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NOTE

My professional career in paleolimnology

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In June 2018, I was awarded the International Paleolimnology Association (IPA) "Lifetime Achievement Award" at the 14th International Paleolimnology Symposium in Stockholm, Sweden. I never expected to receive such an award, but I am very happy and grateful. I thank the executive committee of the IPA and my nominees for this award.

Looking back on my career in paleolimnology, I would first like to thank my Alma Mater, Nanjing University (1957–1962), for giving me a good education. In college, many outstanding professors such as Mei'e Ren (Fig. 1a) and Lingzhi Guo provided me with a solid foundation in the fields of geology, physical geography, geomorphology, geochemistry and Quaternary geology. During my master's program (1962–1965), my advisor, Professor Huairen Yang (Fig. 1b), inspired me to study the evolution of Quaternary geomorphology in the middle and lower reaches of the Yangtze River, from the perspective of tectonics, glacial-interglacial climate change, vegetation fluctuations, and sea-level changes. This project trained me in scientific thinking about Earth System Science, which made it possible for me to engage in paleolimnology from a multidisciplinary perspective.

From 1981 to 1983, as a visiting scholar in the Department of Geology at ETH (Switzerland), I worked with Professors Jinghua Xu and Kerry Kelts (Fig. 1c), received comprehensive training, and improved my analytical skills in lacustrine sedimentology. Systematic study of event deposits at Lurzens Lake gave me the opportunity to experience the entire process of paleolimnological study, including field work, geophysical measurement of lakes, drilling of sediment cores, sample collection, and laboratory analyses. I obtained lifetime benefits from that experience.

My professional career in paleolimnology really began in the 1970s. During that time, China's oil industry, represented by the Daqing Oilfield, developed rapidly. The theory of "terrestrial-derived oil" was proposed, and it suggested that China's main oil fields formed in great paleo-lakes. During the development of Daqing Oilfield, it was discovered that the location of underground oil was a poor match for the designed well network. This resulted in low oil

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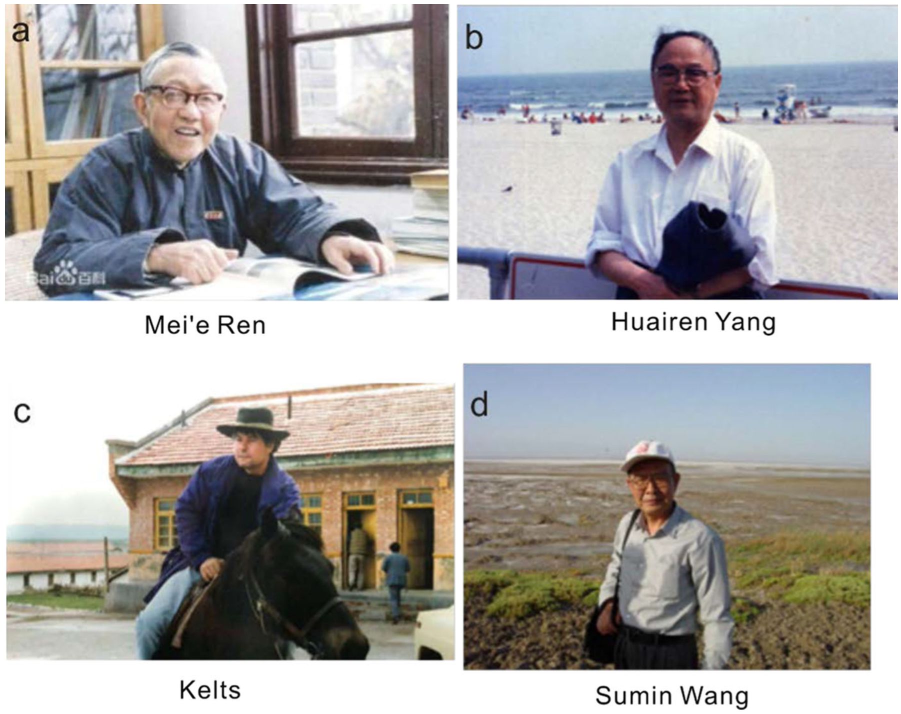

Fig. 1 Photos of **a** Professor Mei'e Ren, former Chair of the Department of Geography, Nanjing University; **b** Professor Huairen Yang, group leader of Geomorphology, Department of Geography, Nanjing University; **c** Professor Kerry Kelts, former Director of the Limnological Research Center, University of Minnesota; **d** Professor Sumin Wang, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences

recovery from wells. Therefore, it was critical to understand the geometry of oil-containing sand bodies (reservoirs), from the viewpoint of lake-basin sedimentation. My institute, as part of the Chinese Academy of Sciences, was the agency that specialized in the study of lakes, so this task fell on us. This opportunity, in fact, launched my study of paleolimnology (Fig. 1d). At that time, scientific information about the Daqing Oilfield was very limited. For me, someone who had never been involved in oilfield research, the best information source was books. I carefully read many volumes, including Haofu Tong's "Principles of Sedimentology," Petite Zhuang's "Sand and Sandstone," and Reneke's "Depositional Environment of Terrestrial Particles." In my 4 years at Daqing, I observed the lithology and sedimentary texture of about 10,000 meters of sediment core, and analyzed minerals, grain size, ostracodes and pollen samples from these cores. I also collected log data from more than 3000 wells. Using these data, I made the first map of the sand body in the Daqing Oilfield, employing the novel method of "marked layer-isometric distance" measurement. The technique revealed that the Daqing Oilfield was a great river delta sedimentary system (Qi and Wang 1983). Thereafter, I reconstructed the sand geometry of multiple oil-bearing formations, and proposed potential new areas for oil and gas exploration, according to the extension direction of the sand body. At the same time, I explored the movement of groundwater and oil, using the porosity and permeability of the microphase in the sand body, and then made suggestions regarding adjustments to the producing well network, which were instituted at different stages in the oil-extraction process. These efforts improved oil recovery substantially.

Given the benefits to oil production of the new techniques applied in the Daqing Oilfield, the new procedures were widely adopted in various oil fields throughout the country. One consequence was that study of the palaeogeography of paleo-lake basins was promoted in China. Thereafter, I completed a study on the relationship between sedimentary characteristics and oil production in sand and gravel reservoirs of the

Karamay Oilfield (Wang and Wang 1993). From 1983 to 1985, I carried out a study on the fan delta-turbidity sedimentary system of the rift valley granite basin in the Zhongyuan Oilfield (Wang et al. 1991). Results of this work improved oil production, which was recognized by the Ministry of Petroleum of China and the Chinese Academy of Sciences. These achievements involved collaborations, and I am very grateful to all my colleagues who worked in the oilfields and at my institute.

To strengthen comparisons between modern and paleo-lake basins, and better understand the geological history of oilfields, we started a new project (1981–1984) that used the fault lakes in Yunnan Province as modern analogues of oilfield paleo-lakes. Specifically, we chose deep Lake Fuxian, moderate-depth Lake Erhai, and shallow Lake Dianchi as representatives of lake basin evolution, at different stages. We systematically studied the physical and hydrodynamic conditions of each lake, the lake biota (including aquatic macrophytes, phytoplankton, zooplankton, and fish), and lake sediments. In particular, we collected sediment samples from multiple locations in the lakes by drilling on a grid with a gravity corer, analyzed multiple sediment variables to reveal the relationship between the sedimentary system and the lake environment at different stages of fault-basin evolution, and evaluated the combination of characteristics of the "source-storage-coverage strata" of basins. This project was led by Professor Yannian Qi, former Deputy Director of the Nanjing Institute of Geography and Limnology, through collaborations with other colleagues from the Lanzhou Institute of Geology and the Institute of Geochemistry (Chinese Academy of Sciences). This work provided a good modern analogue for the sedimentary system of paleo-lake basins, and marked the beginning of comprehensive limnology/paleolimnology studies in China (Qi et al. 1983).

Beginning in the late 1980s, my research interest turned to paleoclimate and paleoenvironment studies, using lacustrine sediments. To lay the foundation for paleolimnology studies, I led a systematic survey of Chinese lakes. Over a period of 6 years, we investigated more than 500 lakes in the five great lake groups of the country, and published the "Encyclopedia on Lakes in China" (Wang et al. 1998). For the study of lacustrine sediments and past global climate change, I chose Daihai Lake in Inner Mongolia, northern China (Fig. 2a). The lake catchment has well-preserved lacustrine terraces, and alternating deposits of river delta and lacustrine silts with intact facies, indicating multiple lake-level fluctuations. Through analysis of multiple variables such as pollen, grain size, mineralogy, elemental chemistry, and stable isotopes, and by comparing results from sediment cores, outcrop profiles and lake landforms, we reconstructed water-level fluctuations and the Holocene evolutionary history of Lake Daihai, which reflected changes in the East Asian Summer Monsoon (Shen et al. 2005; Ji et al. 1993; Wang et al.1996). Thereafter, we studied many other water bodies, including Qinghai Lake (Fig. 2b, c), Hulun Lake, Gucheng Lake, and Mianyang Paleo-lake in the Jianghan Plain. Together with the results from Daihai Lake and the Yunnan lakes, we found that the formation of lakes in the eastern part of China was closely related to changes in the East Asian Summer Monsoon during the Holocene, and that high-resolution paleolimnological records were useful to study paleoclimatology (Shen et al. 1997, 2006; Wang and Feng 1992; Yang et al. 1996). I helped Professor Yafeng Shi, academician at the Chinese Academy of Sciences, to synthesize the data on Holocene climate change in China and publish the book "Holocene Thermal Optimum" and a series of articles (Shi et al. 1993a, b, 1994a, b).

To explore the relationship between lacustrine environmental evolution and monsoon changes on longer timescales, we carried out systematic study of deep drillings from lakes in the Zoige Basin, Cuo'e Lake, and Heqing Basin (Fig. 2d), and geological profiles from Sanmenxia Paleo-lake in Pinglu, Shanxi Province. We used paleomagnetism measurements and radiocarbon and luminescence dating to reconstruct the history of formation and evolution of each basin during the Quaternary. Preliminary findings revealed that orbital-scale changes in the lacustrine environments were controlled by the East Asian Summer Monsoon and westerly circulation, but with strong regional differences. According to ages of the Sanmenxia Paleo-lake floor and covered loess, we proposed that the Yellow River finally cut through the east of Sanmenxia and flowed into the sea about 200,000–150,000 years ago (Wang and Xue 1997, 2002; Shen et al. 2004; Shi et al. 1998; Yang et al. 1998, 2000).

In the late 1990s, under the umbrella of research on global warming and the influence of human activities,

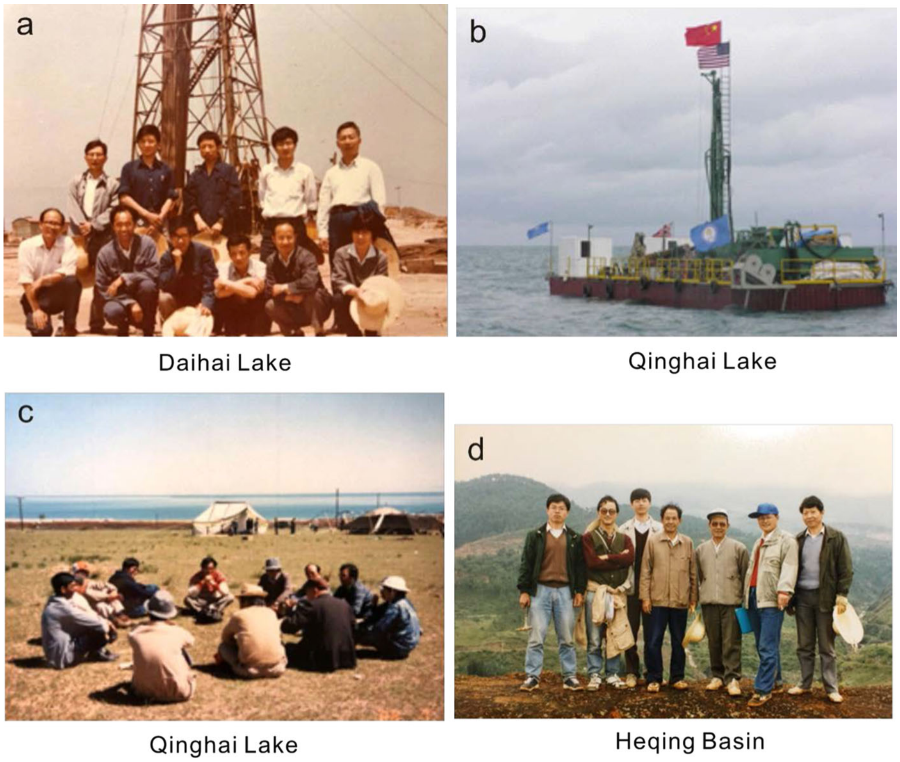

Fig. 2 Photos of fieldwork: **a** Drilling at Daihai Lake, Inner Mongolia, China (1986); **b** The GLAD 800 platform (USA) at Qinghai Lake (2005); **c** A short lakeside meeting at Qinghai Lake with Chinese and Japanese Scientists (1989); **d** Heqing Basin (1997)

we discovered that eutrophication of lakes in eastern China developed rapidly. That has become a major environmental problem of great concern for the whole country. Therefore, study of the relationship between lake eutrophication and both global warming and human activities is being pursued actively. We selected the lake group in the middle and lower reaches of the Yangtze River, where we quasi-quantitatively reconstructed background values and changes in phosphorus concentrations in lake water, using nutrient-sensitive diatoms (Yang et al. 2002; Ji and Wang 1994). Together with indicators of human activities such as population numbers, water conservation projects, fertilizer use, and paleoclimate models, we inferred the evolutionary history of eutrophication and critical stages in its development (Ji and Wang 1993). These projects explored the potential of paleolimnology to reveal the eutrophication history of Chinese lakes.

For the above research contributions, I was awarded the highly competitive CAS Natural Science Award (first class) in 1998, and the National Natural Science Award (second class) in 2006. I could not have accomplished these achievements on my own, and relied on collaborations with colleagues from my research group. I am very grateful to my colleagues at Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, including Professors Ji Shen, Ge Yu, Xiangdong Yang, Jinglu Wu, Bin Xue, Jian Liu, and others. I also appreciate the support of colleagues from other institutes, including Professor Zhisheng An from the Institute of Earth Environment, Chinese Academy of Sciences, Professor Fahu Chen from Lanzhou University, Professor Jule Xiao from the Institute of Geology and Geophysics, Chinese Academy of Sciences, and Professor Xihao Wu from the Institute of Geology and Mechanics, Ministry of Land and Resources, China. I thank all of them for their generous contributions to my work.

In view of the need for lacustrine management and ecological restoration, it will be necessary to study the processes and mechanisms of lacustrine ecosystem degradation, from the perspective of paleolimnology. Furthermore, the field of paleolimnology has been expanding, and paleolimnological techniques have recently been applied to address questions in environmental archaeology and the origin of agriculture.

Although I have retired, I am honored to serve as a council member on the Global Change Specialized Committee of the National Major Research Program (Ministry of Science and Technology, China). I recommended studies on the paleo-monsoon at various timescales, quantitative reconstruction of past climate change, evolution of lake ecosystems and regional differences, global change and development of Silk Road civilization, and global change as it relates to the origin of rice agriculture. These projects have begun, and will certainly contribute to the development of paleolimnology in China. I have been engaged in the study of paleolimnology for more than 40 years. I would like to think that one of my contributions has been to provide a sound basis for future paleolimnological research. Finally, the study of paleolimnology in China is inseparable from the needs of the country's development and international cooperation. I therefore believe that the future of paleolimnology in China is bright. It has certainly played a large role in my life.

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