Modern salt (halite) deposits of the Sambhar Lake, Rajasthan and their formative conditions

Evaporites originate as precipitates in oceans, barred basins and continental lakes in many parts of the world. The Sambhar Lake of Rajasthan is one of the continental lakes, where evaporites precipitate in a series of minerals dominated by halite. As these minerals are susceptible to minor changes in environmental and climatic conditions, they show substantial transformations in surface conditions as well as during burial[1,2]. This makes the genesis of these evaporites significant. We prepared thin sections of evaporite minerals in cooking oil and cool-mounted them. Based on petrographic details of the salts of the Sambhar Lake, we try to decipher influences of formative conditions on salt development.

Sambhar Lake is situated in the eastern part of the Thar Desert (Rajasthan) and southeast of the Aravalli mountain ranges comprising rock formations of early and middle Proterozoic age[3]. This lake is elliptical and shallow with its extension over an area of about 225 sq. km. It has maximum length 22.5 km running ENE-WSW and width of 3.2–11.2 km between 26°52′–27°2′N lat. and 74°53′–75°13′E long. with a catchment area of 5600 sq. km (Figure 1)[4]. Basement of the lake deposit is mainly composed of metamorphic rocks of Delhi and Aravalli Supergroups[5].

Four ephemeral streams flow from the catchment of the Sambhar Lake. They are Mendha, Rupangarh, Kharian and Khandel. Among them, Mendha in the north and Rupangarh in the south are chiefly considered as the source of brine for the lake. The other two rivers are smaller streams and enter into the lake from the northwest and eastern sides respectively. Annual precipitation in this area ranges from 100 to 500 mm and the average temperature is 23°C with maximum reaching 45°C during summer. The easternmost part of the lake around Guda and Jhapok produces large amount of salt.

The two main areas of salt precipitation show a contrast in environmental conditions, such as depth of water and pH. The depth of water is less than 0.5 m in the Guda area and the rate of evaporation is slow during winter. So, it takes 4–5 months for halite crystals to precipitate during that season. The pH in the salt pans of the Guda area varies from 8.5 to 9.5. It is found that the halite crystals of the Guda area are transparent, cubic, but small in size. In Jhapok area, the depth of the brine solution is 1–2 m due to which the rate of evaporation is slow for precipitating halite crystals and it takes 5–6 months to develop pure crystals of halite. The pH of brine near Jhapok is 9.5–10, slightly more alkaline than Guda salt pans. Most of the crystals formed in the Jhapok area are brownish-black in colour and some are transparent, but all the crystals are comparatively big in size than those found in Guda. During winter season (within 4–5 months) the brine solution is less contaminated by dust particles, enabling the formation of purer crystals compared to those formed during summer months. The crystals formed in winter are much more pure containing 98–99% NaCl. During summer, the process of evaporation takes 6–8 days for precipitation of halite crystals and the purity of precipitated salt in terms of NaCl is 96–97%. Salt from the Jhapok area is widely used for industrial purposes, such as in chemical industries and laboratories. In addition to halite crystals, the playa lake also precipitates bitten crust. This variety of salt has maximum content of $NaSO_4$. Bitten salt is insoluble in water and occurs associated with clay.

There is much variation in the textural and bedding characters of halite, depending largely on the environment of precipitation. Thickness of the salt deposits at the margin of the lake near Guda is 0.2–0.3 m. The Guda salt is composed of small crystals, which occasionally show the hopper structure in hand specimen. Salt deposits of the pans near Jhapok are brownish-black in colour with approximate thickness of 0.3–0.5 m. They give sulphur odour. The presence of sulphur may have given the brownish colour to the precipitated salt. The salt crystals collected from Jhapok are big in size and commonly show hopper structure, which is the characteristic feature of halite. At microscopic level, the samples collected from Jhapok area are commonly euhedral with various shapes such as rectangle, square and rhombus (Figure 2 *a*). Samples of the Guda area have dominance of anhedral, transparent crystals of halite which occasionally show the cubic cleavage (Figure 2 *b*). The crystal sizes vary from 400 to 500 μm with common presence of fluid inclusions (Figure 2 *c*). The crystal sizes vary from 1000 to 1500 μm in the Jhapok salt pans (Figure 2 *d*). The crystals possess numerous solid and fluid inclusions. The inclusions are either of cubic or rounded shape (Figure 2 *b* and *e*). The margins of many crystals seem modified as a result of surface transformations of these crystals (Figure 2 *e*). In

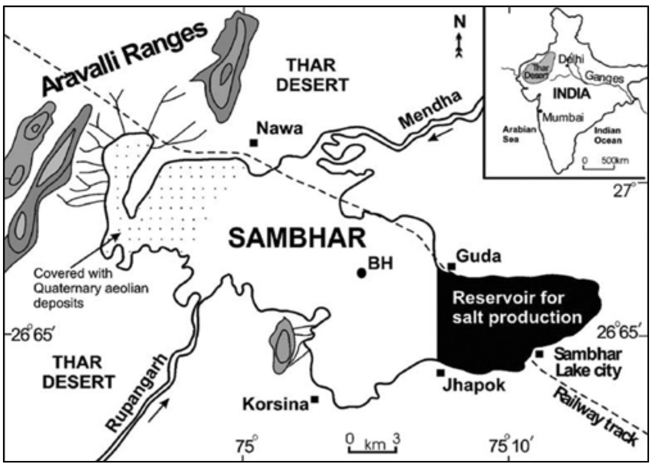

Figure 1. Location map of Sambhar playa in the Thar Desert; the playa is fed by the river Mendha from NE and the river Rupangarh from SW (after Sinha and Raymahasay[4]). (Inset) Location of the Thar Desert in the outline map of India. Note that the easternmost part of the playa is used for salt production.

many cases, the crystals have attained rounded shape because of transformation along boundaries (Figure 2 *f*). Also, the overgrowths can be easily identified in many crystals (Figure 2 *e*).

Three stages to the saline pan cycles have been recognized by Lowenstein and Hardie[6] depending upon the precipitation of salts in different conditions. They are flooding, evaporative concentration and desiccation. According to the authors, evaporation of the shallow water lakes leads to the formation of thin halite rafts on the water surface and bottom nucleation of halite crystals on the settled out rafts. The halite crystals grow most rapidly from their coigns and develop chevron textures[6]. The development of chevron textures in the salt crystals from both Guda and Jhapok formed as result of rapid growth. Complete desiccation of the pan causes the halite crust to break up into polygons[6]. The salt pans of the Sambhar do not show polygons in the winter season, but polygons were observed in the dried-up areas where desiccation occurred. However, we cannot rule out the presence of this feature in summer in the salt pan when evaporation is very high. Further, halite is precipitated from evaporating groundwater as clear cement in vugs in the salt crust and as displacive cubes in the associated muds. These features were observed in the mud that occurs as a floor below the salt pan in the Sambhar Lake at various places.

As halite forms 98–99% of the salt precipitated from the Sambhar Lake, 2–3% constitutes the other minerals. Sinha and Raymahashay[4] identified the minerals in the salt deposits that occur in the subsurface. They are halite, carnalite, sylvite, gypsum, bassanite, thenerdite, mirabilite, kieserite, bloedite, polyhalite, glauberite, calcite, aragonite, dolomite, trona and nahcolite. Sylvite precipitates just after the precipitation of halite and it is generally found at topmost position in borehole samples of the Sambhar Lake[4]. By petrographic study, we found that the isotropic crystals of halite constitute majority of the samples. However, numerous solid and liquid inclusions in the halite crystals suggest that they are of associated minerals that have chloride, sulphate or carbonate composition, as suggested by Sinha and Raymahashay[4] from the study of older salt deposits of the Sambhar Lake.

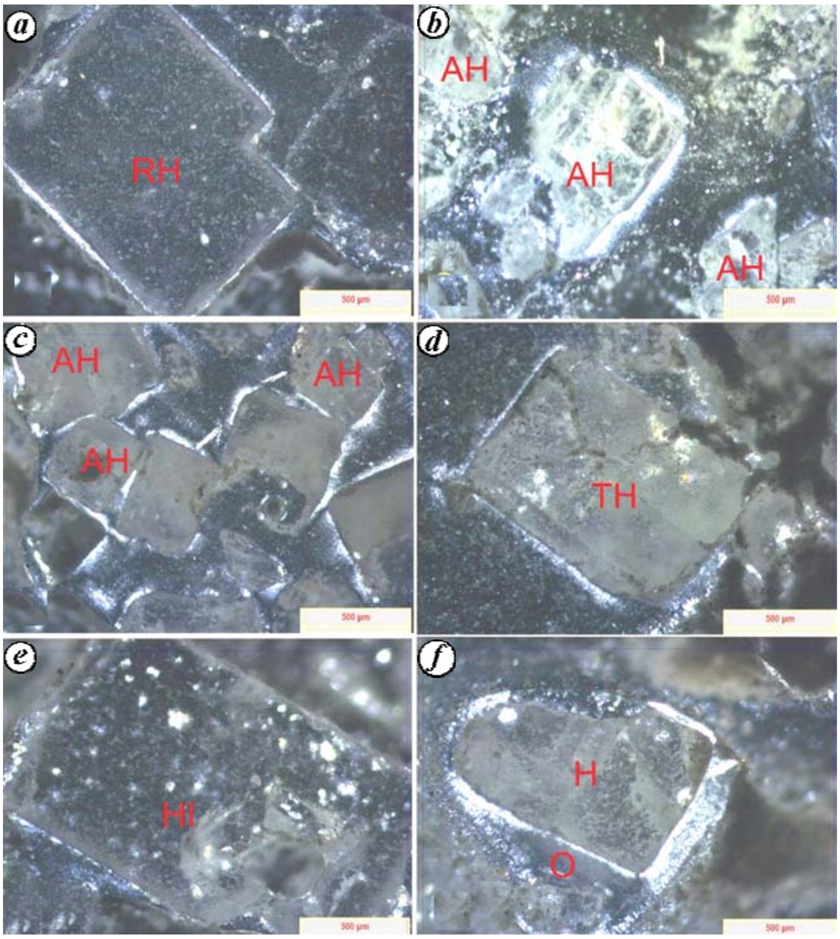

Figure 2. Photomicrographs. ***a***, A large crystal of halite in rectangle shape (RH). ***b***, Anhedral halite crystals (AH) possessing large number of inclusions. ***c***, Halite crystals showing anhedral shapes (AH). Note that individual crystals are fused together. ***d***, Halite crystal showing transformations along boundaries (TH). ***e***, Halite crystal showing overgrowth along the boundary and numerous inclusions (HI). ***f***, Halite (H) showing modified outline of the crystal (O).

Based on isotopic analysis of the lake water, it has been suggested that the lake brine is completely refilled by meteoric water through surface run-off and there is no question of marine input[5,7]. Thus, the rivers Mendha and Rupangarh are the main sources of saline water to the Sambhar Lake. Dey[8] has suggested that Precambrian rocks in Rajasthan, Punjab and Haryana contain surface and subsurface evaporite deposits. The evaporites are likely present in the river catchments, which are dissolved in the river waters and precipitates in the salt pans. Sinha and Raymahashay[4] estimated that the saline condition of the Sambhar Lake had a total time-span of 30 ka, and postulated that the Quaternary climatic fluctuations might be the prime factor in salinity variations in the Sambhar Lake. The lake sediments form a cyclic depositional sequence of clastics (mainly quartz, illite, kaolinite) and evaporites (mainly halite and thenerdite and calcite)[9]. Most likely, the clastic sediments are deposited here during rainy season or during periods of more rainfall and the non-clastic sediments precipitate during winter and summer season when evaporation takes place and supply of clastic sediments ceases.

Sambhar Lake is a shallow lake with maximum depth of 1–2 m only and can be categorized as a playa as it inundates during rainy season and dries up during summer season. Aridity seems to be the main factor in the formation of salt deposits in the Sambhar Lake, as it is a part of the Thar Desert. As a result of evaporation, surface brine becomes concentrated with salt and saline minerals nucleate. The dense brine concentrated with the salt sinks towards the bottom of the lake and less concentrated water comes up and flows over the brine. As the evaporation continues brine solution gets hyper-concentrated and finally evaporites precipitate.

Continuous evaporation of the brine solution with increasing aridity results in precipitation of a variety of evaporitic minerals. It is noted that calcite forms at the early stage of the evaporation process, whereas halite and polyhalite form at a later stage and sylvite (KCl) and carnalite develop at the final stage of evaporation[10]. Salt precipitation in the Sambhar Lake containing 98–99% halite dominantly suggests its precipitation at an intermediate stage of salinity and aridity, and its maximum precipitation is during winter and summer. Further, pH conditions also govern the growth of the halite crystals, i.e. more the pH, higher is the growth of the halite crystals. Furthermore, growth of the salt crystals depends upon the evaporation process and residence time. Evaporation is the key process for the precipitation of salt deposits here and halite precipitates when the brine solution remains 10% of its original volume. In the Sambhar Lake, salt precipitation takes place at temperatures above 22°C. Crystals of 4–5 mm size grow in 15–20 days and crystals of 1–1.5 cm size grow within 6 months, and growth of the crystals depends upon the seasonal variation in evaporation.

Salinity and aridity are the chief factors that govern salt precipitation in freshwater playa of Sambhar. The salt precipitated in this playa lake is mainly halite with purity up to 99%. Halite occurs in the form of chevron crystals and polygons. Petrographic study reveals that the halite crystals are present in the form of euhedral crystals (rectangles and cubes) and anhedral crystals with transformed boundaries, containing numerous inclusions, and the transformations in the euhedral crystals are related to changes in the environmental conditions such as flooding and desiccation.

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B. P. SINGH[1,*]
NEHA SINGH[1]
S. P. SINGH[2]

[1]*Centre of Advanced Study in Geology, Banaras Hindu University, Varanasi 221 005, India*
[2]*Geology Lab, Government Higher Secondary School, Kathua 184 101, India*
**For correspondence.*
e-mail: drbpsingh1960@gmail.com

How important are the 'Correspondence' papers published in *Current Science*?

According to the 'Information for Contributors', the Correspondence section in *Current Science* contains 'letters that are of general interest to scientists and technical comments, including those on articles or communications published in *Current Science* within the previous six months'. Many of these published letters are indeed short comments on the situation in the sciences and education mainly – but not only – in India. According to the *Web of Science* (as of 7 December 2012) around 90% of letters published during 2000–2012 were authored or co-authored by researchers in Indian locations.

Each issue of *Current Science* contains 'Correspondence papers'. For example, the issues of volume 103 contained respectively the following number of 'Correspondence papers': 9 (first issue), 8 (second), 6 (third), 9 (fourth), 7 (fifth), 9 (sixth), 9 (seventh), 10 (eighth), 10 (ninth), 9 (tenth), 10 (eleventh) and 8 (twelfth issue). For example, the eleventh issue of volume 103 contained one paper under 'In Conversation', three Scientific Correspondence, two General Articles, one Review Article, one Research Article, four Research Communications, two Book Reviews, one Personal News and one paper under 'Historical Notes'. Thus we see that although the contribution of the 'Correspondence papers' to the overall length of the issue is never large, the number of such papers per issue is considerable, suggesting their popularity among *Current Science* authors, and of course the openness of the journal editors to scientific discussion.

The question that we ask here is whether these contributions have an impact on science and scientific discourse. To do this we conducted a citation analysis of the 'Correspondence papers' published from 2000 to 2011. Our aim was to see whether or not any of these papers had received a noticeable number of citations, as well as to find out what types of 'Correspondence papers' gained most citations. We also looked to see what kind of knowledge these papers represented, and whether or not the contents and the discussions were of a local or a more global character.