

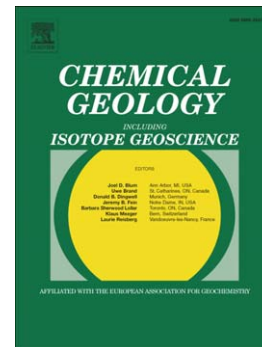
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Yunpeng Wang, David R. Hilton, Zheng Zhou, Guodong Zheng

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# Progress in the Application of Gas Geochemistry to Geothermal, Tectonic and Magmatic Studies

Yunpeng Wang<sup>1\*</sup>, David R. Hilton<sup>2</sup>, Zheng Zhou<sup>3</sup>, Guodong Zheng<sup>4</sup>

1. State Key Laboratory of Organic Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640, China
2. Scripps Institution of Oceanography, University of California San Diego, La Jolla, California 92093-0244, USA
3. Lancaster Environment Center, Lancaster University, Lancaster LA1 4YQ, United Kingdom
4. Key Laboratory of Petroleum Resources, Gansu Province / Key Laboratory of Petroleum Resources Research, Lanzhou Center for Oil and Gas Resources, Institute of Geology and Geophysics, Chinese Academy of Sciences, Lanzhou 730000, China

## Abstract

Gas geochemistry and their associated isotope systematics are developing into powerful tools to understand geological/environmental processes and affirm source origins of geo-fluids. In addition to the traditional noble gas indicators, such as He and Ar, other major and trace gases, including CO<sub>2</sub>, N<sub>2</sub>, H<sub>2</sub>, CH<sub>4</sub>, CO, Ne, Kr and Xe - abundances and isotopes - have shown considerable application in many fields of the Earth and Environmental Sciences. For example, key constraints on geochemical processes including the degassing history of the solid Earth to form the atmosphere and oceans, the origin and migration characteristics of natural gas, the scale of climate variability, the P-T characteristics of both subaerial and deep water geothermal reservoirs, and the dynamics of the earthquake cycle, are only a few areas where gas geochemistry has been successfully exploited. Following the ‘Frontiers in Gas Geochemistry’ Special Issue in this journal (2013), this volume will reflect this diversity in scope and application of gas geochemistry, focusing on geothermal, tectonic and magmatic studies amenable to the gas geochemistry approach.

## Introduction

The continuing success of gas geochemistry is predicated upon innovative approaches involved in their detection, collection, extraction, preparation and measurement, as well as the development of new modeling techniques to further aid interpretation and understanding. This volume aims to document recent advances in gas geochemistry, illustrating their unique geochemical characteristics and application in contemporary research themes, and to explore their application to emerging areas related to geothermal, tectonic and magmatic studies.

The 13th International Conference on Gas Geochemistry (ICGG) held in Chengdu, China in August, 2015 represents a unique gathering of gas geochemists across the geosciences spectrum where the common theme is to understand, exploit and probe the usefulness and limitations of gases in a variety of applications. This Special Issue of Chemical Geology ‘Progress in the Application of Gas Geochemistry to Geothermal, Tectonic and Magmatic Studies’ collects 19 papers focusing on geothermal, tectonic and magmatic studies that emphasize the gas geochemistry approach. ICGG has a tradition to organize special issues in international journals. Following the ‘Frontiers in Gas Geochemistry’ Special Issue in this journal (2013) as well the ‘Geochemical Applications of Noble Gases’ (Chemical Geology, 2009), this volume continues this tradition with a special selection of papers aimed at reflecting the diversity in scope and application of gas geochemistry.

### Themes

The 19 papers of this volume can be grouped into 4 general themes but with considerable overlaps. First, hydrothermal fluids and reservoirs are still the dominant popular target for gas geochemists and this volume contains 7 papers aimed at understanding the origin, nature and extent of geothermal resources, their relationship to geodynamic setting, as well as associated subsurface processes such as fluid mixing and degassing mechanisms.

Bräuer et al. (2017) report new data of the gas and isotope ( $\delta^{13}\text{C}$  and  $^3\text{He}/^4\text{He}$ ) composition of 26 free gas emanations escaping from bubbling springs and mofettes in six different Cenozoic volcanic areas of the French Massif Central, which belongs to the European Cenozoic Rift System. Zhang et al. (2017a) report new data of chemical compositions and He-C-N isotopes for

gas samples from representative hot springs in the hydrothermal belt of India-Asia continental subduction zone, aimed at understanding volatile origins of the hydrothermal degassing systems and their tectonic implications. Italiano et al. (2017a) present the results of a petrochemical and noble gases (He-Ar) study performed in basalts and basanites from basins located onshore the Iskenderun Gulf and developed along the Dead Sea Fault and the Karasu Fault. Their results suggest the melt generation of the alkaline magmas was triggered by a stretching lithosphere resulting from asthenosphere upwelling and decompression melting, analogous to geodynamic models of coeval Syrian alkaline volcanic rocks and older NW Anatolian rocks, rather than by subduction or plume-related processes. Tang et al. (2017) studied the origin of the Zhubu mafic-ultramafic intrusion of the Emeishan large igneous province, SW China, using data of volatile compositions and C-Hf-Sr-Nd isotopes.

Inguaggiato et al. (2017a) point out that Cerro Machín volcano in Columbia is still active by coupling geochemical and seismic information, an approach which they emphasize merits further consideration by the scientific community. Inguaggiato et al. (2017b) confirm previously-formulated geochemical models based on the soil CO<sub>2</sub> fluxes database acquired during recent effusive eruptions by the continuous geochemical network installed in the summit and peripheral areas of Stromboli Island. Zhang et al. (2017b) studied the chemical composition, carbon and noble gas isotopic compositions of volatiles in olivine, pyroxene and plagioclase minerals of the Pobei complex adjacent to the Tarim Large Igneous Province (LIP) to reveal the composition and origin of magmatic volatiles: they suggested that the Pobei mafic-ultramafic complex could have originated from the staged partial melting of heterogeneous H<sub>2</sub>O-rich mantle sources triggered by a mantle plume. Guo et al. (2017) report noble gas (He, Ne, Ar) signatures of chromite and olivine separates from the Luobusa chromitites in Tibet to better understand the volatile compositions trapped in the minerals, and further to trace the origin of melts responsible for formation of the chromite deposits.

The second and related theme is the topic of gas chemistry and its response, or lack thereof, to seismic perturbation is tackled by a number of authors. Martinelli et al. (2017a) review and update the geochemical and geophysical data monitoring of the 2012 Po Valley seismic sequence with the purpose of identifying possible precursory signals. They conclude that possible long and medium term precursory trends have been identified in geofluids and no short-term precursors can be clearly identified. Fu et al. (2017) find that anomalous Rn and CO<sub>2</sub> concentrations from soil gases were observed before the Rueisuei and Fanglin earthquakes, suggesting the

significance of Rn monitoring before major earthquakes at the Longitudinal Valley, Taiwan. Martinelli et al. (2017b) examine the available catalogues of historical and contemporary geochemical and fluid-related precursors of earthquakes using a spatial mapping method and find only some geological and geophysical conditions may allow for the occurrence of fluid-related earthquake precursory phenomena. Cui et al. (2017) investigate the spatial and temporal variations of satellite-acquired total column CH<sub>4</sub> and CO content to understand lithospheric and atmospheric interactions during seismic activity, and they observe anomalies of both parameters to occur along the fault zones where earthquakes occurred, which included a lagged temporal response in the same area.

The third category focuses on gas fluxes, particularly CO<sub>2</sub>, with respect to both mantle and crustal contributions to the total output inventories, particularly gas loss through faulted/rifted segments of Earth's crust. Inguaggiato et al. (2017) studied the role of the aquifer in soil CO<sub>2</sub> degassing in peripheral areas of Stromboli Island (Italy) and showed that the degassing process of soil CO<sub>2</sub> is determined not only by the CO<sub>2</sub> released directly from the magma but also by gas - water interactions in the aquifer. Italiano et al. (2017b) present results on volatiles dissolved in mineral waters discharged in Romania, showing the presence of fluids from different crustal sources besides contributions of mantle-derived fluids. Yuce et al. (2017) present the geochemical characteristics of soil radon and carbon dioxide within the Dead Sea Fault and Karasu Fault in the Amik Basin (Hatay), Turkey, revealing that Rn and CO<sub>2</sub> concentrations in the soil gas show anomalous values at specific positions in the Amik Basin.

Hydrocarbon gases fall into the fourth category. Contributions focus on tectonic and deep controls on hydrocarbon gas accumulation and migration. Dai et al. (2017) present a detailed investigation on the geochemical characteristics of helium and CO<sub>2</sub> from the cratonic Ordos Basin and rift-related Bohaibai Basin in China, and some implications for gas accumulations in China. Liu et al. (2017) discuss the effects of deep CO<sub>2</sub> on hydrocarbon accumulation and thermal alteration using an example of the Huangqiao oil and gas field in China. Ionescu et al. (2017) present the first systematic geochemical study on the content of natural gas (methane, heavier alkanes, CO<sub>2</sub>), and isotopic composition of methane dissolved in natural springs in Romania, from various tectonic and geological settings. They conclude that geothermal sources in the areas of Ciomadul Volcano and Herculane areas are characterized by abiogenic methane. Taking Puguang gas field of Sichuan Basin, China as an example, Liu et al. (2017) calculated a

<sup>4</sup>He accumulation time in natural gas reservoirs of ~32.5 Ma, illustrating a possible method to estimate hydrocarbon gas accumulation histories.

### Concluding Remarks

The ICGG series of meetings provide a lively forum for new ideas and broad discussions focused exclusively on gas geochemistry. The ICGG 13 chose Chengdu city, Sichuan, China mainly because of its long history of gas exploitation, diverse natural gas types, special geographical location at the boundary of the Tibetan Plate, abundant geological phenomena related to natural gases, massive earthquake relics as well as its unique cultures. This meeting attracted around 120 delegates. The four-days meeting included 53 oral presentations and 57 posters covering 7 themes related to geochemistry. This meeting also set up a special session in memory of Professor Tsan-yao F. Yang for his contribution to ICGG community. A pre-conference workshop on noble gas geochemistry was organized, and two distinguished scientists, Prof. Yuji Sano from the University of Tokyo and Prof. David R. Hilton from Scripps Institution of Oceanography, University of California, San Diego gave lectures to around 60 young geochemists from the world. A four-day post-conference field trip was held to experience the unique geological characteristics and diversity of gases phenomena and special natural and cultural attractions between Sichuan to Tibet. Delegates observed active tectonics of the Tibetan Plateau and adjacent region, the spectacular earthquake surface rupture zones related to the 2008 Ms 8.0 Wenchuan earthquake, geological disasters induced by the great earthquake, and other seismic relics in the Longmen Shan Mountains. Delegates also visited the massive travertine landscape in Songpan as well as an outcrop of the Cambrian black shale which was the source of shale gas exploited presently in the Sichuan Basin. Proceedings of the meetings are traditionally published as Special Issues in peer-reviewed journals, as in the present case. ICGG continues to attract widespread participation – in the form of oral and poster presentations - from a diverse international audience. We look forward to the 14th ICGG scheduled to be held in Poland in September, 2017.

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#### References style of references???

Artur Ionescu, Călin Băciu, Boglarka-Mercedesz Kis, Peter E. Sauer, 2017. Evaluation of dissolved light hydrocarbons in different geological settings in Romania. *Chemical Geology* (this issue).

C.C. Fu, T.F. Yang, M.C. Tsai, L.C. Lee, T.K. Liu, V. Walia, C.H. Chen, W.Y. Chang, A. Kumar, T.H. Lai, 2017. Exploring the relationship between soil degassing and seismic activity by continuous radon monitoring in the Longitudinal Valley of eastern Taiwan. *Chemical Geology* (this issue).

Claudio Inguaggiato, Fabio Vita, Iole Serena Diliberto, Lorenzo Calderone, 2017. The role of the aquifer in soil CO<sub>2</sub> degassing in volcanic peripheral areas: A case study of Stromboli Island (Italy). *Chemical Geology* (this issue).

F. Italiano, G. Yuce, M. Di Bella, B. Rojay, G. Sabatino, A. Tripodo, M. Martelli, A. Rizzo, M. Misseri, 2017a. Noble gases and rock geochemistry of alkaline intraplate volcanics from the Amik and Ceyhan-Osmaniye areas, SE Turkey. *Chemical Geology* (this issue).

Francesco Italiano, Boglárka-Mercedesz Kis, Călin Baciú, Artur Ionescu, Szabolcs Harangi, László Palcsu, 2017b. Geochemistry of dissolved gases from the Eastern Carpathians - Transylvanian Basin boundary. *Chemical Geology* (this issue).

G. Martinelli, A. Dadomo, F. Italiano, R. Petrini, F.F. Slejko, 2017a. Geochemical monitoring of the 2012 Po Valley seismic sequence: A review and update. *Chemical Geology* (this issue).

G. Yuce, C.C. Fu, W. D'Alessandro, A.H. Gulbay, C.W. Lai, S. Bellomo, T.F. Yang, F. Italiano, V. Walia, 2017. Geochemical characteristics of soil radon and carbon dioxide within the Dead Sea Fault and Karasu Fault in the Amik Basin (Hatay), Turkey. *Chemical Geology* (this issue).

Giovanni Martinelli, Andrea Dadomo, 2017b. Factors constraining the geographic distribution of earthquake geochemical and fluid-related precursors. *Chemical Geology* (this issue).

Jinxing Dai, Yunyan Ni, Shengfei Qin, Shipeng Huang, Deyu Gong, Dan Liu, Ziqi Feng, Weilong Peng, Wenxue Han, Chenchen Fang, 2017. Geochemical characteristics of He and CO<sub>2</sub> from the Ordos (cratonic) and Bohaibay (rift) basins in China. *Chemical Geology* (this issue).

Karin Bräuer, Horst Kämpf, Samuel Niedermann, Hans-Ulrich Wetzels, 2017. Regional distribution pattern of carbon and helium isotopes from different volcanic fields in the French Massif Central: Evidence for active mantle degassing and water transport. *Chemical Geology* (this issue).

Maoliang Zhang, Zhengfu Guo, Lihong Zhang, Yutao Sun, Zhihui Cheng, 2017a. Geochemical constraints on origin of hydrothermal volatiles from southern Tibet and the Himalayas: Understanding the degassing systems in the India-Asia continental subduction zone. *Chemical Geology* (this issue).

Mingjie Zhang, Qingyan Tang, Chunhui Cao, Wenyan Li, Heng Wang, Zhongping Li, Ming Yu, Pengyu Feng, 2017b. The origin of Permian Pobei ultramafic complex in the northeastern Tarim craton, western China: Evidences from chemical and C-He-Ne-Ar isotopic compositions of volatiles. *Chemical Geology* (this issue).

Qingyan Tang, Mingjie Zhang, Yuekun Wang, Yunsheng Yao, Li Du, Liemeng Chen, Zhongping Li, 2017. The origin of the Zhubu mafic-ultramafic intrusion of the Emeishan large igneous province, SW China: Insights from volatile compositions and C-Hf-Sr-Nd isotopes. *Chemical Geology* (this issue).



Quanyou Liu, Dongya Zhu, Zhijun Jin, Qingqiang Meng, Xiaoqi Wu, Hao Yu, 2017. Effects of deep CO<sub>2</sub> on petroleum and thermal alteration: The case of the Huangqiao oil and gas field. *Chemical Geology* (this issue).

Salvatore Inguaggiato, Fabio Vita, Marianna Cangemi, Agnes Mazot, Aldo Sollamia, Lorenzo Calderonea, Sabina Moricia, Mariana P. Jacome Paz, 2017b. Stromboli volcanic activity variations inferred from observations of fluid geochemistry: 16 years of continuous monitoring of soil CO<sub>2</sub> fluxes (2000 - 2015). *Chemical Geology* (this issue).

Salvatore Inguaggiato, John Makario Londoño, Zoraida Chacón, Marcello Liotta, Edwin Gil, Diego Alzate, 2017a. The hydrothermal system of Cerro Machín volcano (Colombia): New magmatic signals observed during 2011 - 2013. *Chemical Geology* (this issue).

Wei Guo, Huaiyu He, David R. Hilton, Yongfei Zheng, Fei Su, Yan Liu, Rixiang Zhu, 2017. Recycled noble gases preserved in podiform chromitites from Luobusa, Tibet. *Chemical Geology* (this issue).

Wenhui Liu, Cheng Tao, Tenger Borjigin, Jie Wang, Huamin Yang, Ping Wang, Houyong Luo, Changbo Zhai, 2017. Formation time of gas reservoir constrained by the time-accumulation effect of <sup>4</sup>He: Case study of the Puguang gas reservoir. *Chemical Geology* (this issue).

Y. Cui, D. Ouzounov, N. Hatzopoulos, K. Sun, J. Du, 2017. Satellite observation of CH<sub>4</sub> and CO anomalies associated with the Wenchuan MS 8.0 and Lushan MS 7.0 earthquakes in China. *Chemical Geology* (this issue).

Yunpeng Wang  
State Key Laboratory of Organic Geochemistry  
Guangzhou Institute of Geochemistry  
Chinese Academy of Sciences  
Guangzhou 510640, China  
Tel/Fax: +86-20-85290197  
E-mail: wangyp@gig.ac.cn

David Hilton  
Geosciences Research Division,  
Scripps Institution of Oceanography,  
La Jolla,  
California 92093-0244  
USA

Phone: 1 858 822 0639 (office); 822 0716 (lab); Fax: 1 858 822 3310  
Email: drhilton@ucsd.edu

Zheng Zhou  
A511 LEC1  
Lancaster Environment Centre  
Lancaster University

Lancaster  
LA1 4YQ  
United Kingdom  
Tel: +44 (0) 1524 593 371  
Email: z.zhou4@lancaster.ac.uk

Key Laboratory of Petroleum Resources, Gansu Province / Key Laboratory of Petroleum Resources Research  
Lanzhou Center for Oil and Gas Resources  
Institute of Geology and Geophysics,  
Chinese Academy of Sciences,  
Lanzhou 730000, China  
Tel: +86(931)4960815; Fax: +86(931)8278667  
Email: gdzobj@mail.iggcas.ac.cn

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