Syntheses in Limnogeology

Robin W. Renaut
Richard Bernhart Owen

The Kenya Rift Lakes: Modern and Ancient

Limnology and Limnogeology of Tropical Lakes in a Continental Rift

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ISSN 2211-2731 ISSN 2211-274X (electronic)
Syntheses in Limnogeology
ISBN 978-3-642-25054-5 ISBN 978-3-642-25055-2 (eBook)
https://doi.org/10.1007/978-3-642-25055-2

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The registered company address is: Heidelberger Platz 3, 14197 Berlin, Germany

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Lake Bogoria

For Duncan

Preface

We don't receive wisdom; we must discover it for ourselves after a journey that no one can take for us or spare us (Marcel Proust)

In July 1975, we began a lifetime of interest in the Kenya Rift lakes when we began as graduate students supervised by the late Professor WW (Bill) Bishop at Queen Mary College, University of London.

A year later, having spent several months preparing photogeological maps, we arrived at Embakasi Airport in Nairobi on an East African Airways flight, excited to begin our field research in the Suguta Valley in the northern Kenya Rift. After confusion and delay on arrival from London, we set off with Martin Pickford, and Jimmy and Gill Young (University of Edinburgh, Geography), for a tented camp on the western shore of Lake Baringo where Bill was arranging our onward journey to Suguta by a lorry with two Land Rovers, fuel, food, water, a cook, field assistants, and a nurse. *En route* to Baringo, then a 5–6-hour journey, one Land Rover slid sluggishly into a ditch during heavy rains and several wheel nuts sheared off. A passing lorry loaded with Tusker beer came to the rescue. A few hours later, after dark, our second Land Rover became stuck on its side (>30°) while crossing the gravelly Ndau River near Lake Baringo during a flash flood in torrential rain. That Land Rover became partly filled with water. An empty teapot floated symbolically below the dashboard. To the rescue came that same heroic Tusker lorry and driver, who by then had caught up with us. We eventually arrived at Kampi-Ya-Samaki (midwest shore of Lake Baringo) at about 9.00 pm, wet, tired, and bitten by a myriad of mosquitos and other noisy bugs. No mobile phones back then (1976). Grunting hippos came ashore to feed on grass around our tents during the night but delicately missed the guy ropes. But seeing and hearing Lake Baringo the next morning for the first time, while eating posho and fruit for breakfast, even with yucky, soupy, sugary milky tea, was fantastic. Then, two days later, the Kenya Government revoked our research permit to work at Suguta because the Kenya army was training there, linked to security issues along the Ugandan border. Too late: by then we were already hooked…

So began our interest and geological research in the Kenya Rift and its fantastic lakes. We finally reached Suguta in early 2018. By then, our (1975–1976) photogeological maps were a little out-of-date.

This book is our attempt to summarise the geology, general limnology, environmental setting, and recent history of the modern lakes in the Kenya Rift Valley and Nyanza Rift, and to examine the ancient lake deposits preserved in the Neogene stratigraphic record. We are both geologists by training, so we do not pretend to cover the modern biology of the Kenya Rift lakes from the same perspectives and depth as a biologist or ecologist. Nonetheless, we have published our results in journals that span the interface between geology and biology, reflecting our broad (palaeo)ecological interests, and we discuss and reference much of the relevant biological literature.

We briefly include Lake Natron in northern Tanzania because its history has been intimately associated with neighbouring Lake Magadi, and we mention Chew Bahir in Ethiopia because that lake at times overflowed into Lake Turkana. We have visited most of the Kenyan lakes that we discuss, including many of the smaller lakes and wetlands, and have examined many ancient lacustrine successions that have been described in outcrop or core. We include, but do not always highlight, many unpublished results. We have tried to be inclusive but have been unable to reference all relevant papers on all topics because of access, both online and physical, confidentiality (unpublished government and company reports), and space. For this, we apologise. The relevant literature is growing, now almost exponentially, but this is good. Many new journals are East African with Open Access.

We hope that this volume will provide a useful introduction and general background for those beginning research on the modern Kenya Rift lakes and their precursors, especially graduate students, and for those already familiar with some of the lakes but expanding their areas or breadth of interest. Most of all, we hope that readers will be as fascinated by the Kenya Rift lakes as we have been for … now approaching … almost 50 years. They are special.

San Rafael, Segovia, Spain — Robin W. Renaut
Kowloon Tong, Hong Kong — Richard Bernhart Owen
May 2023

Acknowledgements

Many people have helped us in many different ways over many years.

We owe so much to two Kenyans in particular and their support teams. For more than 30 years, William Kimosop, Senior Warden of the Northern Kenya Rift, has given us invaluable help at Lake Bogoria National Reserve and at Lake Baringo. His knowledge of the region, its history, its wildlife, the lakes, and his enthusiastic support for what we were trying to achieve made our efforts so much easier. Similarly, John Ego, Exploration Manager at the National Oil Corporation of Kenya (and one of Robin's former graduate students), has helped both of us with logistics and field research at Baringo and Magadi. We are extremely grateful to both of them.

The late Jean-Jacques Tiercelin was our close friend and colleague from the late 1970s. Over four decades, we worked together to try to make sense of the sedimentology and history of Lakes Bogoria and Baringo, and later (2013) at Magadi. We miss him deeply as do many others.

We are also deeply indebted to Rick Potts and his Smithsonian Institution field-studies support team at Olorgesailie, and especially Kay Behrensmeyer and Al Deino for their knowledgeable guidance on sedimentation and chronological issues. They provided both comfort and excellent meals in the southern Kenya Rift, as well as wide-ranging and stimulating conversations over many years.

Gail Ashley (Rutgers University) enthusiastically showed us the importance of spring-fed wetlands in Kenya and at Olduvai from many perspectives, including for our hominin ancestors and other mammals. We thank her for putting up with working with the "terrible two" for such a long time (although we think she actually enjoyed most of it despite our reticence to break for lunch).

Rob Crossley, when a PhD student, was one of the pioneering geological mappers in the southern Kenya Rift and worked closely with Bernie when he taught at the University of Malawi. His knowledge of the southern Kenya Rift, and of the Nguruman area in particular, has assisted us in our research efforts in the Magadi region. Martin Pickford similarly played an important role in the early part of our work, both in Kenya and in London. In particular, he guided us on our initial explorations of the Baringo District and the diverse sedimentary sequences exposed in the Tugen Hills.

More recently, Chris Campisano, Andy Cohen, Tim Lowenstein, Annett Junginger, Kennie Leet, Nathan Rabideaux, Emma McNulty, Anthony Mbuthia, and other members of the Hominin Sites and Paleolakes Drilling Project (HSPDP) enabled us to do things we could have only dreamt about 40 years ago. Before HSPDP (2014), our efforts were intense but usually at a local scale. We now acknowledge that such large projects can make an enormous difference in understanding the sedimentology, tectonics, and palaeoclimate of rift lakes. We especially thank Andy for including us and leading HSPDP with such good humour and skill.

Many others helped us in the field, in the laboratory, and with information. We cannot name everyone, but they include Luis Buatois, Joel Casanova, Dan Deocampo, Gijs de Cort, René Dommain, Steve Driese, Michele Goman, Paul Griffiths, Jack Harris, Richard Hay, Andrew Hill, Vicky Hover, Glynn Isaac, Brian Jones, Michael Kimeli, Lothar Krienitz, Claudine Le Mut-Tiercelin, Caroline Le Turdu, Gabriela Mángano, Dan Olago, Steven Rucina, Michael Schagerl, Michael Talbot, Corinne Tarits, Annie Vincens, and Jimmy and Gill Young.

We also thank our former graduate students, who did their thesis research in Kenya, especially Jenni Scott and Veronica Muiruri, from whom we learned so much while and since they did their PhDs, and Ray Lee, Ginette Felske and Britni Brenna.

Peter Achammer demonstrated his helicopter skills at Suguta. We also acknowledge the late Bill French, who helped us to complete our research after Bill Bishop died suddenly.

Bill Bishop made this all possible. He accepted us as graduate students and set our careers (and subsequent lives) in motion. Although Bill died in February 1977, he inspired us (and others) to continue research in Kenya for four more decades, and answer some of the questions he originally posed in 1975–1976. We think that we have answered some … but not all! We also thank Sheila Bishop for her long support.

The funding agencies that helped us at various times include the Natural Environment Research Council and the Royal Society (UK), the Natural Sciences and Engineering Research Council (NSERC Canada), and the Hong Kong Research Council. The HSPDP drilling in 2014 was funded by the International Continental Scientific Drilling Program (ICDP) and National Science Foundation (NSF, USA) to the HSPDP Team. Local Maasai communities and Tata Chemicals Magadi provided field support at Magadi, and the local communities at Lake Bogoria and Lake Baringo gave us support over several decades.

Permission to work in Kenya on various projects was kindly granted by the National Commission for Science, Technology and Innovation (NACOSTI), the Kenya Ministry of Petroleum and Mining, the National Environmental Management Authority of Kenya (NEMA), and their precursors, notably the Office of the President, Government of Kenya.

Lastly, but foremost, we thank our families: Linda, Barbara, Holly, Duncan, Richard, and Christopher for their patience while we were writing this book.

Contents

About the Authors

Robin W. Renaut is Emeritus Professor in the Department of Geological Sciences at the University of Saskatchewan. He was born in London, UK, in May 1952 and received a BSc degree in Earth Sciences from Bedford College (University of London) in 1974, where he was instructed by Bill Bishop, Basil King, and many PhD students and postdocs (Martin Pickford, Andrew Hill, Greg Chapman, Paul Griffiths) who were then part of the East African Geological Research Unit (EAGRU). He then spent several months at Geosystems, a geoscience information company, before starting PhD research in the autumn of 1975 supervised by the late Bill Bishop at Queen Mary College (now Queen Mary University of London), where he met Bernie Owen, who was also beginning his PhD research. They began fieldwork together in the Kenya Rift in 1976. After Bill died in February 1977, Bill French, an igneous petrologist, led them through to graduation. Robin emigrated to Canada and taught sedimentology, stratigraphy, petroleum geology and related courses at the University of Saskatchewan in Saskatoon for 33 years. During that time, he maintained his interest in limnogeology developed in Kenya and did research in Kenya, Tanzania, Malawi, British Columbia, Bolivia, and Greece. He expanded his early interests in hydrothermal systems acquired at Lake Bogoria and worked on hot spring deposits in New Zealand (with Brian Jones and Michael Rosen), Iceland, western Canada, Bolivia, and Chile. He has co-edited three books: two SEPM Special Publications (saline lakes, rift sedimentation) and one Geological Society of London Special Publication (rift sedimentology). He retired recently, but in name only.

Richard Bernhart Owen is Emeritus Professor in the Department of Geography at Hong Kong Baptist University. Bernie was born in Bangor hospital in North Wales on 28 December 1953, but was raised in St. Helens, near Liverpool. He was awarded a Geology BSc Degree by Sheffield University in 1975 and went straight on to do a PhD at Queen Mary College (now Queen Mary University of London) under Professor Bill Bishop, where he met Robin Renaut as a fellow postgraduate student. Subsequently, he spent several months learning about diatoms and, with Robin, mapping the Suguta Valley (Kenya Rift Valley) using aerial photographs prior to their first field season in the summer of 1976. Unfortunately, permits for the Suguta were refused at the last minute and Bernie ended up reconnoitering diatom-rich sediments in different parts of the Kenya Rift. Bill Bishop, their supervisor, died in February 1977, and Bill French (with no relevant experience) kindly took over and guided them, with Bernie gaining his PhD in 1981. Bernie moved to Malawi as a University of Malawi lecturer and taught a broad range of geology courses, including unfamiliar topics. His research focussed on the recent sediments in Lake Malawi and other lakes in the country. After 8 years, Bernie and family (Barbara and two young children) left Malawi in order to seek another post, which resulted in them moving to Hong Kong in January 1991. He then worked on marine sediments for a number of years, but his African interests led him to return to Kenya in the summer of 2002, with one or two trips per year from then until the present. He also occasionally took part in geological expeditions to other places (Canada, Greece, Iceland, Thailand, Sri Lanka, and New Zealand) to carry out a variety of limnological and/or hot spring studies. Bernie also edited a book on seismicity in eastern Asia and has authored four books on the geology and landscapes of Hong Kong.

Part I
Background to the Kenya Rift Lakes

Chapter 1
Introduction: About This Book

1.1 The Kenya Rift Lakes

Several books and edited volumes have reviewed one or more of the Kenya Rift lakes from a biological or ecological perspective, or both (Beadle 1974, 1981; Johnson and Odada 1996; Lehman 1998; Harper et al. 2003; Awange and Ong'ang'a 2006; Schagerl 2016; El-Sheekh and Elsaied 2023). A few have examined the geology and tectonics of individual or multiple lake basins (Bishop and Clark 1967; Baker et al. 1972; Coppens et al. 1976; Bishop 1978; Frostick et al. 1986; Morley 1999; Renaut and Ashley 2002), but none has approached the Kenyan lakes specifically from a geological (mainly sedimentological and palaeoecological) perspective. Our goal for this book is to provide a general background to the modern Kenya Rift lakes and their precursors back to the Miocene, and to provide a broad framework for future research. We have tried to include most of the important past studies, covering the last 150 years, but do not claim to have included all previous research.

The lakes of the Kenya Rift and their former extensions into Ethiopia (Chew Bahir) and Tanzania (Lake Natron) are highly diverse physically, chemically, and ecologically (Fig. 1.1). Table 1.1 summarises some of the main characteristics of the Kenyan water bodies that illustrate this diversity. Lake Victoria (~169,685 km^2) lies in a tectonic depression between the eastern and western branches of the East African Rift System with the Winam Gulf extending into the Nyanza (Kavirondo) Rift, about 140 km to the west of the main Kenya Rift. The largest lake within the main Kenya Rift is Lake Turkana, which covered 7430 km^2 in December 2020, an area almost 11 times larger than the next nine water bodies combined. These smaller lakes ranged in area between 11 (Solai) and ~200 (Baringo) km^2 in that same month, but all the main lakes vary in area frequently because of changes in annual and interannual precipitation and changing evaporation rates in their respective catchments. Water depths also differ considerably, from more than 120 m (Lake Turkana) to less than 1 m (Lake Magadi). Many shallow lakes and swamps desiccate completely during periods of drought.

R. W. Renaut, R. B. Owen, *The Kenya Rift Lakes: Modern and Ancient*,
Syntheses in Limnogeology, https://doi.org/10.1007/978-3-642-25055-2_1

Fig. 1.1 The Kenya Rift lakes, locations and appearance

All the Kenya Rift lakes expanded during the late Pleistocene–Early Holocene, now called the African Humid Period (AHP), when conditions became generally wetter. Some merged or overflowed (e.g. Palaeolake Suguta; Lakes Nakuru and Elmenteita) while others switched from closed hydrology (endorheic) to open-basin lakes (e.g. Turkana, Baringo, Bogoria), only to reverse when the climatic conditions became drier during the later Holocene. Such changes have been common, but tectonics has also strongly influenced, and at times controlled, their evolution (Owen et al. 2018).

All lake waters in the Kenya Rift are alkaline. Modern lakes Naivasha, Baringo and Ol' Bolossat have fresh waters, supporting fish, crocodiles, hippos and associated fauna and flora. In contrast, Lake Turkana and Lake Solai have been brackish during the past few decades. Lakes Logipi, Nakuru and Elmenteita are saline but currently do not precipitate lacustrine salts. Nasikie Engida and Lake Magadi are often highly saline and precipitate evaporites. Lake Bogoria varies between dilute and hypersaline. Lake Natron occasionally precipitates trona, but the salts are generally not preserved. These varied conditions support contrasting phytoplankton and zooplankton, reptiles, mammals and birds. Flamingos, for example, move between

Table 1.1 Major physical and chemical parameters of the Kenya Rift lakes

Lake	Basin type	Area (km^2)	Perimeter (km)	Area/perimeter	Max depth/s (m)	Conductivity – μS cm^{-1}/ or (TDS in ppm)	pH range
Victoria	Inter-rift depression with extension (Winam Gulf) into Nyanza Rift	69,685	3670	19.0	69[11]	97–145[8, 9]	6.4–9.8[10]
Turkana	Coalesced border-faulted asymmetric rift grabens. Volcano-dammed to south	7430	730	10.2	109–125[3, 12, 13]	2763–3190[1, 3] (2279–2536)[2]	8.7–9.5[1, 7]
Logipi	Axial rift graben. Volcano-dammed to north	51	30	1.7	5	~5000–17,000[14, 15]	9.5–9.6[15]
Baringo	Volcanic-dammed rift graben	199	85	2.3	~7	(458–1383)[4]	6.7–8.98[4]
Bogoria	Border-faulted asymmetric graben. Dammed by alluvium to north	42	72	0.6	11.5[18]	Mixolimnion – >50,000[18] Monimolimnion – 90,000[18]	9.3–10.2[18]
Solai	Border faulted rift-marginal graben	11	15	0.7	>8.5[17]	776–2398[16]	8.1–9.0[16]
Ol' Bolossat	Border faulted rift-marginal graben	33	41	0.8	1.83[20]	150–418 (174.9–192.6)[19]	6.7–8.3[19]
Nakuru	Axial rift graben. Volcano-dammed to north	69	36	1.9	4.5[6]	27,600–54,000[6, 22]	9.8–10.3[6, 21]

(continued)

Table 1.1 (continued)

Lake	Basin type	Area (km^2)	Perimeter (km)	Area/ perimeter	Max depth/s (m)	Conductivity – µS cm^{-1}/ or (TDS in ppm)	pH range
Elmenteita	Axial rift graben. Volcano-dammed to south	22	35	0.6	3.1[22]	39,000[21]	10–10.1[21, 22]
Naivasha	Axial rift graben. Volcano-dammed to south	163	74	2.2	16[24]	74–2480[5, 23, 24]	8.01–8.98[5, 24]
Nasikie Engida	Axial rift graben	10.5	18	0.6	1.6[26]	207,000[26] (30,000–270,000)[26]	9.21–9.9[25]
Magadi	Coalesced axial rift grabens	91	121	0.75	~0–2	(122,000–313,000)[27]	9.65–10.9[27]

Physical data are based on Google Earth and reflect a period of high lake levels in December 2020
1: Beadle (1932); 2: Yuretich and Cerling (1983); 3: Hopson and Hopson (1982); 4: Tiercelin (1981); 5: Mugo (2010); 6: Raini (2007); 7: Olago (1992); 8: Duke (1924); 9: Akiyama et al. (1977); 10: Mwirigi et al. (2005); 11: Johnson and Odada (1996); 12: Yuretich (1979); 13: Källqvist et al. (1988); 14: Junginger and Trauth (2013); 15: Castanier et al. (1993); 16: de Bock et al. (2009); 17: Herrnegger et al. (2021); 18: Renaut and Tiercelin (1994); 19: Karuku and Mugo (2019); 20: NEMA (2012); 21: Oduor and Schagerl (2007); 22: Melack et al. (1982); 23: Njenga (2004); 24: Ndungu et al. (2015); 25: Renaut et al. (2020); 26: de Cort et al. (2019); 27: Jones et al. (1977)

the highly saline lakes seeking suitable food sources, which vary with changing water chemistry as the lakes expand and contract.

Geologically, the modern lakes are the successors of a series of Neogene palaeolakes. Both modern and ancient water bodies are important for many reasons. Their sediments preserve detailed records of past environmental change and also provide models for interpreting ancient lacustrine rift basins and saline, alkaline palaeolakes in other parts of the world. Biologically, the modern lakes are homes for a rich and diverse fauna and flora, as were their predecessors. Most modern lakes are highly productive and home to endemic fish and diverse and abundant birds, as recognised by many areas that have been given Ramsar and UN World Heritage status. They also have palaeoanthropological significance with their ancient deposits associated with important hominin and archaeological sites. Despite their international value, the lakes have been heavily impacted by population growth and related impacts from agriculture, industrial development, dam construction and hydrological change. Consequently, the ecological status of the modern lakes is under threat, and many have already experienced rapid change during the last few decades, although much remains that should be preserved. Many lakes have been unusually high since

2010–11, flooding marginal lands and disrupting livelihoods, and are experiencing physical and ecological changes (Government of Kenya 2021).

In **Part I** of the book, we provide a broad background with general information that is needed to understand subsequent sections. This chapter (1) introduces the rift lakes and structure of this book. Chapter 2 presents a brief history of limnological and sedimentological research undertaken since the nineteenth century. Chapter 3 outlines the geology of the Kenya Rift, placing the modern and ancient lakes in a broader physical context. This includes summaries of the origins of the Kenya Rift and the East African Rift System. The chapter examines the structural and volcanic geology and emphasises the importance of tectonism in the formation of sedimentary basins and the long-term palaeogeographical development of the rift.

Chapter 4 focuses on modern environmental conditions and includes explanations of the climate system and modern weather patterns in the region. In addition, the chapter explores aspects of the river drainage, hydrology and hydrogeology, including the important geothermal systems. The importance of weathering and sediment production is also noted as this partly controls the unusual chemistry of the various lakes. Subsequent portions discuss the nature of soils, vegetation, wildlife and the importance of geothermal springs and meteoric waters.

Chapter 5, the final chapter in Part I, provides a limnological background for understanding the physical, chemical, and biological processes that occur in the Kenya Rift lakes. These include, for example, the importance of physical mixing, stratification, currents, and waves. The chapter also examines the hydrochemistry of lakes in terms of evaporative concentration, solutes and particulate sources, major ions and salinity as well as chemical and biochemical processes. Depositional models are explored, noting controlling factors that influence processes and facies in deltas, littoral zones and pelagic regions.

Part II presents the physical and chemical limnology, ecology, and sedimentation of the modern lakes. Chapters 6 and 7 provide details for the northern Rift lakes (Turkana; Logipi-Suguta). Chapters 8, 9, 10, and 11 examine the major water bodies of the Central Kenya Rift (Baringo; Bogoria; Nakuru; Elmenteita; Naivasha) with details of the southern lakes (Magadi; Nasikie Engida) presented in Chap. 12, including a brief introduction to Lake Natron in Tanzania. Lake Victoria partially lies in the adjacent Nyanza (Kavirondo) Rift of western Kenya and is considered separately in Chap. 13. Chapter 14 presents information on the many smaller and lesser-known lakes (e.g. Solai, Ol' Bolossat, Kwenia, reservoirs).

Each of the main lakes is described in turn using a common format. After a broad introduction, the chapters present the geological and geomorphological setting of the relevant drainage basin, followed by descriptions of the climate and basin hydrology (including springs), vegetation and wildlife. The physical and chemical limnology are then described followed by an examination of the biology and ecology of the individual lakes. Each chapter also explains the dominant sedimentary processes active in the respective lakes and the nature of recent deposition. The chapters conclude with an exploration of the environmental and geological history of the African Humid Period (~15–5 ka) and Holocene precursor lakes from outcrop, core and other evidence, as these have important implications for the modern