The updated heat flow map exhibits a heat flow pattern consisted of four heat flow provinces in continental China: eastern mantle-induced high flow province, southwestern crust-induced high heat flow province, central normal heat flow province and northwestern low heat flow province. The major heat flow provinces correspond to the Cenozoic lithosphere-scale tectonic units. The heat flow shows good correlation with crustal thickness and elevation, agreeing with the thermal isostasy. The heat flow distribution also corresponds with the Meso-Cenozoic tectonic activities. The present heat flow-tectonic pattern in continental China is formed by the Meso-Cenozoic geodynamic processes, including the Cenozoic India-Eurasian collision and the Mesozoic-Cenozoic western subduction of the Pacific Plate.

Publications:

- Jiang G., Gao, P., Rao, S., et al., 2016. Compilation of heat flow data in the continental area of China (4th edition) Chinese J. Geophys. (in Chinese) 59(8), 2892-2910.
- Jiang G., Hu S., Shi Y., et al., 2019. Terrestrial heat flow of continental China: Updated dataset and tectonic implications. Tectonophysics, 753, 36-48.

2. Thermal study of Chinese cratons

Craton's thermal state is one of the main gateways to understand the craton dynamics. Three cratons in China, the Tarim, North China, and Yangtze cratons, are in different thermal states and differ in their stabilities. Low heat flow usually corresponds to stable craton but not vice versa. The Tarim Craton is cold (~44 mW/m²) and still keeps its stability now. The western North China Craton and the upper Yangtze Craton are not too cold (50–60 mW/m²) but also remain stable. The eastern North China Craton and the Middle-Lower Yangtze Craton are relatively hot with heat flow of 60–70 mW/m², both have been heated and destroyed in the Mesozoic. All these cratons have experienced complex tectonothermal events since their formation. Some tectonothermal events only thin and heat craton but others can destroy craton. Several sedimentary basins are developed in these cratons, which recorded individual thermal histories. These thermal records could help to understand the thermal evolution of these cratons and provide constraints on craton dynamics including stability or destruction. The thermal results indicate parts of craton in western China (Tarim and Sichuan)

have secular cooling histories, which were locally disturbed by mantle plume activities in the Permian. The Middle-Lower Yangtze Craton has undergone similar thermal evolution as the eastern North China Craton. All parts of cratons in eastern China might all have been destroyed due to subduction and dehydration of the Pacific Plate during the Mesozoic.

Publications:

- Chang, J., Qiu, N., Zhao, X., Shen, F., Liu, N., Xu, W., 2017. Mesozoic and Cenozoic tectono-thermal reconstruction of the western Bohai Bay Basin (East China) with implications for hydrocarbon generation and migration. J. Asian Earth Sci. <u>http://dx.doi.org/10.1016/j.jseaes.2017.09.008</u>.
- Chang, J., Qiu, N., Zhao, X., Xu, W., Xu, Q., Jin, F., Han, C., Ma, X., Dong, X., Liang, X., 2016. Present-day geothermal regime of the Jizhong depression in Bohai Bay Basin, East China. Chinese J. Geophys. 59, 1003-1016.
- He, L., Zhang, L., 2018. Thermal evolution of cratons in China. Journal of Asian Earth Sciences, 164: 237-247.
- He, L., 2015. Thermal regime of the North China Craton: Implications for craton destruction. Earth-Science Reviews. 140:14-26.
- Liu Q, He L., Chen L., 2018. Tectono-thermal modeling of Cenozoic multiple rift episodes in the Bohai Bay Basin, eastern China and its geodynamic implications. International Journal of Earth Sciences, 107(1), 53-69
- Liu, Q., Zhang, L., Zhang, C., et al., 2016. Lithospheric thermal structure of the North China Craton and its geodynamic implications. J. Geodyn. 102, 139–150.
- Qiu, N., Zuo, Y., Xu, W., Li, W., Chang, J., Zhu, C., 2016. Meso-cenozoic lithosphere thinning in the eastern North China Craton: evidence from thermal history of the Bohai Bay Basin, North China. J. Geol. 42, 195–219.
- Qiu, N.S., Xu, W., Zuo, Y.H., Chang, J., 2015. Meso-Cenozoic thermal regime in the Bohai Bay Basin, eastern North China Craton. Int. Geol. Rev. 57, 271–289.

3. Thermal study on hot dry rock geothermal resources

Basic geothermal research on hot dry rock geothermal resources in China, including surface heat flow and lithospheric thermal structure.

Publictions:

- Wang, Z., Jiang G., Zhang, C. et al., 2018. Thermal regime of the lithosphere and geothermal potential in Xiong'an New Area. Energy Exploration & Exploitation, 37(2):787-810.
- Xu, W., Huang, S., Zhang, J., et al., 2018. Present-day geothermal regime of the Uliastai Depression, Erlian Basin, North China. Energy Explor. Exploit. 54831538.

- Zhang, C., Jiang, G., Shi, Y., et al., 2018. Terrestrial heat flow and crustal thermal structure of the Gonghe-Guide area, northeastern Qinghai-Tibetan plateau. Geothermics 72, 182– 192.
- Chao Zhang, GuangZheng Jiang, Xiaofeng Jia, Shengtao Li, Shengsheng Zhang, Di Hu, Shengbiao Hu, Yibo Wang. 2019. Parametric study of the production performance of an enhanced geothermal system: A case study at the Qiabuqia geothermal area, northeast Tibetan plateau. Renewable Energy, 132:959-978.

Drs. Vladimir Cermak and Jan Safanda, Czech Republic

Building effect on the ground temperature distribution, case study Prague, the Czech Republic

Vladimir Cermak, Louise Bodri, Jan Safanda and Petr Dedecek (submitted as an poster to be presented at the IUGG Assembly 2019)

More than two decades of the activities of the Geothermal Climate Change Observatory (GCCO) at Prague clearly proved that the local urban climate has become substantially warmer by more than 2 K since 1993. A 150 m deep borehole, part of the observatory, has been repeatedly logged since then to trace the corresponding time changes in the subsurface temperature field. Transient components of the individual logs indicated a strong impact of the downward penetrating (climate) warming. Its magnitude exceeded 1.3 K at 20 m below the ground surface and reached 0.7 K at 40 m and 0.15 K at 80 m within years 1993 through 2016. Special attention has been paid to the analysis of the surface temperature offset, the difference between the near surface air temperature and the "skin" ground surface temperature. The monitored ground surface temperature series were further used as the forcing function to model the corresponding temperature-depth distribution and the resulting time-variable geothermal models based on a real environment structure were compared with the measured temperature logs. It was proved that the observed warming must have been sizably affected by the later terrain alternations and by the additional effect of buildings erected nearby. Some 30-40 per cent of the observed warming can be attributed to the human activities in the nearest vicinity.

Variability trends in the daily air temperatures series

Vladimir Cermak, Louise Bodri, Jan Safanda, Milan Kresl and Petr Dedecek (accepted for publication in the journal of the Amer. Inst. Math. Sci., Environmental Science, 2019)

Temperature variability was investigated for the near surface air temperature time series measured at Sporilov station (Prague, the Czech republic) between 2003-2016. The interpretation of the Sporilov daily air temperature averages was completed with the results of the long-term observation at the Prague Klementinum station (daily averages, daily maximum and daily minimum temperatures). Variability was detected by the method of absolute difference of temperature anomalies between two adjacent discrete time periods. The results demonstrated increasing warming trends for all investigated temperature time series and a general reduction of the diurnal temperature range. The range of temperature oscillations reduces also on the annual scale. The temperature variability have shown general decline, however the velocity of the detected variability decreasing trend is significantly minor in comparison with the previously investigated period 1994-2001. The analysis also revealed that the occurrence of both hottest and coldest extremes have been increasing during the investigated period at both stations.

Spurious additional warming reconstructed from borehole temperatures corrected for the effect of the Last Glacial Cycle

Jan Šafanda (Geophysical Research Letters, 45, 2780–2785, https://doi.org/ 10.1002/2017GL075343, 2019)

Reconstructions of past ground surface temperature changes from temperature logs conducted in several hundred meter deep boreholes have proved to be a valuable independent source of information on climate variations over the last millennium. The reconstruction techniques have been evolving for more than two decades to extract optimally the climate signal of the last millennium contained in the temperature logs of different length performed in sites with different histories of the Last Glacial Cycle. This paper analyzes the method of the Last Glacial Cycle thermal effect removal from such borehole temperature profiles used by Beltrami et al. (2017, https://doi.org/10.1002/2016GL071317) in reconstructing the last 500 year history. I show that the reported results of additional warming in this period reconstructed from the corrected borehole data for North America are an artifact generated by the correction.

Lithosphere Thickness from New Heat-Flow Data of the Odra Variscan Area, S-W Poland

Jacek Majorowicz, Jan Šafanda

(Pure Appl. Geophys. 175, 4343-4354, https://doi.org/10.1007/s00024-018-1941-7, 2018

Equilibrium temperature data from shafts in a mining area of SW Poland in the Paleozoic Platform were used for heat-flow calculations. A new technique to calculate paleoclimatic correction for heat-flow determination from single deep temperature data and equilibrium surface temperatures was applied. Elevated surface heat flow of 82–87 mW.m⁻² and mantle heat flow of some 37–41 mW. m⁻² were found. This high heat-flow zone spreads from S-W Poland, in the Variscan deformation front, towards the German part of the Polish-German basin. Calculations of geotherms for a variety of heat production models of the crust

and upper mantle point to lithosphere–asthenosphere boundary depths of about 80–90 km compared to seismologically determined depths of 90–120 km.

Lithology, thermal state and Moho heat flow at the NE termination of the European Variscan orogen: different mantle beneath eastern part of Armorican Terrane Assemblage and Eastern Avalonia

Jacek Puziewicz, Leszek Czechowski, Marek Grad, Jacek Majorowicz, Anna Pietranik, Jan Šafanda

(International Journal of Earth Sciences, 108, 673-692, https://doi.org/10.1007/s00531-018-01674-7, 2019)

Geotherms of four crustal profiles across the Variscan orogen in SW Poland have been constructed to better understand the variation in thermal state of the region. Seismic and drilling data as well as rock sequences in exposed parts of the orogen were used for Wilcza Gora (Sudetic Block), Polkowice-Rudna (Middle Odra Horst), Świeciechowa (Wolsztyn-Leszno Horst) and Września (Szczecin-Miechow Synclinorium within TESZ) profiles. The palaeoclimate-corrected surface heat flow map and the heat-production calculations based on literature data enabled the construction of geotherms and estimation of Moho heat flow. Exception is the Polkowice-Rudna profile, where the surface heat flow was calculated using temperature measurements in underground copper mines, and K, U and Th contents and density/heat conductivity measurements in rocks drilled in the Middle Odra Horst were used to calculate geotherm. The basaltic lava migration through the lithospheric mantle and its effect on crustal geotherm in Wilcza Gora (area of Cenozoic alkaline volcanism at ca. 30-18 Ma) was shown to increase slightly both current surface and current Moho heat flow (by ca. 4 mW/m²). The presented approach couples geological and geophysical information and thus differs from standard purely geophysical assessment of lithosphere thermal state. It shows that surface heat flow is enlarged to 84 mW/m² by granitic plutons in the upper crust in the Lubin-Polkowice site. Heat flow on the Moho varies from 28 to 34 mW/m^2 in sites located in the Sudetic-/Fore-Sudetic Blocks, Middle Odra Horst and Wolsztyn-Leszno Horst. Locally it may slightly increase because of extraneous heat input by Cenozoic basaltic volcanism, but the values close to 30 mW/m^2 are specific for mantle root of Saxothuringian Zone in SW Poland. Mantle heat flow is 36 mW/m^2 in Września site and supposedly is a manifestation of different nature of lithospheric mantle underlying TESZ.

Dr. Christoph Clauser, Germany

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Dr. Andrea Förster, Germany

Report of major activities and publications in the time period 2015-2019

Our team at GFZ German Research Centre for Geosciences in Potsdam (Germany) is presented as "Earth Thermal Field Lab" at the ResearchGate platform under <u>https://www.researchgate.net/lab/Earth-Thermal-Field-Lab-Andrea-Foerster</u>. This allows outreach to the heat flow community and a briefing about ongoing research activities.

Activities:

Work of the Lab mainly focused on

- Development of new methodologies in thermal petrophysics namely for the determination of thermal rock properties (thermal conductivity and thermal diffusivity)
- A new laboratory device was designed to measure thermal properties for dry or saturated conditions under simultaneously elevated T (up to 250 °C) and p (up to 300 MPa). The proof of concept was accomplished in 2018. The device is currently assembled.
- Research also focused on the quantification of paleoclimate effects by glacial events on subsurface temperature and terrestrial heat flow in Germany. This is aimed to fill a gap in central Europe between observations in Poland, Denmark and France.
- The new petrophysical methodologies were implemented in heat-flow studies. Those studies were conducted for areas in Europe (Luxembourg, Denmark and Germany)
- New aspects of heat flow and thermal petrophysics also were implemented in studies that foster the use of thermal energy in sedimentary as well crystalline rocks (Denmark and Germany). The goal is to establish a thermal exploration strategy.
- A quality re-evaluation of the German heat-flow database has started in 2018. This is of urgent need as these data are used nationwide but are also part of the IHFC global heat flow database.

Members of the Lab participated with contributions and as conveners to international conferences (the World Geothermal Congress 2015, 26th General Assembly of the IUGG (Prague), the annual General Assemblies of the European Geosciences Union (EUG) in Vienna 2015-2019, the Joint Scientific Assembly of the IAG and IASPEI in Kobe 2017, and the 27th IUGG General Assembly in Montreal 2019) as well as to national meetings.

Conference Proceedings:

- Norden, B., Fuchs, S., Förster, H.-J., Förster, A. (2019) Lithosphere temperature models: Uncertainties from in-situ thermal conductivity in a diversified crust, 27th IUGG General Assembly (Montreal, Canada).
- Fuchs, S., Norden, B., Förster, A. (2919) Revisiting the quality of the German heat-flow data towards advanced documentation, reproducibility, and reliability, 27th IUGG General Assembly (Montreal, Canada).
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Re: IHFC Business Meeting

Dear Shaopeng, dear Massimo, dear IHFC participants

I have to apologize for not being able to attend the IUGG. Together with the IHFC member, Eva Schill, we have major proposals to elaborate which are both unique to the Helmholtz Association. To our knowledge, both proposals, DeepStor and GeoLaB, represent the first large infrastructure investments of Helmholtz into geothermal energy and require a careful elaboration to comply with corresponding deadlines, 15 July and 15 September.

However, I will stay committed to the IHFC and I am glad reporting to the proposed points 1 and 3:

1 Report on major activities and progresses over the past four years

My contributions at KIT are concentrating strongly on the assessment of geothermal energy in its geological and geophysical context. The investigation of heat flow remains therefore an essential tool especially for the petrophysical, the temperature and the hydraulic data. The following example illustrate our activities:

1.1 Geothermal data analysis in the Upper Rhine Graben (prep. DeepStor, GeoLaB projects) The DeepStor projects intends to install high temperature geothermal storage on the location of - or even in - former oil reservoirs in the Rhine Graben. The project should be located on the possibly highest temperature anomaly of Germany (>170°C in 3km depth !) requiring the compilation of numerous temperature, petrophysical data from the northern Rhine Graben system.

- Grimmer, J. C.; Ritter, J. R. R.; Eisbacher, G. H.; Fielitz, W., 2017, The Late Variscan control on the location and asymmetry of the Upper Rhine Graben, International Journal of Earth Sciences, 106 (3), 827–853. doi:10.1007/s00531-016-1336-x
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By the GeoLaB infrastructure project, a reservoir analogue site in a deep sited mining facility shall be constructed to observe the processes related to high fluid flow in fractured rock. It requires the installation of a cavern next to a fault zone below several 100 m overburden. The infrastructure will be used subsequently in various short-term and long-term experiments that cover the whole 3D pattern of geophysical and hydraulic

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fields as well as changes in geological structures. The site will be next to a real geothermal production in the same rock massifs.

- Meixner, J.; Grimmer, J. C.; Becker, A.; Schill, E.; Kohl, T., 2018, Comparison of different digital elevation models and satellite imagery for lineament analysis: Implications for identification and spatial arrangement of fault zones in crystalline basement rocks of the southern Black Forest (Germany), Journal of structural geology, 108, 256–268. doi:10.1016/j.jsg.2017.11.006
- Schill, E.; Meixner, J.; Meller, C.; Grimm, M.; Grimmer, J. C.; Stober, I.; Kohl, T. 2016, Criteria and geological setting for the generic geothermal underground research laboratory, GEOLAB, . Geothermal Energy, 4 (1), 4:7. doi:10.1186/s40517-016-0049-5

1.2 Geothermal Analysis in the Villarica Area of Southern Chile

In areas of no available borehole data like Southern Chile, the assessment of the subsurface temperature field requires additional information, besides geophysical data. Therefore, new approaches were taken to improve the results of standard geothermometry by including the influence of the adjacent rock matrix. This has led to a considerable improvement of the standard applications with its large uncertainties and allowed to estimate possible reservoir temperatures with hgh precision. The method is continuously developed and can now be applied in the framework of an inversion scheme to most subsurface lithologies.

- Nitschke, F.; Held, S.; Villalon, I.; Neumann, T.; Kohl, T., 2017, Assessment of performance and parameter sensitivity of multicomponent geothermometry applied to a medium enthalpy geothermal system, Geothermal Energy, 5 (1), 12. doi:10.1186/s40517-017-0070-3
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- Held, S.; Schill, E.; Pavez, M.; Díaz, D.; Muñoz, G.; Morata, D.; Kohl, T., 2016, Resistivity distribution from mid-crustal conductor to near-surface across the 1200 km long Liquiñe-Ofqui Fault System, southern Chile Geophysical journal international, 207 (3), 1387–1400. doi:10.1093/gji/ggw338

2

3 Nomination for the Election of IHFC 2019-2023.

3.1 Re-nomination

Herewith, I re-nominate myself for the IHFC. I intend to pursue my ongoing activities with a team of approx. 16 collaborators. I see my participation in IHFC as to connecting their activities to the needs of the energy transition to a non-fossil based energy supply.

3.2 Nomination of Sven Fuchs, GFZ

I am glad to nominate Sven Fuchs, GFZ Potsdam, for the IHFC. When leading the Geothermal Task Group at the German Geophysical Society I met Sven as an active member. He is that type of young motivated researcher with special interest in Earth crustal thermal field analysis, paleoclimate and data bank systems that IHFC requires for its future development. Besides these personal skills, he is also active in maintaining the German heat-flow database and has a considerable track record on geothermal and heat flow studies at numerous locations. As such, his investigations are focusing on central and northern Europe (e.g. Fuchs & Förster, 2010 (Geochemistry); Fuchs et al., 2015 (Geophysical Journal International), Fuchs & Balling, 2016 (Geothermics), Fuchs, 2018 (Geothermics); Fuchs et al., 2018 (JGR)).

I wish you a fruitful meeting with high-level contributions to our research field.

Please convey my warm greeting to all

Ber

Dr. Sukanta Roy, India

1. Thermal structure of cratons

(a) Geothermal regime of Koyna Seismogenic Zone, Deccan Traps, India constrained from scientific deep drilling

Geothermal measurements carried out in deep boreholes up to 3 km depth in Koyna seismogenic zone, western India provided a rare opportunity to characterize the geothermal regime and study its implications on seismogenesis in the top ~ 10 km of the Koyna reservoir triggered earthquake region. Precise temperature-depth measurements were carried out in the 3 km deep pilot borehole and a few other deep boreholes of 1500 m deep. Laboratory measurements on core samples constrain the thermal conductivity and radiogenic heat production of the Deccan basalts and underlying granite-gneiss rocks. Salient results are as follows. (i) The range of geothermal gradients in Deccan basalt and granite-gneiss basement are 22-26 mK m⁻¹ and 15-16 mK m⁻¹. (ii) The contrast in gradient is consistent with the contrast in mean thermal conductivity between the two rock types, 1.7 Wm⁻¹K⁻¹ and 2.8 Wm⁻¹ 1 K⁻¹ respectively, yielding near identical heat flow of 41 and 43 mW m⁻² over the two rock formations and a mean of 42 mW m⁻². (iii) Low heat flow in the Koyna seismogenic zone is typical of Archaean cratonic nuclei, which confirms that thermal transients potentially associated with ~65 Ma Deccan volcanism have decayed and the heat flow is consistent with crustal radiogenic heat production. (iv) Radioelement analysis on 45 core samples of granitegneiss basement yielded the first estimates of radiogenic heat production of the basement underlying the Deccan traps and aided in thermal modelling. (v) The study provided strong constraints for the temperature not likely to exceed 130 °C at 6 km depth, a critical piece of information for proposed deep drilling and design of a deep fault zone observatory. (vi) Although thermal considerations alone allow for deep (>25km) seismic- aseismic transition, the earthquakes in the Koyna region occur in the shallow "cold" parts of the crust only.

The work was carried out by the Ministry of Earth Sciences, Borehole Geophysics Research Laboratory, Karad, Maharashtra, India.

(b) Crustal thermal structure of the Bundelkhand craton, northcentral India

Temperature measurements carried out in 10 boreholes at five sites in the 2.5-3.5 Ga Bundelkhand craton, the oldest cratonic core in northern Indian shield, combined with systematic thermal conductivity measurements on major rock types yield low heat flow in the range 32-41 mW m⁻², which is distinct from the generally high heat flow reported from other parts of the northern Indian shield. The low heat flow is consistent with the Archaean Dharwar craton in south India and provides yet another evidence for low heat flow in Archaean nuclei worldwide. Radioelemental measurements on 243 samples of drill cores and outcrops reveal both large variability and high average heat production for the Neo-Archaean

to Palaeo-Proterozoic granites $(4.0\pm2.1 \text{ (SD) }\mu\text{Wm}^{-3})$ relative to the Meso-Archaean TTG gneisses $(2.0\pm1.0 \text{ (SD) }\mu\text{Wm}^{-3})$. On the basis of new heat flow and heat production datasets combined with available geological and geophysical information, a set of steady-state, heat flow - crustal heat production models representative of varying crustal scenarios in the craton are envisaged. Mantle heat flow and Moho temperatures are found to be in the range 12-22 mW m⁻² and 290-420 °C respectively, not much different from those reported for the Dharwar craton in southern India. This study reveals similar mantle thermal regimes across the northern and southern parts of the Indian shield, in spite of varying surface heat flow regimes, implying that much of the intra-province and inter-province variations in the Indian shield are explained by variations in upper crustal heat production.

(c) Radioelemental, petrological and geochemical characterization of the Bundelkhand craton: Implication in the Archean geodynamic evolution

In this study, radioelemental (²³²Th, ²³⁸U, ⁴⁰K), petrological and geochemical analyses on granitoids and gneisses covering major rock formations of the Bundelkhand craton were carried out. Data revealed that above characteristics are distinct among granitoids (i.e., potassic, biotite and sodic granitoids) and gneisses (i.e., potassic and sodic types). Among the granitoids, radioelements are highest in potassics granitoid (45.0±21.7 ppm, 7.2±3.4 ppm, 4.2 ± 0.4 %), intermediate in biotite granitoid (44.5 ± 28.2 ppm, 5.4 ± 2.8 ppm, 3.4 ± 0.7 %) and lowest in sodic granitoid (17.7±4.3 ppm, 4.4±0.6 ppm, 3.0±0.4 %). Among gneisses, potassic type gneisses have higher radioelements (11.8±5.3 ppm, 3.1±1.2 ppm, 2.0±0.5 %) than the sodic type gneisses (5.6±2.8 ppm, 1.3±0.5 ppm, 1.4±0.7 %). The study suggests that radioelemental variations in the lithounits are mainly related to abundances of the radioactive minerals that have formed by the fractionation of LILE from different magma sources. Based on present data, the craton can be divided into three distinct zones that can be correlated with its evolution in time and space. The central tectonic zone, where TTG gneisses are exposed is characterized by least radioelement concentrations and heat production. The region to the south of this tectonic zone is mainly dominated by potassic granite and is characterized by high radioelement concentrations accounting for high heat production. Northern part of the massif, dominated by sodic and biotite granite is characterized by moderate radioelement concentrations and heat production.

(d) Evaluation of best-mixing model for estimating thermal conductivity for granitoids from mineralogy: A case study from the Bundelkhand craton, central India

An attempt is made to arrive at the best mixing model for granitic rocks by using thermal conductivity of the individual minerals and compare the deviation between the measured and calculated values. The considered mean models are: arithmetic, geometric, harmonic, effective, Voigt-Reuss-Hill and Hashin-Shtrikman along with its lower and upper bound. Studied rocks are. Thermal conductivity measurements are done in the laboratory on 21 samples covering potassic granitoid potassic granitoid, biotite granitoid (BG), sodic granitoid 30

(GG) and gneisses (BnG) from the Bundelkhand craton, central India, biotite granitoid, sodic granitoid and TTG gneiss from the Bundelkhand craton, central India using steady-state method. Data show wide variations in thermal conductivity values for granitoids (potassic granitoid: 2.7-3.2, biotite granitoid: 2.6-2.9, sodic granitoid: 2.9-3.0 Wm⁻¹ K⁻¹) and TTG gneiss (2.9-3.7 Wm⁻¹ K⁻¹). Modal mineralogy of the rocks are determined using petrological and geochemical data through modal analysis and normative (CIPW-NORM) methods. The calculated thermal conductivity arrived by both the methods provide a satisfactory agreement for the harmonic mean model, showing deviation from 10.9 to 17.6% for modal analysis and - 16.1 to 11.5% for NORM method. The deviations are further reduced (-23.3 to 2.8% and - 27.7 to -3.1%, respectively) using minimum mineral thermal conductivity. The study therefore suggests in the case of non-availability of the proper sample for direct measurement, the thermal conductivity of very low porous granitoids could be satisfactorily determined by assessing their modal mineralogy and considering the harmonic mean model.

The work was carried out by the CSIR-National Geophysical Research Institute, Hyderabad, India.

2. Geothermal Energy

Utilization of geothermal resources as an alternate, sustainable energy in the country was promoted. An attempt has been made to delineate geothermal prospect at Dholera area, Gujarat using gravity, LANDSAT imagery, magnetotellurics (MT) and water chemistry. The outcomes are as follows. i) Target zones/hot springs are identified based on Low Vegetation Index and high land surface temperature from Remote sensing analysis. ii) Hot springs exist over gravity high, which is the surface manifestation of deep and shallow water sources. iii) Physical and chemical characterization of the thermal spring waters show that these waters have meteoric origin. iv) 2D MT and AMT surveys concluded that the structure beneath Dholera is 1D and 2D in nature. The polar diagram shows that the structure is 3D in nature at some places. v) Integrating both Gravity and MT interpretation, the model supports that beneath the surface manifestations (hot springs), low-density and low resistivity geophysical anomaly is present which might be an indication of the existence of a geothermal reservoir at depth.

Based on geophysical, geological and geochemical data, two geothermal wells of 1000 ft deep have been drilled at Dholera during 2015 and 2016. The temperature of the water is 47 to 50 °C, with a flow rate of three to five litters per second. The hot water produced from these wells is now being utilized in the Swaminarayan temple at Dholera through Geothermal Space Heating and Cooling system.

The work was carried out by PDPU, Gandhinagar, India.

3. Publications

- Chopra, N., L. Ray, M. Satyanarayanan, and R. Elangovan, 2018. Evaluate best-mixing model for estimating thermal conductivity for granitoids from mineralogy: A case study for the granitoids of the Bundelkhand craton, central India, Geothermics, https://doi.org/10.1016/j.geothermics.2018.03.011.
- Haldar, C., P. Kumar, M. Ravi Kumar, L. Ray, and D. Srinagesh, 2018. Seismic evidence for secular evolution and alteration of Archaean crust in Indian shield, Precambrian Research, <u>https://doi.org/10.1016/j.precamres.2017.10.023</u>.
- Podugu, N., L, Ray, S.P. Singh, and S. Roy, 2017, Heat flow, Heat production and crustal temperatures in the Archaean Bundelkhand craton, north-central India: Implications for thermal regime beneath the Indian shield, Journal of Geophysical Research: Solid Earth, doi: 10.1002/2017JB014041.
- Gupta, H., K. Arora, N.P. Rao, S. Roy, V.M. Tiwari, P.K. Patro, H.V.S. Satyanarayana, D. Shashidhar, C. Mahato, K.N.S.S.S. Srinivas, M. Srihari, N. Satyavani, Y. Srinu, D. Gopinadh, H. Raza, J. Monikuntala, V.V. Akkiraju, D. Goswami, D. Vyas, C.P. Dubey, D. Raju, U. Borah, K. Raju, K. Chinnareddy, N. Babu, B.K. Bansal and S. Nayak, 2017, Investigations of Continued Reservoir Triggered Seismicity at Koyna, India, Geological Society of London, Special Publications, doi:10.1144/SP445.11.
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- Gupta, H., N.P. Rao, S. Roy, K Arora, V.M. Tiwari, P.K. Patro, H.V.S. Satyanarayana, D. Shashidhar, K. Mallika, V.V. Akkiraju, D. Goswami, D. Vyas, G. Ravi, K.N.S.S.S. Srinivas, M. Srihari, S. Mishra, C.P. Dubey, D.Ch.V. Raju, U. Borah, K.C. Reddy, N. Babu, S. Rohilla, U. Dhar, M. Sen, Y.J. Bhaskar Rao, B.K. Bansal, S. Nayak, 2016, Investigations related to scientific deep drilling to study reservoir-triggered earthquakes at Koyna, India, International Journal of Earth Sciences, doi:10.1007/00531-014-1128-0.
- Sircar, A., M. Shah, S. Sahajpal, D. Vaidya, S. Dhale, and A. Chaudhary, 2015. Geothermal exploration in Gujarat: case study from Dholera, Geothermal Energy, doi: 10.1186/s40517-015-0041-5.

Name	Title of the thesis	Year of award	Supervisor & degree awarding University
Nagaraju Podugu	Heat flow, heat production and crustal thermal structure in the Bundelkhand craton, northcentral India	March 2015	Sukanta Roy [CSIR-NGRI & Osmania University, Hyderabad]
Deepjyoti Goswami	Geothermal and geomechanical regime of the Koyna seismogenic zone, Deccan	June 2018	Sukanta Roy [IIT (ISM), Dhanbad]

Traps, India	

Dr. Adele Manzella, Italy



June 21, 2019

Shaopeng Huang IHFC Chairman 2015-2019

Re: IHFC Business Meeting

Dear Shaopeng, dear Massimo, dear IHFC participants

On behalf of the research group in Geothermics of the Institute of Geosciences and Earth Resources of the National Research Council of Italy, dr. Gianluca Gola will attend the IUGG in Montréal and the Business Meeting of IHFC.

Report on major activities and progress in heat flow related studies

Our main research activities, developed through participation and coordination in national and international research projects, are aimed to enhance the understanding of the geological and chemical-physical processes occurring in crustal levels in the presence of hydrothermal fluids. Our research focus on the following main topics:

- 1. *Implementation and maintenance of the National Geothermal Data Base* (BNDG). Our Institute manages the BNDG which incorporates location, litho-stratigraphic, thermal and hydraulic information from shallow and deep exploratory boreholes as well as chemical, physical and isotopic data of fluids sampled in springs all over the country. The database, including site-specific heat flow data, is constantly updated and implemented.
 - Pauselli, C; Gola, G; Mancinelli, P; Trumpy, E; Saccone, M; Manzella, A; Ranalli, G. (2019). A new surface heat flow map of the Northern Apennines between latitudes 42.5 and 44.5 N, Geothermics, 81, 39-52.
 - Verdoya, M; Chiozzi, P; Gola, G; El Jbeily, E (2019). Conductive heat flow pattern of the central-northern Apennines, Italy, International Journal of Terrestrial Heat Flow and Applications, 2, 37-45.
 - Trumpy, E. and Manzella, A. (2017). Geothopica and the interactive analysis and visualization of the updated Italian National Geothermal Database. International Journal of Applied Earth Observation and Geoinformation, 54, 28-37.
- 2. Evaluation and exploration of geothermal resources. We are involved in national and international research projects (i.e. GECO, GeMex, DESCRAMBLE and IMAGE) for the characterization of hydrothermal and unconventional geothermal systems. The project's objectives are achieved by the integration of geological, hydrogeological, geophysical, geochemical, isotopic, petrographic studies and by the improvement of subsurface investigation techniques as well as by the enhancing of numerical modelling approaches. Moreover, field laboratory facilities allow us the evaluation of the surface heat flow distribution through well thermal logs and thermal conductivity measurements on rock samples and to infer the earth's subsurface electrical resistivity from Magnetotelluric measurements. These prospection methods find application in geothermal, volcanological and deep crustal exploration.





Institute of Geosciences and Earth Resources

- De Franco, R.; Petracchini, L.; Scrocca, D.; Caielli, G.; Montegrossi, G.; Santilano, A.; Manzella, A. (2019). Synthetic seismic reflection modelling in a supercritical geothermal system: An image of the K-horizon in the Larderello Field (Italy). Geofluids, 21 pages.
- Santilano, A; Trumpy, E; Gola, G; Donato, A; Scrocca, D; Ferrarini, F; Brozzetti, F; de Nardis, R; Lavecchia, G; Manzella, A (2019). A methodology for assessing the favourability of geopressured-geothermal systems in sedimentary basin plays: a case study in Abruzzo (Italy), Geofluids, 28 pages.
- Montanari, D., Minissale, A., Doveri, M., Gola, G., Trumpy, E., Santilano, A., Manzella, A. (2017). Geothermal resources within carbonate reservoirs in western Sicily (Italy): A review, Earth-Science Reviews, 169, 180-201.
- Trumpy, E; Botteghi, S; Caiozzi, F; Donato, A; Gola, G; Montanari, D; Pluymaekers, MPD; Santilano, A; Van Wees, JD; Manzella, A. (2016). Geothermal potential assessment for a low carbon strategy: A new systematic approach applied in southern Italy, Energy, 103, 167-181
- 3. *Thermal and rheological structure of Lithosphere*. We investigate the crustal and sub-crustal thermal and rheological structure in different geological settings by a multidisciplinary approach developed in a numerical environment that tries to simulate the natural phenomena in a multiphysics context.
 - Gola, G; Bertini, G; Bonini, M; Botteghi, S; Brogi, A; De Franco, R; Dini, A; Donato, A; Gianelli, G; Liotta, D; Manzella, A; Montanari, D; Montegrossi, G; Petracchini, L; Ruggieri, G; Santilano, A; Scrocca, D; Trumpy, E (2017). Data integration and conceptual modelling of the Larderello geothermal area, Italy, Energy Procedia, 125, 300-309.
 - Castaldo, R., Gola, G., Santilano, A., De Novellis, V., Pepe, S., Manzo, M., Manzella, A., Tizzani, P. (2017). The role of thermo-rheological properties of the crust beneath Ischia Island (Southern Italy) in the modulation of the ground deformation pattern, Journal of Volcanology and Geothermal Research, 344, 154-173.

Nomination for the Election of IHFC 2019-2023.

Given the scientific background of the colleague Gianluca Gola and his interest in thermal and rheological aspects of Earth's crust, I inform you that I am receding the IHFC and I propose Gianluca Gola as active member of the community.

Kind regards

adele Manzella

Adele Manzella

Dr. Massimo Verdoya, Italy

Report of major activities and publications in the time period 2015-2019

1. Titles of projects during 2015-2019 in basic and applied geothermics.

The research group took part to national research projects funded by academic institutions and scientific/industrial geothermal exploration projects granted commercial institutions:

1) Characterization of underground physical properties and thermal regime for planning borehole heat exchangers.

2) Review of heat flow data from northern Africa in cooperation with scientists from Morocco;

3) Marine heat flow and bathymetry in the Indian Ocean and in the Eastern Mediterranean Sea4) Heat flow measurements in a hot-spot realm (Mauritius)

5) Heat flow and geothermal resources of the Northern Apennines chain and surrounding sedimentary basins;

6) Review and re-processing of geophysical data in geothermal areas of the East African Rift System (EARS);

2. Main results of the projects mentioned above described very shortly.

1) Concerning the underground thermo-physical properties, we focused on laboratory and in situ measurements of thermal conductivity. We developed an apparatus for measurements of thermal conductivity in the laboratory (Transient Divided Bar) and a technique for the evaluation of the in-situ thermal conductivity also in presence of advective heat transfer (a moving line source). Moreover, we proposed an approach for evaluating the thermal conductivity with depth from records of temperature recovery after stimulation of boreholes with heat injection.

2) We revised thermal data available from water and oil wells in the northern sector of the Middle Atlas region, North Africa. The results slightly modify the picture reported in previous investigations. The heat flow value over the investigated region is rather uniform and is similar in oil wells and in water boreholes. Geothermal calculations indicate that such a surface heat flow is compatible with normal thermal conditions in the asthenospheric mantle.

3) and 4) We analyzed the sea-bottom heat-flow of the Indian Ocean and measured new heatflow data on the Mauritius island, which is part of the long-lived Reunion hotspot track. These values do not significantly deviate from the reference cooling-plate model. Thus, lithosphere erosion does not seem a likely mechanism for the swell formation. The lack of significant reheating due to a mantle plume impacting the lithosphere base is confirmed by thermal modeling. Moreover, the coherency between on-land and marine data is argument against advective redistribution of heat near the axis of the swell.

Concerning the Eastern Mediterranean Sea, we investigated terrestrial heat-flow data and sediment thickness and to explore the nature of the lithosphere. We processed bathymetric data by removing the subsidence caused by sediment deposition to obtain the water-loaded seafloor depth. Terrestrial heat flow measurements were corrected for sedimentation and climatic changes to infer the purely conductive steady-state geothermal flow. Water-load seafloor depths and thermal data were then compared to reference models of continental lithosphere stretching and ocean plate cooling. The results argue that the eastern sector is floored by a continental stretched crust, whereas the western part is of oceanic type.

5) Thermal data from deep oil exploration and geothermal boreholes in the 1000-7000 m depth range were collected and analyzed to unravel thermal regime beneath the centralnorthern Apennines chain and the surrounding sedimentary basins. We particularly selected deepest bottom hole temperatures, all recorded within the permeable carbonate Paleogene-Mesozoic formations, which represent the most widespread tectono-stratigraphic unit of the study area. The available temperatures were corrected for the drilling disturbance and the thermal conductivity was estimated from detailed litho-stratigraphic information and by taking into account the pressure and temperature effect. The thermal resistance approach, including also the radiogenic heat production, was used to infer the terrestrial heat flow and to highlight possible advective perturbation due to groundwater circulation. Only two boreholes close to recharge areas argue for deep groundwater flow in the permeable carbonate unit, whereas most of the obtained heat-flow data may reflect the deep, undisturbed, conductive thermal regime.

6) We studied the most some of the most important geothermal fields of the EARS namely Alalobeda (Ethiopia), Menengai (Kenya) and Kilambo-Ilwalilo (Tanzania). These fields well represent the different structural, volcanological and hydrogeological realms that may be encountered in EARS. Alalobeda and Menengai are examples of two possible geothermal play types of the Eastern Branch of EARS. The former is a fault-leakage-controlled geothermal system, located in a graben structure, where the heat source is likely diffuse, deep-seated magmatism, associated to the lithosphere thinning that regionally affects this area. The Menengai geothermal field can be classified as a convection-dominated magmatic play-type, where the heat source could be a magmatic intrusion, located beneath the caldera. The Kilambo-Ilwalilo field is geothermal system located in a half-graben realm, in which the ascending groundwater flow is controlled by the main regional fault and the source of heat is provided by the elevated mantle.

3. Total amount of researchers and students involved in the projects.

2 researchers and 2 PhD students

4. Whole monographs and/or separate chapters in monographs published in 2015-2019 and accepted to the publication.

PASQUALE, V., VERDOYA, M., CHIOZZI, P., 2017. Geothermics, Heat Flow in the Lithosphere (2nd Edition). SpringerBriefs in Earth Sciences, Springer International Publishing, pp. 139.

5. Articles with principal results published in journals in 2015-2019 or accepted to the publication.

- V. PASQUALE, M.VERDOYA, P. CHIOZZI, 2015. Measurements of rock thermal conductivity with a Transient Divided Bar. *Geothermics* 53:183–189. DOI:10.1016/j.geothermics.2014.05.008 IF 2.323
- CHIOZZI P., BARKAOUI A.E., RIMI A., VERDOYA M., ZARHLOULE Y., 2017. A review of surface heat-flow data of the northern Middle Atlas (Morocco). Journal of Geodynamics 112, 58–71
- VERDOYA M., CHIOZZI P., 2018. Influence of groundwater flow on the estimation of subsurface thermal parameters. *Int J Earth Sci (Geol Rundsch)*, 107:137–144 IF 2.283.
- CHIOZZI P., VERDOYA M., 2018. Heat-flow anomaly and residual topography in the Mascarene hotspot swell (Indian Ocean) *Int J Earth Sci (Geol Rundsch)*, 107:35-51 IF 2.283
- CERMAK, V., HUANG, S., RAVAT, D. VERDOYA, M. 2018. EDITORIAL TO "HEAT FLOW: RECENT ADVANCES". INT J EARTH SCI (GEOL RUNDSCH) 107:1–3. IF 2.283
- VERDOYA M., PACETTI C., CHIOZZI P., INVERNIZZI C., 2018. Thermophysical parameters from laboratory measurements and in-situ tests in borehole heat exchangers *Applied Thermal Engineering* 144, 711–720. IF 3.771
- CHICCO J., VERDOYA M., GIULI G., INVERNIZZI C., 2019. Thermophysical properties and mineralogical composition of the Umbria-Marche carbonate succession (Central Italy). in Koeberl, C., and Bice, D.M., eds., 250 Million Years of Earth History in Central Italy: Celebrating 25 Years of the Geological Observatory of Coldigioco: Geological Society of America Special Paper 542, p. 59–67, https://doi.org/10.1130/2019.2542(02).
- VERDOYA M., G. IMITAZIONE, P. CHIOZZI, M. ORSI, E. ARMADILLO, C. PASQUA, 2015. Interpretation of Thermal Response Tests in Borehole Heat Exchangers Affected by Advection, Proceedings of the World Geothermal Congress, Melbourne, Australia, 19-25 April 2015, 7 pp.
- ARMADILLO E., D. RIZZELLO, M. VERDOYA, C. PASQUA, P. PISANI, 2015. Cubic spline regularization applied to 1D magnetotelluric inverse modeling in geothermal areas Proceedings World Geothermal Congress 2015 Melbourne, Australia, 19-25 April 2015, 6 pp.
- RIZZELLO D., E. ARMADILLO, M. VERDOYA, C. PASQUA, S. KEBEDE, A. MENGISTE, N. ABERA, 2016. Integrated geophysical imaging of the Alalobeda geothermal field (Ethiopia). Proceeedings of the European Geothermal Congress 2016, Strasbourg, France, 19-24 Sept 2016, 8 pp.
- PASQUA C., M. VERDOYA, P. CHIOZZI, L. MARINI, 2016. Evaluation of geothermal resources in a hotspot realm: Mauritius Island (Indian Ocean). Proceedings, 6th African Rift Geothermal Conference, Addis Ababa, Ethiopia, 2nd – 4th November 2016, 11 pp.

- RIZZELLO D., E. ARMADILLO, C. PASQUA, M. VERDOYA, S. KEBEDE, A. MENGISTE, G.H. GIORGIS, 2016. Threedimensional geophysical modelling of the Alalobeda Geothermal Field. Proceedings, 6th African Rift Geothermal Conference, Addis Ababa, Ethiopia, 2nd – 4th November 2016, 11 pp.
- BARBERO D., BUCCI A., CHIOZZI P., DE LUCA D., FORNO M., LASAGNA M., VERDOYA M., 2016. Underground temperature logs for well field monitoring. Atti Atti 35° Convegno del Gruppo Nazionale di Geofisica della Terra Solida, Trieste 2016
- GIACOMINII J., INVERNIZZI M.C., MAPONI P., VERDOYA M., 2018. Testing a Model of Flow and Heat Transfer for U-shaped Geothermal Exchangers. Proceedings of the 3rd AIGE/IIETA International Conference and 12th AIGE 2018 Conference, Reggio Calabria – Messina, 14 – 16 June 2018 6pp. Exchangers. Advances in Modelling and Analysis. Series A), 55, 151-157 (ISSN 12585769)
- BARBERO D., BUCCI A., CHIOZZI P., DE LUCA D. A., FORNO M. G., LASAGNA M., VERDOYA M., 2018. Subsurface temperature measurements for detecting tectonic dislocations. International Journal of Terrestrial Heat Flow and Applied Geothermics, 1, 41-45. DOI: https://doi.org/10.31214/ijthfa.v1i1.16
- HAMZA V., HUANG S., VERDOYA M., 2018. Editorial to the inaugural issue of "International Journal of Terrestrial Heat Flow and Applied Geothermics". International Journal of Terrestrial Heat Flow and Applied Geothermics, 1, I-V. <u>http://ijthfa.com/</u>
- EGIDI N., J. GIACOMINI, M.C. INVERNIZZI, P. MAPONI, M. VERDOYA, 2018. A mathematical model to infer underground thermal parameters for designing of borehole heat exchangers Proceedings of the 15th MEETING ON APPLIED SCIENTIFIC COMPUTING AND TOOLS – MASCOT - 2-5 October 2018, University of Rome La Sapienza, Rome, 13 pp.
- VERDOYA M., P. CHIOZZI, G. GOLA, E. EL JBEILY , 2019. Conductive heat flow pattern of the centralnorthern Apennines, Italy. International Journal of Terrestrial Heat Flow and Applied Geothermics, VOL. 2, NO. 1 (2019); P. 37-45, ISSN: 2595-4180.
- EL JBEILY E., VERDOYA M., CHIOZZI P., IVALDI R., GHAITH A. 2019. Geothermal Flow and Water-Load Seafloor Depth of the Eastern Mediterranean Sea, TMREES19 Int. Conference Series of Technologies and Materials for Renewable Energy, Environment and Sustainability April 10 to 12, 2019. Beirut-Lebanon *AIP Conference Proceedings (in press)*
- VERDOYA M., PASQUA C., CHIOZZI P., 2019. Overview of geothermal resources of Northern Italy. PROCEEDINGS of the 7th Indonesia International Geothermal Convention & Exhibition (IIGCE) 2019. Assembly Hall - Jakarta Convention Center Indonesia, August 13 - 15, 2019, 9 pp.

6. Participation and election in National Academies, Committees, Boards

Board of the International Geothermal Association (2016-2020)

Dr. Jacek Majorowicz, Poland

Heat Flow LAB, Seismological LAB study in Poland

Grad M., Puziewicz J., Majorowicz J., Chrapkiewicz K., Lepore S., Polkowski M., Wilde-Piórko M., (2018) The geophysical characteristic of the lower lithosphere and asthenosphere in the marginal zone of the East European Craton, *International Journal of Earth Sciences*, vol. 107(8), pp. 2711–2726, 10.1007/s00531-018-1621-y

Majorowicz J., Grad M., Polkowski M., (2019), <u>Terrestrial heat flow versus crustal thickness</u> and topography – European continental study, *International Journal of Terrestrial Heat Flow and Applied Geothermics*, vol. 2(1), pp. 17-21, <u>10.31214/ijthfa.v2i1.30</u>

Majorowicz J., Polkowski M., Grad M., (2019), Thermal properties of the crust and the lithosphere–asthenosphere boundary in the area of Poland from the heat flow variability and seismic data, *International Journal of Earth Sciences*, vol. 108(2), pp. 649–672, 0.1007/s00531-018-01673-8

Puziewicz J., Czechowski L., Grad M., Majorowicz J., Pietranik A., Šafanda J., (2019), Crustal lithology vs. thermal state and Moho heat flow across the NE part of the European Variscan orogen: a case study from SW Poland, *International Journal of Earth Sciences*, vol. 108(2), pp. 673–692, 10.1007/s00531-018-01674-7

Dr. Yuri Popov, Russia Federal

Results of research activity in basic and applied geothermics during 2015-2019

- 1. The algorithm for determination of equilibrium temperature and temperature gradient from temperature measurements in industrial oil&gas wells was developed within a joint project with Bashkir State University (Russia, Department of Geophysics leaded by Prof. R.Valiullin).
- 2. Experimental investigation of vertical variations in specific heat flow and terrestrial heat flow were performed for Orenburg region (Russia).

The investigations were performed to provide reliable data on heat flow and rock thermal properties for basin and petroleum system modeling. Three continuous temperature logging operations were performed in exploration oil well (3780 m, 12.5 months of shut-in). Temperature gradient was calculated for every 10 m interval with elimination of intervals with signs of equilibrium disturbance. The thermal conductivity, volumetric heat capacity and thermal anisotropy coefficient measurements were performed on 1699 as-received full-size core samples using a new method of continuous thermal core logging within 13 depth intervals (with a total length of 235 m) where well drilling provided continuous coring. Representative core samples were selected for drilling 29 core plugs which were used for thermal property measurements in as-received, dry and brine-saturated states with the new laser optical scanning instrument and at elevated temperatures. The pressure influence was accounted for. Influence of technological fissuring was analyzed from variations in thermal conductivity tensor components for different states of core plugs and was accounted for the equivalent thermal conductivity determination for every 10 m interval taking estimated influence of brine saturation, anisotropy, and PT corrections into account. A new method of thermal conductivity prediction was applied for intervals without coring. As a result, vertical variations in heat flow were established with its increase by ~25% within a depth interval of 1400-3500 m. The terrestrial heat flow was determined as 74.4 ± 3.7 mW/m² that is by ~119% larger than the data published for the well drilling site previously (26-48 (34.0 average) mW/m^2).

3. The continuous thermal core profiling technique was developed and widely implemented for basic and applied research in oil&gas science and industry in Russia. The technique is based on application of the optical scanning instrument and provides continuous non-contact non-destructive high-resolution (0.2-2 mm) profiling all full sized core samples along wells under study. Determination of elastic wave velocities, acoustic anisotropy (γ Tomsen parameter), natural radioactivity, density, total organic carbon, porosity, the thermal properties of rock mineral matrix have became possible

from the data inferred from the thermal core logging due to the close correlations established between the rock thermal properties and other rock properties. Combination of thermal core logging and standard petrophysical logging data has allowed determination of geomechanical parameters – Young's modulus, Poisson's ratio, unconfined compressive strength, etc. - from the new thermal core logging technique results and correlations established. The rock matrix thermal properties can be determined from the thermal core logging as well as from the measurements on core plugs. The results are being applied for basin and petroleum system modeling, hydrodynamic modeling thermal methods of EOR, geomechanical and geochemical modeling, detailed characterization of geological structure of hydrocarbon reservoirs. In 2016-2019 the new thermal core techniques was applied for geothermic study of more than 30 000 core samples of 42 wells drilled in 29 conventional and unconventional oil fields in Russia within projects for oil&gas companies Lukoil, Gazprom, Gazprom netf', Rosneft', RITEK, NOVATEK, Zarubezhneft. The thermal core logging measurements were combined with the rock thermal property measurements at elevated temperatures and with successive saturation of rock samples with different fluids (gas, oil, brine) on core samples which were well-based selected using the continuous thermal core logging data and lithological description of core samples.

- 4. A new technology for determination of the thermal properties (thermal conductivity, thermal diffusivity and volumetric heat capacity) of rocks using drilling rock cuttings was developed. The technology is based on (1) fabrication of solid synthetic samples as mixture of rock cuttings with a material-filler (wax, water, air), (2) measurement of the effective thermal properties of the synthetic samples with the optical scanning technique, and (3) determination of the rock thermal properties from theoretical models of heterogeneous medium using the measurement results. Regime of non-contact optical scanning measurements of the effective thermal conductivity and volumetric heat capacity of the synthetic samples were optimized to provide a high-precision level of the thermal property measurements.
- 5. A new technology was developed for the measurements of rock thermal conductivity on rock cuttings at elevated temperatures (up to 300 ^oC). The technology is based on combination of (1) the technology for the thermal conductivity measurements on rock cuttings described above, (2) application of the DTC-300 instrument for the measurements at elevated temperatures, and (3) application of the advance theoretical model of effective thermal conductivity of heterogeneous materials.
- **6.** New method was developed to determine thermal conductivity from petrophysical well-logs. The method can be applied for anisotropic rock formations and involves the continuous thermal core logging within a technique calibration for a test well. The

method was implemented for applied geothermic investigations of unconventional oil fields in Russia.

- 7. The advanced laser optical scanning instrument was developed to provide the thermal conductivity and thermal diffusivity measurements on core samples, non-consolidated rocks, and rock cuttings. The instrument is portable and allows us to adjust easily the measuring regime parameters accounting for rock sample dimensions, penetration depth required, accepted heating temperature values, required spatial resolution of profiling thermal conductivity and volumetric heat capacity.
- The technique was developed to transform the thermal core logging data into highresolution (1 mm) profiles of total organic carbon for unconventional hydrocarbon reservoirs. The technique is implemented widely in oil&gas industry and science in Russia.
- 9. A special technique was developed to provide continuous control of the state of the rock samples during the laboratory petrophysical investigations to account changes of rock matrix, inter-grain contacts and pore/fracture space during mechanical treatment, cleaning drying, fluid-saturation and heating of the rock samples within the petrophysical complex. The control technology is based on systematic and regular non-destructive non-contact measurements of the thermal conductivity tensor components of studied rock samples with the optical scanning instruments. The control technique is implemented in the Center for Hydrocarbon recovery of the Skolkovo Institute of Science and Technology (Moscow, Russia),



Determination of surface heat flow through time (relative to site AZ8) to a precision of \pm 50 mW/m² using a 'Heat Needle' deployed at the Earth's surface. After Beardsmore (2020).

Dr. Robert Harris. USA

Harris group, Oregon State University

I'm only including publications reporting new heat flow data or directly linked to new heat flow data. As you can see we've been working on hydrothermal circulation within oceanic crust and its influence on the thermal regime and seismicity. We have also started working on better understanding the thermal environment of rifting and the thermal environment of fracture zones.

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