AG Classics

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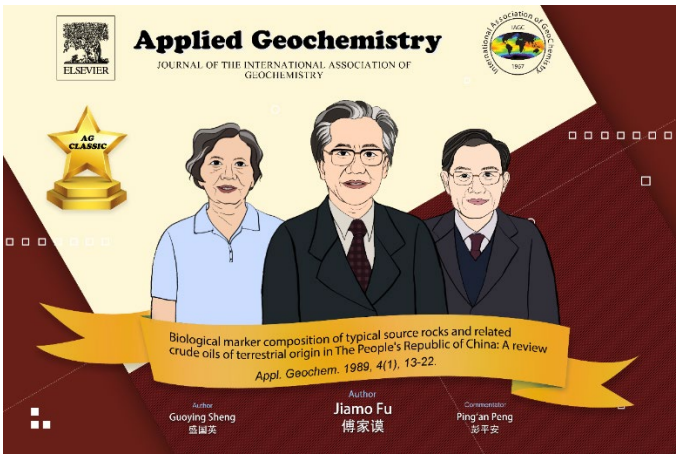
Fu, J., & Guoying, S. (1989). Biological marker composition of typical source rocks and related crude oils of terrestrial origin in the People's Republic of China: a review. *Applied Geochemistry*, 4(1), 13-22.

About AG Classics

The celebration of 35 years is a great moment to reflect on *Applied Geochemistry's* publication milestones, which often shaped their respective research areas. In our special program "*AG* Classics," we select and highlight those key publications. When possible, the journal will invite authors and a few commentators, who work in the same area and might have been influenced by the paper, to create a virtual panel discussion to present their perspectives on the evolution of the topic and identify the current frontiers, knowledge gaps, and research needs. We anticipate that this initiative will engage researchers all over the world with various backgrounds and eventually present valuable documentation of the journal's history and the discipline of geochemistry at large.

This issue of *AG* Classics is a conversation with **Sheng Guoying** (Professor Emeritus, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences) and commentator **Peng Ping'an** (Academician of Chinese Academy of Sciences, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences). They discuss the paper by **Fu Jiamo** (1933-2015); Academician of Chinese Academy of Sciences) and Guoying on biomarkers crude oil source rocks from China.



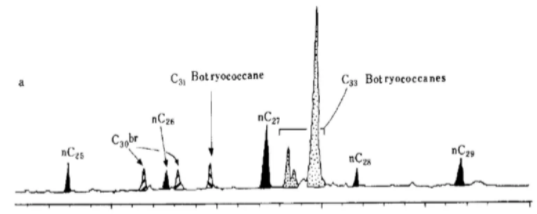
Introduction to Biomarkers

Biomarkers are also called biological markers, molecular markers, and chemical fossils, referring to organic compounds (individual compounds and/or a group of homologues series) extracted from many geologic bodies, such as sediment, crude oil, oil shale, and coal, which basically preserve the carbon skeleton of the original biomolecules derived from living organisms. Most biomarkers are relatively stable in diagenesis; therefore, they document the special molecular structure information of the original biological input. They can be used to identify or trace the source input and its related living water environments in geologic rocks over millions of years. They were built as related parameters or indicators to identify the

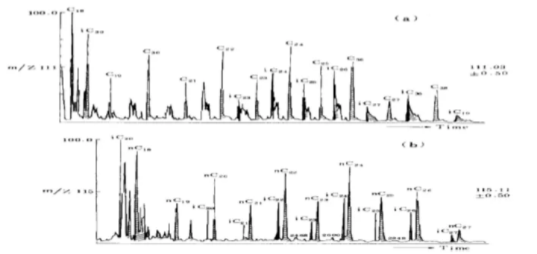
characteristic biological sources and their related organic matter in source rocks and crude oils. For example, many applications were widely and successfully used in petroleum geochemistry as follows: 1) oil-oil and oil-source rock correlation; 2) evaluation of thermal maturity and/or biodegradation; 3) regional variations in the characteristics of oils and source rocks as controlled by organic matter input and characteristics of the depositional environments; and 4) petroleum generation and kinetics information on kinetics of petroleum generation and basin. Biomarkers are the core content of organic geochemistry and are still rapidly progressing in research intersecting with other disciplines, such as sedimentology, paleontology, palynology, biology, microbiology, oceanography, climatology, and ecology.

Q: This article was selected as a classic paper in the AG journal. Could you please briefly introduce this article?

Sheng: This AG paper is one of the many progressive results of our research on biomarkers in crude oil and sediment in China. These results reflected the representative progress in the field of molecular organic geochemistry at that time. The article published in AG titled "Biological marker composition of typical source rocks and related crude oils of terrestrial origin in the People's Republic of China: a review" summarized five typical depositional environments distributed in China's terrestrial basins: A) sedimentary formations in large basins in China's interior plates, such as Songliao Basin and Jizhong Depression; B) Lacustrine clastic rock formations in fault-subsidence basins, mainly source rocks in Shengli Oilfield, Liaohe Oilfield, Jizhong and Subei Basins; C) saline-lake with gypsum-clastic formations in fault-subsidence basins, typically as Jianghan Basin and Biyang Basin; D) lagoonal-lacustrine intermontane basins with volcano-clastic rocks, such as the Carboniferous-Permian source rocks in Junggar Basin; E) paralic coal-bearing formations of the platform facies, with special liptobiolite occurrence in Suqiao, Hebei. Each type has its specific biomarker characteristics, as follows: (1) environment A is poor in gammacerane and triterpane of higher plant origin; (2) environment B contains abundant biomarkers, especially hopanoid and steroid hydrocarbons, with some triterpanes of higher plant origin; (3) environment C has extremely high amounts of phytane and series of organic sulfur compounds, with high ratios of phytane/pristane, gammacerane/C30αβ hopane, and occasionally high even carbon predominance of n-alkanes; (4) environment D contains abundant isoprenoid alkanes and carotanes (β-carotane and γ-carotane); (5) environment E is rich in biomarkers of higher plants, such as diterpenoids and aromatized terpenoids. Overall, this paper is a typical example of the application of molecular marker distribution characteristics to reconstruct the paleoenvironment, oil/source and oil/oil correlation, which greatly enriches and develops the petroleum hydrocarbon generation theory with the large-scale occurrence of terrestrial strata in China. It is of great significance to build confidence and paces in the exploration and development of China's petroleum resources.



A 、B组：淡水湖相--茂名油页岩样品中的烷烃分布-富含丛粒藻烷（左图）



C组：膏盐环境-江汉油田原油芳烃中烷基噻吩类和烷基四氢化噻吩类化合物（左图）

Figure 1. Characteristic biomarkers in typical terrestrial source rocks and crude oil in China (original data, reproduced with permission)

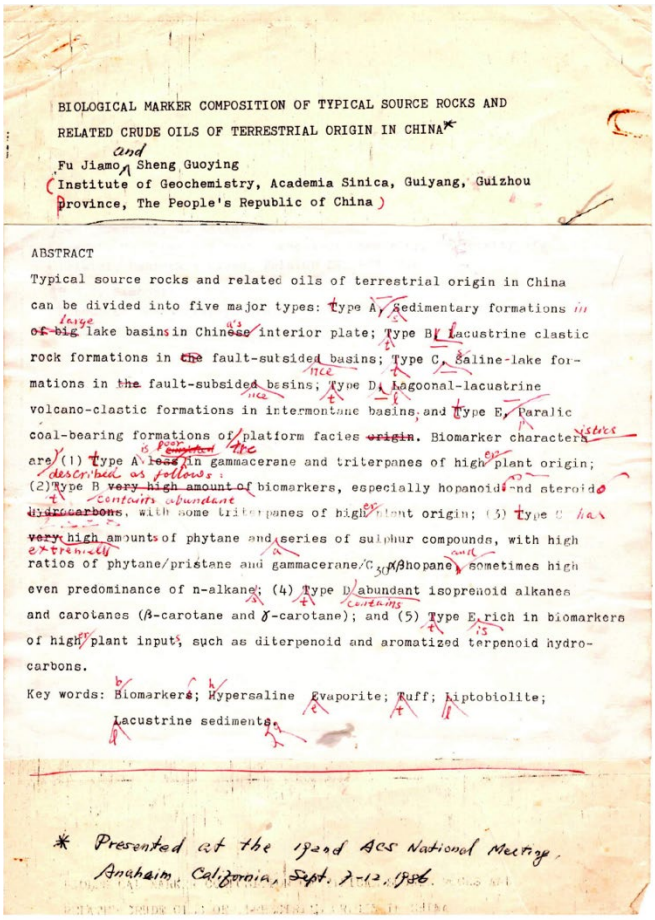
In fact, part of the laboratory work in this paper was done at the University of Bristol, UK. Since 1979, Prof. Fu Jiamo and his research group started long-term collaboration on molecular organic geochemistry with the Organic Geochemistry Lab at Bristol University led by Prof. G. Eglinton, with whom he developed a lifetime friendship. In the early 1980s, the collaboration was funded by two UNDP projects (UNDP CPR/80/037, 1980-1981; 84/005, 1985-1987), a joint project "Sino-UK Molecular Organic Geochemistry Research", Prof. Fu Jiamo and Prof. G. Eglinton are the heads of the Chinese and British sides, respectively.

Figure 2. Professors Fu and G. Eglinton (middle: Prof. Weijian Zhou) on a field trip in Qinghai Salt Lake in 1980

Q: Are there any interesting stories?

Sheng: Behind this article, there are several stories about me and Prof. Fu Jiamo working on organic sulfur biomarkers. In 1985, I just returned to China after completing a Sino-UK cooperation project. Our team hoped that I would go to the United States to attend the Gordon Conference on Organic Geochemistry in 1986. After the conference, I visited a famous organic geochemist at the University of Oregon, Prof. B.R. T Simoneit, with whom we have a cooperative relationship. We learned the analysis skills of atmospheric aerosols from his group. He said that there was an annual meeting of the American Chemical Society in Anaheim, California, and he encouraged me to attend. In fact, we only submitted the abstract at that time without registering, but this paper was still included in the conference abstract collection (because it was not registered, the abstract page was stamped with a cancellation). Therefore, there is this piece of information (presented in the ACS conference in 1986) on the corner note of the AG paper.

I have a deep memory of this article because Prof. Fu and I were very serious about preparing this article. In the past few days, I also determined a manuscript that we prepared with a typewriter, which was approximately 1987, with densely packed corrections handwritten by Prof. Fu. At that time, there was no computer, and it was very inconvenient to write and



BIOLOGICAL MARKER COMPOSITION OF TYPICAL SOURCE ROCKS AND RELATED CRUDE OILS OF TERRESTRIAL ORIGIN IN CHINA*

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ABSTRACT

Typical source rocks and related oils of terrestrial origin in China can be divided into five major types: Type A, sedimentary formations in large lake basins in Chinese interior plate; Type B, lacustrine clastic rock formations in the fault-subsided basins; Type C, saline-lake formations in the fault-subsided basins; Type D, lagoonal-lacustrine volcano-clastic formations in intermontane basins and Type E, paralic coal-bearing formations of platform facies origin. Biomarker characters are described as follows: (1) Type A is poor in gammacerane and triterpanes of high plant origin; (2) Type B very high amount of biomarkers, especially hopanoid and steroid hydrocarbons, with some triterpanes of high plant origin; (3) Type C has very high amounts of phytane and series of sulphur compounds, with high ratios of phytane/pristane and gammacerane/C_{30} αβhopane, sometimes high even predominance of n-alkane; (4) Type D abundant isoprenoid alkanes and carotanes (β-carotane and γ-carotane); and (5) Type E rich in biomarkers of high plant input, such as diterpenoid and aromatized terpenoid hydrocarbons.

Key words: Biomarkers; Hypersaline Evaporite; Tuff; Liptobiolite; Lacustrine sediments.

* Presented at the 192nd ACS National Meeting, Anaheim, California, Sept. 7-12, 1986.

Figure 3. The original photocopy of the manuscript over 35 years ago.

Figure 4. In 1986, Prof. Fu Jiamo organized and presented at an international conference on biomarkers hosted by the Chinese Academy of Sciences (CAS) organic geochemistry open lab. Foreign Participants include B.R.T. Simoneit, I.R. Kaplan, P.A. Schenck, D. Vitorovio.

Q: As one the key pioneers in organic geochemistry in China, Prof. Fu has left profound legacies. Would you please briefly summarize them?

Sheng: Since 1966, our laboratory has carried out organic geochemistry research under the leadership of Prof. Fu, with the breakthrough of research and establishment of biomarkers, and has successively achieved outstanding results in the theory of oil and gas genesis and exploration and development of major oil and gas basins in China. These results have had a significant impact both domestically and outside the country. In 1989, open CAS laboratories were upgraded to the level of a state key laboratory: the State Key Laboratory of Organic Geochemistry (SKLOG). The purpose of his scientific research is to study what the country needs. When our country urgently needs oil, he studied organic geochemistry and established ten new biomarkers and methods applicable to oil and gas exploration and assessment in China to promote the development of China's terrestrial oil generation theory. In 1992, he led the establishment of the "Guangdong Key Laboratory of Environmental Resources Utilization and Protection", the mission of which was to address micropollutants in the environment of the Pearl River Delta. Then, he aimed at the international frontier and led us to carry out research on persistent organic pollutants (POPs) in the environment. Some research won the second prize of the National Natural Science Award in 2006. Furthermore, while studying organic micropollution, he is also concerned about the research on environmental

pollution control and established the "Pearl River Delta Environmental Pollution and Control Research Center of the Chinese Academy of Sciences".

The development of China's petroleum exploration is mainly accredited to the contributions of colleagues in the Petroleum Ministry, the Geological and Mining Ministry (Fu Jiamo, "The Progress of Organic Geochemistry Research in China and Its Application in Oil and Gas Exploration", 1989, Oil and Gas Geology). Prof. Fu's greatest contribution is to introduce the theories and methodologies of organic geochemistry into China's petroleum exploration industry. Especially in the 1970s, in the process of establishing ten major biomarker indicators for searching for oil and gas, our state key laboratory (SKLOG) became a training center for major oil and gas fields to carry out biomarker research. This has greatly promoted the development of organic geochemistry in China and enabled the application of biomarkers in the practice of oil and gas exploration. It is particularly important that the theory of petroleum organic genesis has made significant progress. This profound change in the theory of petroleum genesis has greatly promoted the prospective evaluation of petroleum resources and geological exploration. Organic geochemistry has been juxtaposed with geophysics and petroleum geology as the three pillars of petroleum exploration. He's research of "New Biomarkers, New Method and Application of Organic Geochemistry in Searching for Oil and Gas" won the second prize of the National Science and Technology Progress Award in 1985.

Prof. Fu Jiamo is one of the founders of organic geochemistry in China. His research areas, oil/gas exploration, and environmental science and technology, have made significant contributions to the national economy. He enjoys a great reputation internationally and is included in the biographies of international scientists and celebrities.

Q: This paper is selected as a classic in the AG journal. From the authors' perspective, would you please elaborate its historical value?

Sheng: This AG paper is a review, and it takes a long time from writing to final publication. In fact, most of our group's research papers are published in the journal "Organic Geochemistry". When we published a collection of research articles on the 80th birthday of Prof. Fu, this paper was not included. However, this review paper summarized and witnessed the early pioneering process of organic geochemistry in our country. Areas A and C summarized in this article are terrestrial petroleum generation, which is rare worldwide. At that time, it was generally considered that lacustrine sediment has difficulty generating oil, so this review recorded the pioneering practice of China's establishment of terrestrial oil generation theory.

Furthermore, this paper is also one of the systematic summaries of Sino-UK collaboration projects funded by the United Nations. These achievements were shown to Queen Elizabeth and governmental officials and were highly appreciated. In 1989, the Organic Geochemistry Laboratory created and led by Prof. Fu was approved by the State Planning Commission as a State Key Laboratory. In 1988, Prof. Fu, as a head of the Sino-UK project, visited Prof. G. Eglinton's laboratory and systematically summarized the molecular organic geochemistry research results completed by our colleagues in the UK laboratory since 1983. Prof. Fu and coauthors from the UK published a paper titled "Application of biological markers in the assessment of paleoenvironments of Chinese non-marine sediments" in 1990 on "Organic Geochemistry".

Figure 5. The results of relevant Sino-UK collaborative research were shown in a Royal Society exhibition in 1987, which Queen Elizabeth and many government officials attended.

Q: As a witness, could you share the story about this article?

Peng: From 1981 to 1988, I studied organic geochemistry in the group led by Professors Fu and Sheng and witnessed the preparation of this AG paper.

Looking back on the history behind this paper, I would like to make two comments: 1) International cooperation is a very important resource for the development of organic geochemistry. For example, Professors Eglinton and Schenk and many other foreign colleagues offered tremendous help and support to us. They encourage people to cooperate and contribute to the development of the discipline as a shared asset. 2) Several decades ago, we (Chinese colleagues) did have our own shortcomings, and we could not identify unknown compounds without the ability to synthesize standard chemicals. The difference in geochemistry between China and Western developed countries is that there are particularly many chemists in Western geochemists, and they have relatively strong chemical knowledge. However, most geochemists in China were originally geologists.

Due to the trace levels of biomarker compounds in geological bodies, the full structure identification of a compound is generally achieved through synthesis standards and co-injection with standards. However, chromatographic-mass spectrometry analysis of the compound can only provide preliminary structural information and cannot identify the full structure. Because of the limitation of synthesis ability, in the 1980s, we did not perform the identification of unknown compounds. However, some compounds were identified by our independent establishment of chromatography-mass spectrometry methods, and they were discovered almost simultaneously with international colleagues.

Q: Do you have any experience and thoughts to share with us?

Peng: This classic AG paper by Prof. Fu and Prof. Sheng is the epitome of the hard work of the older generation of scientists. As a witness, I saw Prof. Fu overcoming many difficulties in order to buy a Finnigan 4515 GC–MS. The part of data in this classic AG paper are analyzed by this instrument. In the 1980s, everyone was able to concentrate on scientific problems and was doing research down-to-earth and wholeheartedly. In contrast, currently, in most cases, if people cannot obtain large funding or publish high-impact papers, then they do not want to spend time performing this type of research, resulting in an increasing number of studies in this area. Therefore, at present, Prof. Fu's devoted scientific research spirit is very worthy of us to learn.

Q: Are there any new advances in the research on biomarkers?

Peng: An obvious geological feature in China is the rich and diverse lacustrine sedimentary strata. This classic AG paper summarized the different biomarkers of different basins in China. If we continue to study, we still have the chance to discover a large

number of new biomarkers. In my opinion, more researchers should be encouraged to carry out research in this area.

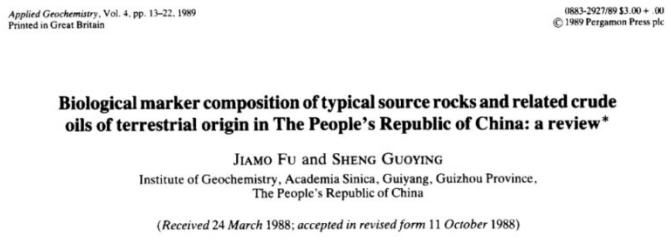
To overcome the shortcomings in the synthesis of standard samples, we can use another internationally recognized approach to complete the structural identification of unknown biomarkers, that is, to separate the compounds from the geological body, such as using preparative chromatography, and then perform NMR to identify the compounds. Recently, for example, our colleague Prof. Hong LU's group re-identified botryococcane in Maoming Shale and corrected the previous structural speculation (Refs, Liao et al., 2018, 2020; Organic Geochemistry).

Q: Would you comment on the future directions and prospects of biomarker research in organic geochemistry?

Peng: The biomarkers summarized by Prof. Fu's AG paper were very novel at that time, although it seems to be very common now. Prof. Fu systematically summarized the differences in biomarkers in different sedimentary environment basins, which was of guiding significance for the identification of oil sources in our country's oil and gas exploration at that time. I think we can continue research on lake biomarkers, which will make a significant contribution to organic geochemistry and beyond.

Biomarkers in organic matter, such as those in geological macromolecules of kerogens, humic acid, and soil, are also important research directions for us in the future. These organic substances are the parent materials for petroleum hydrocarbon generation and were used to build the classic organic theory of petroleum origin. If extended to the area of environmental research, the adsorption of organic pollutants in the organic phase is mostly related to the heterogeneity of organic matter. Prof. Fu performed many pioneering and fundamental studies on biomarkers, which created many new research directions.

I believe that research on biomarkers in China will receive more achievements in the future. At this time, it is very meaningful for AG to review the contributions of Prof. Fu and let more organic geochemists know the history of biomarker research in China.



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Biological marker composition of typical source rocks and related crude oils of terrestrial origin in The People's Republic of China: a review*

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