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GEOCHEMICAL, MINERALOGICAL AND ISOTOPIC INVESTIGATION OF INLE LAKE (SOUTHERN SHAN STATE, MYANMAR): PRELIMINARY RESULTS

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Abstract: This paper reports some preliminary results obtained on waters and sediments from the Inle Lake. Carbonate equilibria dominate the lake water hydrochemistry. During the summer season, strong evaporation affects the water body, coupled to intense photosynthetic activity. These processes favour authigenic carbonate precipitation, as indicated by the high calcite content detected in the lake sediments. Isotopes of the water molecule indicate a residence time shorter than one year. The short residence time and calcite precipitation likely prevent the accumulation of anthropogenic contaminants and nutrients within the lake.

1. INTRODUCTION

Inle Lake, situated in Naung Shwe Township, Southern Shan State (20°27'–20°40' N, 96°52'–96°57' E, 870 m a.s.l.) is the second largest and the most important lake in Myanmar. Its average length is 18 km and the width is 11 km [1]. The Inle Lake region is characterized by a large, flat valley running N to S, surrounded by mountain ranges. The basin is located in the Shan Plateau, mainly constituted by limestone, about 50 km E of the tectonically active Sagaing fault and faults along the Shan scarp [2]. The lake is fed by several streams, the main contributor being the Nanlit Chaung, which flows from N to S with headwaters 16 km north of the inlet to the lake. The lake outlet flows to the S, entering the Thanlwin River [3]. The drainage area and storage capacity of the lake have been estimated at 5.612 km^2 and 3.5 x 10^7 m^3, respectively, while annual inflow and water residence time are estimated as 1.1 x 10^8 m^3 $year^{-1}$ and 0.32 year [4, 5]. The climate in the lake area is tropical monsoon with three seasons: hot dry, rainy and winter season. Approximately 70% of the annual rainfall occurs during the months of July, August, and September: the mean annual rainfall is 920 mm, generally occurring on 70–75 individual days. Mean air temperature near the lake ranges from 16.9°C to 31.5°C. The depth of the lake fluctuates with the seasons ranging from four meters in summer and seven meters in the rainy season [3].

The lake is a vital part of the broader ecosystem and economy of Shan State, providing many goods and services to its surrounding communities. Over 200 villages surround the lake and inhabit the immediate watershed. The lake is a main water resource for Law Pi Ta hydroelectricity power plant, a major tourist attraction upon which many in the local economy rely, a provider of agricultural products, and a habitat for rich biodiversity and traditional culture.

Inle lake is severely threatened by anthropogenic activities on the lake sides and in its drainage basin, causing an increase in sedimentation, with a consequent shrinking of the open water surface, and a change in water quality [6, 7]. The objectives of this study are to investigate present day water dynamics and sedimentation processes, to reconstruct its environmental evolution and assess the anthropogenic impact.

2. METHODS

During the one-year sampling period, water and sediment samples were collected from 5 study sites, selected based on their environmental setting (Table 1 and Figure 1).

Table 1. Sampling stations.

Station	Environmental setting	Characteristics
1	Natural biodiversity fishes and birds	Wildlife Sanctuary
2	Input from the main inflow	Inflow Stream
3	Water at the center of lake	Wide View Area
4	Influence of agrochemicals and anthropogenic pollution	Floating Cultivation Area
5	Output from the lake	Outflow Stream

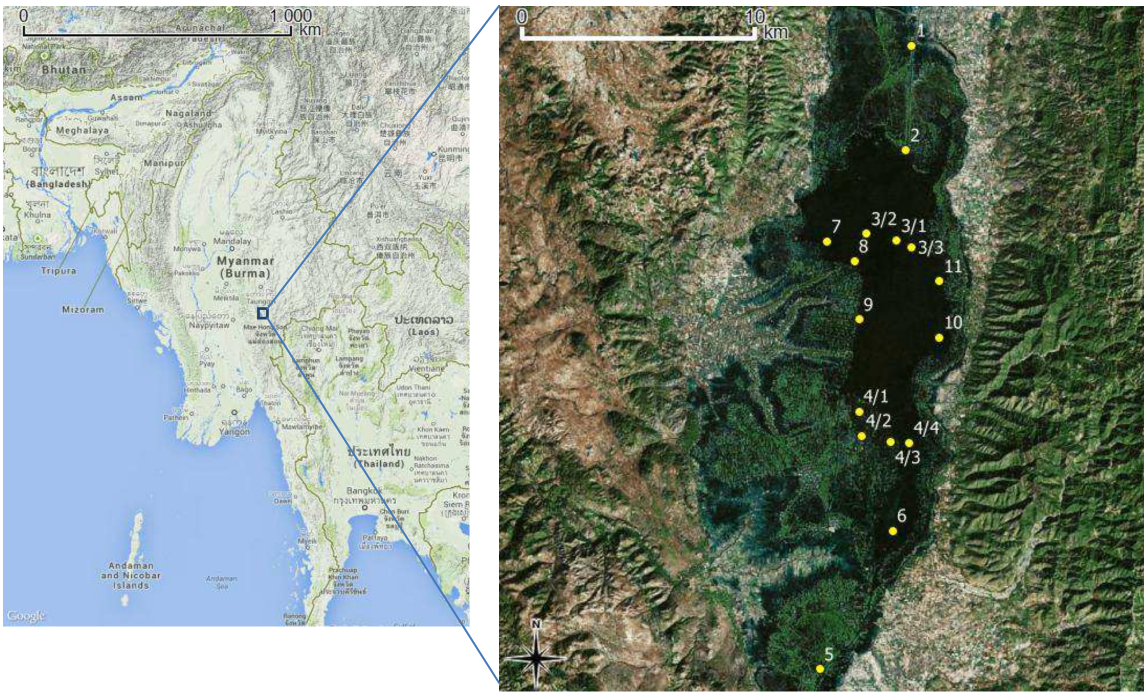

Figure 1. Location of the Inle Lake in Myanmar with water and sediment collection stations.

Sampling campaigns were performed in August, September and October 2013 (monsoon), in November and February 2014 (winter), and in May 2014 (summer) for hydrochemical and isotopic monitoring. Nine sediment cores were also collected in October 2013. A more detailed sampling campaign was carried out in March 2014 (summer), increasing the number of sampling stations (Figure 1) and collecting surface and bottom water, together with dredged bottom sediment, and sediment cores. During this campaign, water depth, surface temperature, pH, Eh, and alkalinity were measured in the field. In the laboratory, all water samples were (re)analyzed for pH, electrical conductivity and alkalinity (by titration). The major ion contents were determined by ion chromatography. Stable isotopes of the water molecule were analyzed by WS-CRDS. Water samples from the March 2014 campaign were also analyzed for $\delta^{13}C_{DIC}$ using the gas evolution technique [8]. Sediment samples were dried at room temperature for 2-3 days. Major shells were eliminated by manual picking and the sediment was ground to fine powder in an agate mortar. The mineralogical composition of sediment samples were measured by XRD powder diffraction.

3. RESULTS

Water stable isotopes range from -8.23 to -0.76‰ in $\delta^{18}O$ and from -63.55 to -18.06‰ in $\delta^{2}H$. In the rainy season, the isotopic compositions align parallel to the Global Meteoric Water Line (GMWL), but with a lower d-excess (Figure 2). At the end of winter, but mostly during the summer season, with rising temperatures, the lake water is subject to strong evaporation under low relative humidity conditions. In all sampling campaigns, the most enriched isotopic value is displayed by Station 3 at the center of the lake. Also, at the onset of the rainy season, this station maintains an enriched isotopic composition, whereas at the end of the rainy season it displays a composition in agreement with that of precipitation. This observation indicates that, during the rainy season, the lake water is fully flushed by the inflow water, and therefore the residence time is < 1 year. As a reference, the isotopic composition of precipitation in Yangon (retrieved from the Global Network of Isotopes in Precipitation - GNIP database) is also shown in Figure 2.

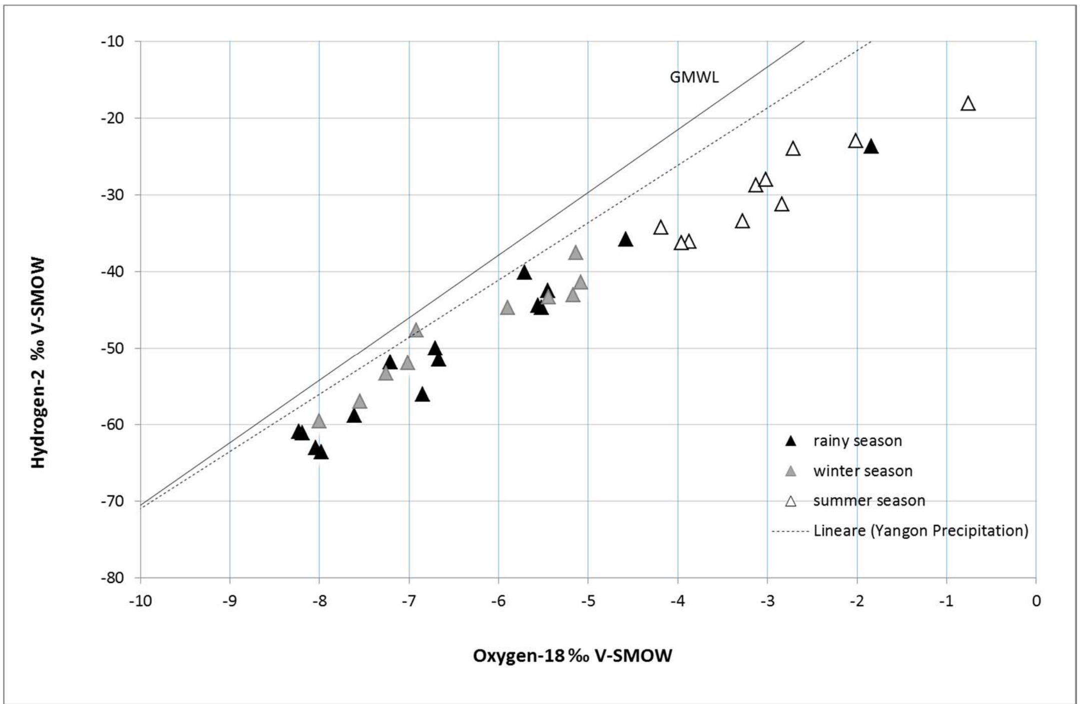

Figure 2. Stable isotope composition of water samples collected during one hydrological year, the GMWL and the regression line for Yangon precipitation data (GNIP database).

Lake waters are characterized by relatively low conductivities (range 257 to 486 µS/cm during the annual monitoring, with higher conductivities characterizing samples from the summer season), neutral to alkaline pH (range 6.51 to 8.37) and oxidizing conditions (range 122 to 250 mV). The most abundant cation is calcium, followed by magnesium, sodium and potassium, whereas bicarbonate is the most abundant anion, followed by chloride, sulphate and carbonate. Therefore carbonate equilibria dominate the lake water hydrochemistry.

The isotopic composition of dissolved carbonates ($\delta^{13}C_{DIC}$), measured during the March 2014 campaign, ranges from -7.74 to -1.86‰ PDB, with the most depleted values characterizing inflow water and the most enriched values recorded in open lake water. Depleted DIC could derive from the dissolution of soil CO_2 in areas dominated by C4 vegetation, while in open lake waters, DIC could be enriched as a result of photosynthetic activity.

In the bulk sediment, the most abundant mineral is calcite, followed by quartz, mica/illite, kaolinite, aragonite and traces of dolomite. The clay fraction is mostly composed by kaolinite with lower mica and chlorite, and traces of smectite. Calcite is not evenly distributed in the lake area: samples collected at the inflow and outflow show a percentage of about 50%, rising up to 90% in samples collected within the lake. This observation suggests that authigenic calcite precipitation could significantly contribute to sedimentation.

Preliminary isotope data obtained on sediment calcite range from -1.34 to +4.67‰ in $\delta^{13}C$. Based on $\delta^{13}C_{DIC}$, the more depleted values could correspond to authigenic calcite precipitated from open lake waters, whereas enriched values could correspond to detrital calcite.

4. CONCLUSIONS

Preliminary results indicate that carbonate equilibria dominate the lake water hydrochemistry. During the summer season, strong evaporation affects the water body. The increase in temperature, coupled to intense photosynthetic activity, induces authigenic carbonate precipitation, as testified by the high calcite content detected in the sediments. Isotopes of the water molecule indicate a residence time shorter than one year. The relatively short residence time and calcite precipitation likely prevent the accumulation of anthropogenic contaminants and nutrients within the lake. The characterization of sediment core samples will allow for the reconstruction of the environmental evolution in time and assess the anthropogenic impact on this valuable ecosystem.

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