ALKALINE ENVIRONMENTS AND BIODIVERSITY

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Summary

Stable alkaline conditions are caused by an unusual combination of climatic, geological, and topological conditions. Soda lakes represent the most stable high-pH environments on Earth and commonly have pH values above 11.5. These environments are characteristically associated with a low Mg^{2+}, Ca^{2+} geology together with rates of evaporation that exceed any inflow. Such environments are found in arid and semi-arid areas of tropical or subtropical rain-shadow deserts such as in North America or in the continental interiors of Asia. Other examples are found in areas of tectonic rifting such as the East African Rift Valley. Despite apparently hostile conditions, these caustic lakes are the most productive aquatic environments in the world, with productivity rates an order of magnitude greater than the mean rate for all aquatic environments on Earth. Alkaliphilic cyanobacteria drive these systems, providing fixed carbon that is utilized by a vast range of alkaliphilic aerobic and anaerobic chemo-organotrophs, notably halomonads, bacilli and clostridia methanogens. There is also active cycling of nitrogen and sulfur in the lakes, brought about by novel alkaliphilic groups.

1. Introduction

Transient alkalinity in microhabitats arising through biological activity such as ammonification or sulfate reduction is a widespread feature of heterogeneous environments such as soils. This is presumably the reason for the widespread presence of alkaliphiles in such environments that would be considered neutral or even acid on the basis of bulk pH measurements. Commercial processes such as cement manufacture,

and paper and hide processes also generate alkaline conditions because of the chemistry of the components used as part of the process. However, such environments have a relatively restricted range of alkaliphilic inhabitants, usually *Bacillus* or related species that survive from one alkaline episode until the next by producing endospores. A far more diverse population of alkaliphiles is to be found where stable, naturally occurring alkaline conditions are maintained. ,There are two kinds of such environments caused by a combination of geological, geographical and climatic conditions.

Highly alkaline Ca^{2+}-dominated groundwaters are present in various geological locations around the world. This type of alkaline groundwater has been of interest because the hydrochemical characteristics mimic the conditions in cement pore water. Concrete is a major structural component and there is a need to assess any microbial or chemical activity that might compromise long-term integrity. The chemistry of such groundwater is determined by CO_2-mediated weathering of the calcium and magnesium minerals olivine and pyroxene, which decompose as depicted in Figure 1, resulting in the release of OH^-, which generates alkaline conditions. Mg^{2+} is removed by precipitation as serpentine, leaving a $Ca(OH)_2$-dominated environment which is, in addition, highly reducing because of the release of Fe^{2+} and H_2. There are records of pH values of >11 in these low-ionic content environments and preliminary microbiological analyses have been recorded in a few instances, although culture procedures have not been attempted under the conditions pertaining at the site. As such, the low bacterial populations are reported as being similar to that in much less extreme soil and water environments.

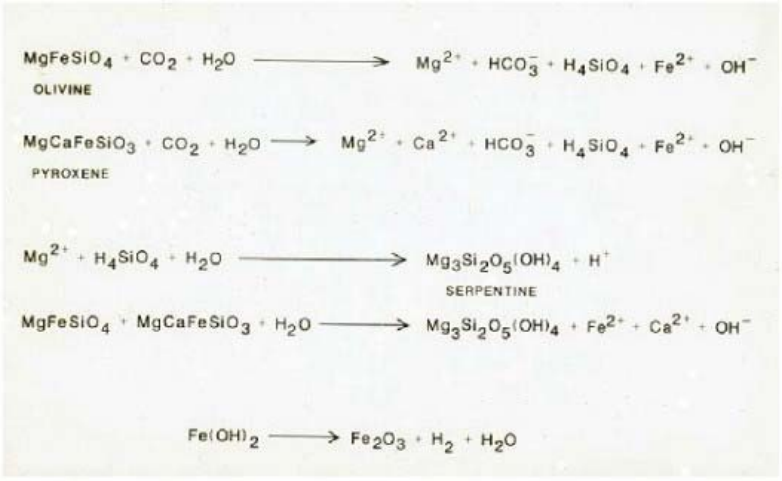

Figure 1. Scheme for the hydrogeological generation of alkalinity in Ca^{2+}-dominated groundwaters

Soda lakes and soda deserts represent the other and major type of naturally occurring highly alkaline environment, often exhibiting pH values >11.5. Such environments are widely distributed, but the more extreme examples are often relatively inaccessible. Examples are known in North America, Central America, South America, Europe, Asia (notably in Siberia, Outer Mongolia, and Tibet), throughout Africa, and in Australia (Table 1). Although highly alkaline lakes are confined to specific geographic regions, more than 80% of all inland waters, by volume, are on the alkaline side of neutrality, exhibiting a less intense form of the chemistry seen in the more concentrated and

alkaline types. Soda lakes exist throughout the geological record. One of the largest fossil soda lakes is the Green River formation in Wyoming and Utah, which is between 36 and 55 million years old. Fossil soda lakes of even greater age are implied from geological formations such as the 2.3 billion-year-old Ventersdorf formation in South Africa.

Continent	Country	Location
Africa	Libya	Lake Fezzan
	Egypt	Wadi Natrun
	Ethiopia	Lake Aranguadi, Lake Kilotes, Lake Abiata, Lake Shala, Lake Chilu, Lake Hertale, Lake Metahara
	Sudan	Dariba Lakes
	Kenya	Lake Bogoria, Lake Nakuru, Lake Elmenteita, Lake Magadi, Lake Simbi, Crater Lake (Lake Sonachi), Lake Oloidien
	Tanzania	Lake Natron, Lake Eyasi, Lake Magad, Lake Manyara, Lake Balangida, Bosotu Crater Lake, Lake Kusare, Lake Tulusia, El Kekhooito, Momela Lakes, Lake Lekandiro, Lake Reshitani, Lake Lgarya, Lake Ndutu,
	Uganda	Lake Rukwa North Lake Katwe, Lake Mahenga, Lake Kikorongo, Lake Nyamunuka,
	Chad	Lake Munyanyange, Lake Murumuli, Lake Nunyampaka Lake Bodu, Lake Rombou, Lake Dijikare, Lake Monboio, Lake Yoan,
Asia	Siberia	Kulunda Steppe, Tanatar Lakes, Karakul, Chita, Barnaul, Slavgerod, Lake Baikal region, Lake Khatyn
	Armenia	Araxes Plain Lakes
	Turkey	Lake Van, Lake Salda
	India	Lake Looner, Lake Sambhar
	China	Outer Mongolia, various “nors”; Sui-Yuan, Cha-Han-Nor and Na-Lin-Nor; Heilungkiang, Hailar and Tsitsihar; Kirin, Fu-U-Hsein and Taboos-Nor; Liao-Ning, Tao-Nan Hsein; Jehol, various soda lakes; Tibet, alkaline deserts; Chahar, Lang-Chai; Shansi, U-Tsu-Hsein; Shensi, Shen-Hsia-Hsein; Kansu, Ning-Hsia-Hsein, Qinhgai Hu
Australia		Lake Corangamite, Red Rock Lake, Lake Werowrap, Lake Chidnup
Central America	Mexico	Lake Texcoco
Europe	Hungary Former Yugoslavia	Lake Feher Pecena Slatina

North America	Canada	Manito
	USA	Alkali Valley, Albert Lake Lenore, Soap Lake, Big Soda Lake, Owens Lake, Borax Lake, Mono Lake, Searles Lake, Deep Springs, Rhodes Marsh, Harney Lake, Summer Lake, Surprise Valley, Pyramid Lake, Walker Lake, Union Pacific Lakes (Green River), Ragtown Soda Lakes
South America	Venezuela Chile	Langunilla Valley Antofagasta

Table 1. Worldwide distribution of soda lakes and soda deserts

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Biographical Sketch

Bill Grant is Professor of Environmental Microbiology at the University of Leicester, UK. He obtained his BSc and PhD in Microbiology from the University of Edinburgh, UK, and had a spell at the McArdle Laboratory for Cancer Research in Madison, Wisconsin, USA working on the cell cycle in slime molds. Since coming back to Leicester in the UK in the early 1970s he has developed a long-standing interest in microbial biodiversity in East African soda lakes and has repeatedly visited these sites since his first expedition in 1978. Other interests include the systematics of the haloarchaea (the halobacteria), originally driven by the discovery of a new group of these in an East African soda lake. He also has an interest in astrobiology, in particular, the detection of microbial signatures in ancient evaporite deposits as terrestrial analogues of extraterrestrial sites on Mars and other planets of the solar system.