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Salinity Model Inferred from Two Shallow Cores at Sambhar Salt Lake, Rajasthan

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Abstract: The Sambhar lake of central Rajasthan, located between Ajmer and Jaipur, is a hypersaline lake. The present study focuses on the mineralogy of the lacustrine sediments of this region. X-ray diffraction patterns of shallow auger hole samples show a broad pattern of fluctuation in vertical profiles. It is apparent that rock weathering in the catchment area supplies a flux of clastic minerals like quartz, feldspar and mica during the wet period. This is followed by an evaporite sequence of carbonate-sulfate-chloride in dry climate. Thus, an abundance of calcite indicates the beginning of evaporation, while later stages are characterized by the dominance of thenardite and finally of halite.

Keywords: Sedimentology, Sediment geochemistry, Clay minerals, Evaporites, Saline lake.

INTRODUCTION

Sambhar is the largest inland saline lake of India covering an area of approximately 225 sq. km in central Rajasthan (Fig. 1). It is a rather special lake not only because of its geological importance but also because of its peculiar physical and chemical characteristics. The waters of the Sambhar lake have been used for centuries to make salt. However, the origin of salt has been debated for a long time. Recently, Biswas et al. (1975) and Bhattacharya et al. (1975) presented geochemical data on the Sambhar lake brine and have reviewed the current theories of origin of salinity of the lake. Ramesh et al. (1993) have carried out limited isotopic analysis of waters from Didwana, Sambhar and Kuchaman lakes of Rajasthan and hypothesized that the lake water is meteoric (non-marine) and the salt in the lake water may be locally derived from the weathering of rocks. A few radiocarbon determinations have also been made of the lacustrine deposits of Sambhar by Singh et al. (1972) in conjunction with stratigraphic and palynological investigations. Wasson et al. (1984) carried out a study on the Didwana lake, about 64 km northwest of Sambhar lake, highlighting the geochemical history of the lake interpreted through the lake sediments. Sundaram and Pareek (1995) outlined the major fluvial and lacustrine facies in the Sambhar lake region using borehole data and provided interesting observations on depositional environments. A detailed geochemical model based on evaporation-precipitation sequence was tested at Sambhar lake by Yadav (1997). Roy (1999) has reviewed the physical evolution of saline lakes of Rajasthan and has reiterated that the Sambhar lake may have evolved as a pull-apart structural depression due to strike-slip faulting along curvilinear planes as suggested originally by Sinha-Roy (1986). The present paper focuses on the sediment mineralogy of shallow cores from the Sambhar lake with a view to proposing a preliminary model for chemical evolution of the lake.

STUDY AREA AND METHODS

Located about 80 km northwest of Jaipur in central Rajasthan, Sambhar is a shallow lake, reaching only about 3m at its deepest, with an

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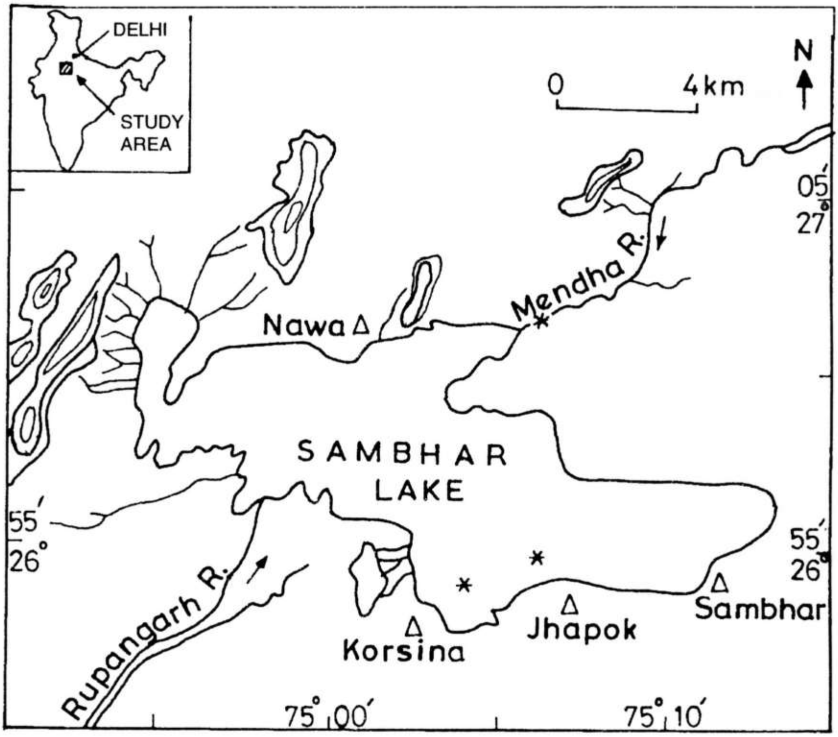

Fig.1. Sambhar lake and its surroundings; some important localities (Δ) and sampling sites (*) are marked.

average depth not exceeding 0.61 m. The maximum length of the lake basin is 22.5 km, while the width ranges from 3.2 km to 11.2 km. The lake bed (360 m above sea level) is almost flat, with a slope of less than 10 cm per km. (Brijgopal and Sharma, 1994). The area covered by the lake is spread over a transitional climatic zone with arid climate at the west and a semi-arid climatic zone towards the east. The climate of the area is influenced mainly by the monsoon and the physiography of the area i.e. the Aravalli range. The average annual precipitation over this region ranges from 550 mm to 650 mm, while the temperature averages around 23°C, with a maximum of 45°C (Sharma, 1990).

Sambhar lake is situated on the eastern flank of the Aravalli mountains, which is in turn dissected by a number of windgaps. The lake basin is on a stretch of flat sand sheet concealing the underlying structural and lithological features. The surrounding uplands are made of rocks of Delhi Supergroup consisting of jointed and foliated micaceous quartzites, which have prominent outcrops in the Govindi-Nawa area to the north of the lake. Nodules of limestone/marble with underlying mica schist form the basement below a thick layer of sand, which is overlain by a zone of saliferous silt (Brijgopal and Sharma, 1994).

Sambhar lake is fed by two major rivers namely, Mendha and Rupangarh, flowing from NNE and SSW directions respectively. Many other small streams debouch from the Aravalli hills and then disappear in the aeolian sand cover. The entire drainage system of this area is structurally controlled, as suggested by parallel drainage, lineament controlled river captures, inversion of slopes and consequent inversion in drainage direction, and anomalous terracing in adjacent rivers. East of the main Aravalli axis, all paleochannels belonging to Mendha river show the initial dominance of

NE-SW lineaments and subsequent superposition of N-S courses through river capture.

Sediment samples were collected by hand augering upto about 1.6m depth from the Mendha river bed and at two locations namely, Jhapok and Korsina on the dry lake bed (Fig.1). Sample of a thin salt incrustation formed on the dry riverbed was collected separately.

RESULTS AND DISCUSSION

XRD determination of the mineralogy of lake sediments collected from Jhapok indicated a depth-wise variation (Fig.2). The sediments show the dominance of quartz (3.3Å) along with illite (10Å), kaolinite (7.1Å), smectite (14.95Å) and variable amounts of mixed layer clays (11.13Å). The presence of smectite was confirmed by glycol treatment. The amount of smectite (X-ray peak height) is maximum around 100 cm. Around this depth, the saline minerals indicate a rapid evaporation phase. It appears, therefore, that apart from detrital origin, smectite also forms through evaporation. Sediment samples from Korsina also show similar assemblage of clay minerals, although the smectite peaks in X-ray patterns are relatively broad and poorly defined.

During the progressive evaporation of water in a saline lake, the sequence of minerals precipitated follows the chemical divides proposed by Eugster and Hardie (1978). The first precipitate in most cases is $CaCO_3$ (calcite). Subsequently, the relative concentration of Ca, Mg, HCO_3, SO_4 and Cl control the succession of sulphates, Mg-silicates and finally chlorides (Fig.3). For example, if Ca is less than HCO_3^- alkalinity, precipitation of calcite removes all Ca. Next, all Mg is removed by formation of Mg-clay, e.g. smectite, and the water evolves into a Na-CO_3-SO_4-Cl brine as found in Sambhar lake. This model is also supported by the available water chemistry data (Yadav, 1995) listed in Table 1. It is clearly seen that in the river water, alkalinity is greater than (Ca+Mg), thereby encouraging precipitation of calcite followed by Mg-clay.

Samples collected from a shallow auger hole at Jhapok, situated on the southern shore of Sambhar lake, show the presence of calcite and thenardite (Na_2SO_4) in the XRD patterns. The fully evaporated brine deposits halite in the salt

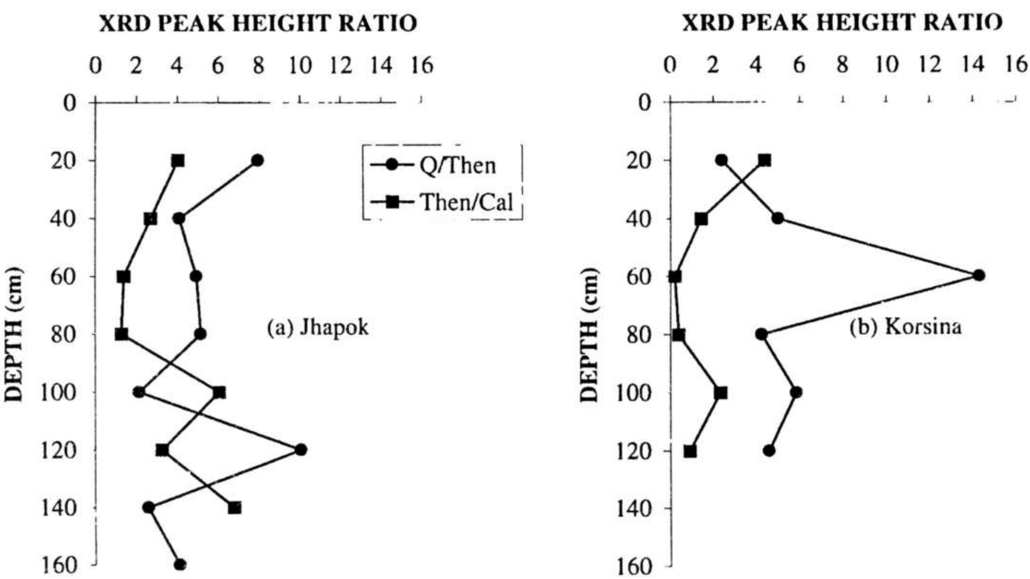

Fig.2. (**a**) Plot of XRD peak height ratio vs. depth for Jhapok site, (**b**) Plot of XRD peak height ratio vs. depth for Korsina site

Table 1. Summary of available water chemistry data (after Yadav, 1995), (Concentrations in mmol/L)

Sample location	pH	Na	K	Ca	Mg	Cl	SO_4	Alk
River Mendha	8.2	24.1	0 365	0.972	1.525	9.75	4.15	11.35
Ground Water	7.94	21.5	0.09	1.65	2.67	24.33	0.75	4.4
Sambhar Lake	8.4	142.6	6.31	0.665	0.085	129.28	4.165	7

pans. The absence of gypsum possibly reflects relatively low concentration of Ca in the inflow water. For the purpose of illustrating the relative abundance of evaporite and detrital minerals in the successive layers, the ratios of X-ray peak heights of calcite (3.03Å), thenardite (2.81Å) and quartz (3.34 Å) have been plotted against depth (Fig. 2a).

It is interesting to note that the thenardite/calcite ratio goes through a maximum around 100 cm depth. The quartz/thenardite ratio is also minimum at this depth. A sulphate mineral like thenardite precipitates at a more advanced stage of evaporation compared with the early stage calcite. We conclude, therefore, that an increase in thenardite content with respect to calcite and quartz in this horizon is due to rapid evaporation and absence of detrital input in a dry climate. Similarly, a high quartz content at 120 cm depth accompanied by a low in the thenardite/calcite ratio provides evidence of flooding with higher input of aeolian sand. A similar trend is observed at another location Korsina, albeit with slight variation in actual levels of maximum and minimum values (Fig. 2b), which may be a function of local differences in the basin geometry.

In addition to the above minerals, samples from the top level at Jhapok also contain pellets of the phosphate mineral dufrenite, $3FePO_4.Fe(OH)_3.Fe(OH)_2.2H_2O$. The X-ray pattern shows its characteristic peaks at 3.10, 3.24 and 2.44Å. Its presence here is suspected to be authigenic, contributed from an organic source, like bird's faeces (Wasson et al. 1984).

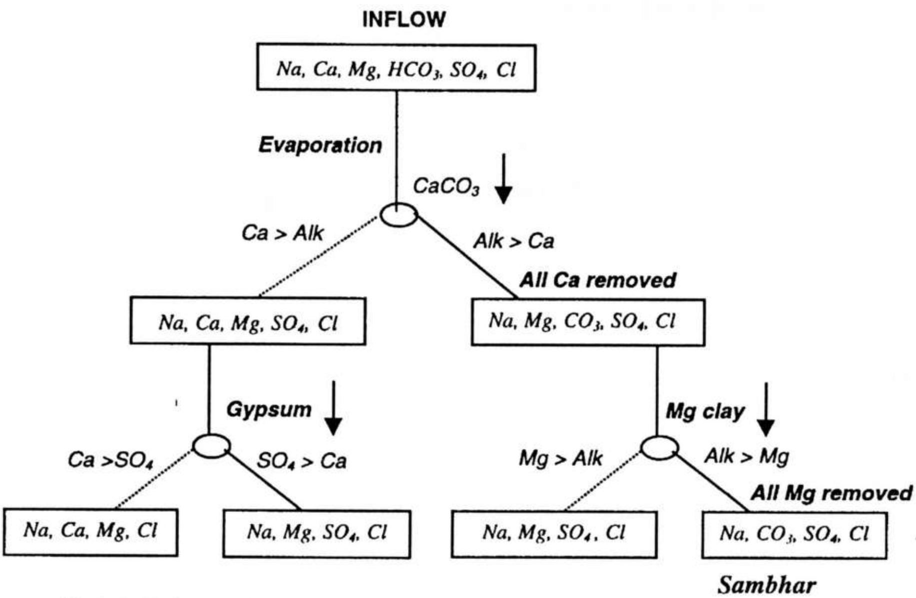

Fig.3. Preliminary salinity model for Sambhar lake (adopted from Eugster and Hardie, 1978)

The bed of the Mendha river draining into Sambhar lake from northeast direction shows abundant salt incrustation. The X-ray pattern of this material shows peaks of Na_2CO_3, $NaNO_3$, Na_2SO_4 (thenardite) along with quartz and feldspar. A SEM-EDX analysis of one of the salt crystals showed a prismatic shape with triangular cross section and high S-content. This mineral is, therefore, tentatively identified as thenardite.

CONCLUSIONS

The Sambhar, a recognized saline lake of international importance, has peculiar physical and chemical characteristics. It is a shallow lake with a maximum depth of 3m fed by seasonal rivers carrying fresh water. The lake brine is of the Na-CO_3-SO_4-Cl type. From our preliminary study of water chemistry and sediment mineralogy, the brine appears to have evolved through progressive evaporation of inflow water. Typical products of evaporation such as calcite and thenardite were identified in the samples from shallow auger holes along with detrital influx of quartz, illite, kaolinite and smectite. These sediments highlight a cyclic depositional sequence of clastics and evaporites reflecting wet and dry phases respectively. The presence of Mg-clay (smectite) in the lake sediments strongly suggests a mechanism of Mg-removal during evaporation of lake water. The lack of gypsum in the near surface sample of Sambhar lake sediments may be due to a low influx of Ca into the lake during recent times.

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