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Characterization of brines and evaporites of Lake Katwe, Uganda

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ABSTRACT

Lake Katwe brines and evaporites were investigated to determine their chemical, mineralogical and morphological composition. 30 brine samples and 3 solid salt samples (evaporites) were collected from different locations of the lake deposit. Several analytical techniques were used to determine the chemical composition of the samples including Inductively Coupled Plasma–Atomic Emission Spectrometry (ICP–AES), Inductively Coupled Plasma–Sector Field Mass Spectrometry (ICP–SFMS), ion chromatography, and potentiometric titration. The mineralogical composition and morphology of the evaporites was determined using X-ray diffraction (XRD) and scanning electron microscopy (SEM), respectively. Physical parameters of the lake brines such as density, electrical conductivity, pH, and salinity were also studied. The results show that the lake brines are highly alkaline and rich in Na^+, Cl^-, CO_3^{2-}, SO_4^{2-}, and HCO_3^- with lesser amounts of K^+, Mg^{2+}, Ca^{2+}, Br^-, and F^- ions. The brines show an intermediate transition between Na–Cl and Na–HCO_3 water types. Among the trace metals, the lake brines were found to be enriched in B, I, Sr, Fe, Mo, Ba, and Mn. The solid salts are composed of halite mixed with other salts such as hanksite, burkeite and trona. It was also observed that the composition of the salts varies considerably even within the same grades.

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1. Introduction

Lake Katwe is a closed saline crater lake located on the northern side of Lake Edward within the western branch of the East African Rift system and about 15 km below the equator in western Uganda (Fig. 1). The lake lies at an elevation of 885 m, with a maximum area of 2.5 km^2, depth ranging between 0.4 and 1.6 m, and measuring 9 km in circumference The lake is the largest among the eight saline crater lakes within the Katwe-Kikorongo volcanic field. Climatic data around the lake basin indicates that the area is generally hot, dry, and semi-arid with an average precipitation of 860 mm/year. Furthermore, the evaporation rates are as high as 2160 mm/year. The relative humidity varies from 36% to 95%. Much of the rain falls during the short intense storms. There are intermittent wind regimes in the area with speeds ranging between 0 and 12 m/s mainly from the south-western direction of the lake. The ambient temperature varies from 24 °C to 38 °C. There are four distinguished climate seasons every year, namely two dry seasons from February to April and July to September and two rainy seasons from May to June and October to January. The level of the lake falls about 3 mm per day during normal hot dry weather, except when a significant part of the surface is covered by floating salt crystals Preliminary investigative studies proved that the lake contains the best salt reserves in Uganda evident in its brines and evaporite deposits (UDC, 1997). It has been estimated that there is a total of 20–30 million tonnes of crystalline salts present in Lake Katwe (Morton and Old, 1968; Dixon and Morton, 1970). The chief evaporite minerals present in the deposits are: trona, burkeite, halite, and hanksite (Morton, 1973). Geologically, the salt lake lies on the floor of an explosion crater formed in tuffs with about 230 m of rock separating Lake Edward from the crater at the closest point. The explosion crater ejected pyroclastics, tuffs with abundant granite and gneissic rocks from the basement which dominate the area. The volcanic rocks are mainly composed of pyroclastics and ultramafic xenoliths which are deposited on the extensive pleistocene lacustrine and fluvial Kaiso beds and in some places directly on precambrian rocks (Morton and Old, 1968; Dixon and Morton, 1970).

Lake Katwe has attracted attention over the past century and a number of hypotheses have been proposed to explain its salinity. The lake is fed by numerous springs around its shores which have a total flow of about 600 m^3 per day (Dixon and Morton, 1970). These springs are saline or brackish and bring about 1500 tons of salts per year to the lake. It is likely that they are the main source of salts in the lake. As the lake has no outlet, the water level in the lake is determined by the hydrological balance between the water

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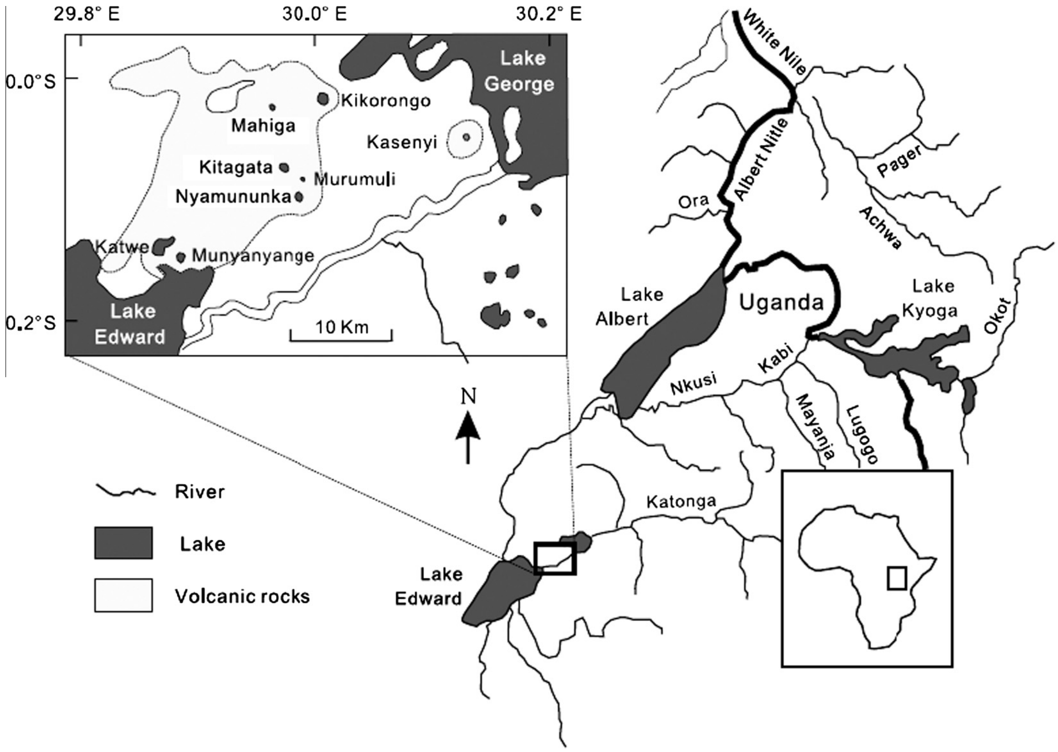

Fig. 1. Location of Lake Katwe and the other saline crater lakes within the Katwe-Kikorongo volcanic field, after Ma et al. (2011).

inflow from the springs and the intensive evaporation due to the aridity of the local climate. Earlier works have suggested that the salinity of the lake and the other closed saline lakes within the region is derived mainly by evaporative concentration of mineral spring waters (Arad and Morton, 1969). The saline spring waters filled the crater after pleistocene vulcanism. Other suggestions have also indicated that salt has been leached out of the surrounding tuffs by water percolating from nearby Lake Edward into Katwe crater which lies about 30 m below the fresh lake level (Barnes, 1961).

In Uganda and the Lake Victoria region, Lake Katwe is of particular interest as for many years, it has been the main source of salt extraction and it presents a promising deposit for future intensification and commercial development. Presently, salt is extracted and processed at the lake using traditional solar evaporation techniques. This activity is done mainly in the dry season. There is no purification of the salt as the chemistry of the deposit prevents this from being done by simple physical sustainable methods. Previous studies on the lake deposit have addressed the lake's geological setting, chemistry of the mineral springs, and major elemental composition of the lake waters (Arad and Morton, 1969); feasibility of commercial production through estimation of the salt reserves (Morton, 1973); mineralogical composition of the evaporites (Nielsen, 1999), and devising techniques and concepts of improving salt mining and extraction from the lake resources (Kirabira et al., 2013).

Although the lake has been studied for the last fifty years, there is more information needed to closely define the possible range in the major and trace elemental composition of the lake waters and evaporites. Most of the data reported is based on single or few irregularly collected samples from the lake deposit as reported elsewhere (Kirabira et al., 2013). The primary goal of the present study is to characterize the brines and precipitated evaporites in the Katwe salt lake. Characterization involves physical and chemical composition, mineralogical investigation and morphological analyses. The study will lead to a better understanding of the nature of the salt lake raw materials in view of their economic significance to many people who extract salt both for domestic consumption, animal feed suppliments, fertilzers, and industrial uses susch as leather tanning and textile production.

2. Materials and methods

To account for the seasonal changes in the lake brines, field sampling was undertaken twice, first in January 2012, towards the end of the rainy season, and later in March 2012, during the dry season. Brine samples were collected in plastic bottles and stored at room temperature prior to laboratory analysis. In order to obtain representative samples that define the overall composition of the lake brines, eleven sampling locations, code named A1–A11, were selected. Brine samples were also taken randomly from four salt pans around the lake, namely Nambawu, Kakindo, Kakukuru 1 and Kakukuru 2. The sampling locations within the lake were tracked using a Geographical Positioning System (GPS) (Garmin Oregon 550t). A total of 30 brine samples were collected for chemical analyses. The location of the sampling points is shown in Fig. 2. Solid salt grades produced at the lake were also collected for analyses. The salts are classified into grades based on the visible impurities and were collected as three sets. The first set involved grade 1 salt (G-1) which is high quality crystallized salt extracted from the clean salt pans during the long dry season. It is primarily used for human consumption. The second set involved grade 2 salt (G-2) which is extracted from the mud-lined salt pans towards the end of the dry season. The third set involved grade 3 salt or rock salt (G-3) which is extracted manually from the lake bed.

At each location, the sampling time, the depth of sampling, the GPS coordinates, and elevation were recorded. Also, *in situ* measurements of sample pH, and temperature were done using an Electrode probe field meter (HANNA instruments HI 98127, Woonsocket, RI, USA) and a rotary digital thermometer (Omega Engineering TPD36, Delaware, NJ, USA) respectively.

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