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Status Report

Some Evaporite Deposits of India

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A general review of evaporite ocuurences in India has been given. Some estimates of their economic potentials are also presented. Some controversies related to stratigraphic correlation of evaporite bearing successions in western Rajasthan has been discussed. Petrography and fluid inclusion studies on Hanseran salts have been highlighted.

Key Words: Evaporates; Hanseran Halite; Tso Kar Lakes; Ladhakh; Mandi Salts; Petrography; Fluid Inclusion

Introduction

A basin in which evaporates constitute predominant component of the sediments over terrestrial sediments is designated as Evaporite basin. Evaporites containing isolated gypsum deposits are found in Kargil, Leh, Barmula and Doda districts of J&K, Dehradun, Garhwal and Tehri Garhwal districts of Uttaranchal and Sirmur, and Lahaul & Spiti districts of Himachal Pradesh. Workable gypsum deposits in some isolated sub-basins are also found in Jaisalmer, Barmer, Bikaner, Nagaur, Churu and Jodhpur districts of Rajasthan. Gypsum occurrences are recorded from Jamnagar and Kachchh districts of Gujrat; Rewa, Durg and Rajnandgaon districts of Madhya Pradesh and Raichur and Gulbarga districts of Karnataka.

Tso-Kar Lake, Ladakh District, Jammu and Kashmir

Tso-Kar Lake Basin in Ladakh District of Jammu and Kashmir (33 18 N: 78 E) is spread over 175 sq.km of area and is located about 170 km of south east of Leh. This region of Rupshu has an altitude of 4535mts. above MSL. Geological and structural studies in the region suggested this basin originated in the form of a graben with confining faults on the eastern and western margins named Tso-Kar and Nuruchan faults. Another fault, the Puga Fault show WNW-ESE trend and strikes the centre of the basin. The salt deposits of Tso-Kar provides salt to the local population of Ladakh, Kargil and Baltistan and adjoining areas. This lake was identified as evaporate water body and described during expeditions to Ladakh in 1853 by Cunningham (1853) and Drew (1875). In later years viz. 1968, 1973, 1975 and 1977, the Geological Survey of India sent expert teams to evaluate its potential as potash resource for the country.

The basin harbors two lakes, the Startspuk Tso, a fresh water lake and the Tso-Kar Lake, which is dumbbell shaped and is hypersaline. Fresh glacial melt water from the Nuruchen Lungapa draining the southern glacial basin is aligned N-S which shows a knee bend towards south-east and meets the Startspuk Tso. The stream from Polokongkhala drains the eastern part and debouches in to the Startspuk Tso. The Startspuk Tso drains into the Tso-Kar through a narrow meandering channel. The Nalabokhar nala drains the northern part of the basin and joins Tso Kar. The geomorphology of the basin has been sculptured through fluvio-glacial sedimentation and tectonic movements and presently shows the bottom of a desiccated lake basin. The basin margin shows a large number of ancient strand lines, the upper most located at a height of 66 m. from the present lake water level is the most prominent. Other concentric strand lines provide a history of the shrinking of the lake through time. The impact of changes in the water supply and consequent expansion of the lake are also noted besides tilting of the lake bottom and consequent asymmetrical overlap of the shore line is also seen. The Nalabokher and Shingbuk nalas show eastward migration most likely caused by tilting of the lake bottom. The brine of the Tso Kar lake is of Na-K-Ca-Mg-Cl-SO_4 composition. The salinity in this lake increases radially from the point of inflow of fresh water from the Startspuk Tso. In the western part, the lake bottom has

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crystalline sodium chloride layer reaching to a thickness of 1mt. The concentration of sodium and potassium in the lake brine, increases from 5gms per litre at the eastern end to 38gms per litres at the western end. Potash concentration varies and changes from 0.32gms per litre to 5.6 gms per litre in a similar fashion. The surrounding areas of the lake, especially in the southern part, show development of mirabilite changing to thenardite .

The resources of salts were estimated to be 0.78 million tonnes in the precipitated salt layer and 0.65 million tonnes in the brine. Wunnemann et al. (2010) has described the Quaternary history of the lake region and discussed its evolution through time. His data sets indicate that the present desiccation of the lake dates back to 7.5 kys.

Mandi Salt Belt, Himachal Pradesh

Mandi Salt Belt, lying at the fringe of the Siwalik Foothills and Lesser Himalayan Zone has been reported to continue from Larji in the south east via Mandi to Shiunta in Chamba district extending for about 200 km. Its presence is expressed through hypersaline brine in the sub- surface at Larji, saline springs at Harkalan and Dewalkhas and salt mines at Megal, Drang and Guma. These salt occurrences are known since the time of Mughal king Akbar, and was a major source of revenue for the Sikh rulers of that time. Scientific studies were undertaken by a galaxy of pioneer workers like Jameson, Warth, McMohan, Capt. Palmer, Hayden, and Pascoe. Capt.Palmer in 1921 pointed out that the salt is of the same age as that of the Krol Formation which was then considered Permo-Triassic in age. Some workers assigned Tertiary age to these salt beds. Dubey *et al*. (1949) and Boileau *et al*. (1949) inferred that the salt got concentrated in the elevated part of folds and pushed out like butter from the crests of folds. Such disposition is clearly exhibited at Guma, Drang and Megal, where the cap rocks have been pushed up.

Mandi salt has peculiar mineralogical characteristic where gypsum is absent but dolomite and clayey units are closely associated. Some workers felt this salt may be recycled although original source material could not be identified.

This salt is pink, white and colorless, crystalline in nature. Original crystal shapes are not discernable. Chemically, these are 70% NaCl and 3-7% KCl (as Potash minerals) and the remaining ~25% insoluble detrital minerals.

The salt deposits at Drang were investigated through drilling by Escher and Wyss in 1956 who proposed extraction of 66,000 tonnes of salt per year through solution mining. Indian Bureau of Mines in 1963-65 also explored the Drang block and estimated reserves of salt of the order of 6.5 million tones. GSI in 1970-73 investigated the Megal Block to establish continuity of salt further east below the Mandi Trap but up to the depth of 156 m there was no change in the trap lithology.

Bikaner-Nagaur-Ganganagar Evaporite Basin

An extensive evaporite basin is located in the NW Rajasthan. This evaporite basin has been identified in the subsurface and is inferred to extend across the international border up to Salt Range in Pakistan. The south-eastern part of this extensive Neoproterozoic evaporite basin is named by the Geological Survey as Nagaur-Ganganagar Evaporite basin. This basin contains a thick pile of sedimentary rocks of Marwar Supergroup lying unconformably above the basement of Malani rhyolitic suite. In northern part, these unmetamorphosed sedimentaries are resting directly on the metamorphosed rocks of Delhi Supergroup. The Marwar Supergroup is divisible into:

(i) Jodhpur Group of sandstones of different kinds forms the base,

(ii) Bilara Group of carbonate rocks overlying the Jodhpur Sandstones and

(iii) Nagaur Group of reddish to purple shale, siltstone and sandstone occuring with a gradational to sharp contact with the Bilara rocks.

Correlation of these rocks in the region is rather speculative, although similarities in lithology, tectonic position in the basin, similarities in nature of mineralization and other rock associations help in making some intelligent speculations regarding continuity of the rock formations. At times, comparison of order in stratigraphic sequence with far fetched geological locations tend to provide clues for their correlation. In most cases however, the evidence presented are interpretative rather than factual. Hence, all correlations attempted in this region vary according to the interpretation preferred by the individual worker. Following this trend, the unfossiliferous, unmetamorphosed Jodhpur Sandstone has been correlated by the GSI with the Randha Formation of the Birmania basin, although sandstones of the two stratigraphic units do not match. Similarly, phosphatiic carbonates of the Birmania Formation in the Birmania basin have been correlated with the Bilara Group of carbonates due to presence of stromatolites, although Bilara carbonates are distinctly non-phosphatic. Most workers in GSI and others consider Bilara Group of rocks to extend to the north in subsurface where halite bearing beds are prominently preserved. These halite bearing beds are considered facies variant of Bilara carbonates and has been given the name 'Hanseran Evaporite Group' and have been compared to the Saline series in the Karampur Oil Field and Salt Range in Pakistan. The Nagaur Sandstone and Shales have been linked to the Purple Shale of the Salt Range succession.

As mentioned above, the Jodhpur Sandstones are overlain by the Bilara carbonates which is limy in some sectors and dolomitic in other places. These are typical platform carbonate reflecting origin under restricted marine water circulation. Stromatolitic reefs denotes the extent and distribution of the slightly uplifted basinal topography where algal colonies could remain perched and get desiccated while occasional trangressive inundations produced cross bedded carbonates. Many previous workers including one of us (VK) is of the view the Bilara carbonates can be subdivided into distinct carbonate members. There is however, no mappable sedimentological feature which could be observed on the outcrop to make such distinction. Slight changes in the rock hue and granularity can not be used for such differentiation. Variable dolomitization and calcitization are both diagenetic and post-diagenetic, hence controlled by the depth of burial rather than by differential age. The stratigraphic contact between the Jodhpur sandstone and platformal Bilara carbonate is sharp and abrupt. A drastic change in the depositional environment is indicated, whereby the sediment transport from the hinterland completely stopped due to onset of aridity in the region resulting into onset of tidal flat to lagoonal depositional set up at that point of time. Strong foetid odour in freshly broken carbonates, stringers of voids denoting gas escape features, anastomose cracks filled with secondary calcite and gypsum characterize these carbonates. In other word, a bacterially induced sulfidic organic rich carbonate succession was deposited in the Bilara shallow peritidal sea.

Both Jodhpur sandstones and Bilara carbonates are inclined northwards with less that 5^o dips and the overlying rock succession is covered by the transgressive Tertiary sediments and Holocene sands. The next younger exposed succession is that of Nagaur Sandstone far to the north of last exposure of Bilara Dolomite. Underneath the Bilara Dolomite in the sub-surface, occurs a distinct evaporate succession of halite-dolomite-shale which is known in the GSI literature as Hanseran Evaporite Group (HEG). Most workers, including two of us (VK,SPR) consider HEG as the lateral facies variant of the Bilara Dolomite, mainly because drill holes in the region seem to encounter carbonates of the Bilara Dolomite as well as HEG on top of the Jodhpur Sandstone. It is worth pointing out that fossiliferous Tertiary rocks are also found resting directly on top of the Jodhpur Sandstone with conformable lithological contacts, without being correlated to the Bilara Dolomites. It has therefore been argued(DMB) that the evaporate succession of HEG is a successor unit of Bilara Dolomite and is therefore stratigraphically younger than the Bilara Dolomite and has a distinct identity of its own.

In the Birmania area, south-east of the main evaporite basin, rocks equivalent of Nagaur Group are believed to be missing. The reason for this missing link is unresolved. The rocks of Nagaur Group and their lithological equivalents are overlain unconformably by different formations and possibly of different ages in the entire expanse of this region. In the Phalodi-Khichan-Khirwa-Badhaura-Bap area, gritty-pebbly Khichan conglomerate with clasts of Bilara carbonate override the Nagaur Formation, in another sector Nagaur Group is unconformably overlain by the sandstone-siltstone sequence of the Badhaura Formation of Permian age and also the polymictic Bap Boulder Bed, supposed to represent the Permo-Carbonifenous glacial age. Still in other places, the Nagaur Sandstones are overlain by the Quaternary sediments. Lower Jurassic Lathi Formation and brown Tertiary shales and sandstones are also found overriding the Nagaur sandstones.

Hanseran Evaporite Group

Hanseran Evaporite Group (H.E.G) is the collective name given to the entire halite-bearing subsurface sequence, occurring in the central and northern parts of the Nagaur-Ganganagar Evaporite basin. Interpreting the subsurface drilling data, GSI suggests that the HEG is resting on the floor of Jodhpur Group of sandstones with argillites of the Nagaur Group at the top. GSI geologists interpret both the contacts as gradational. The HEG comprises cyclic deposits of halite as the most dominant constituent containing potash minerals, alternating with laminated anhydrite, clay, dolomite and magnesite. Potash minerals within the halite include polyhalite [$K_2MgCa_2(SO_4)_4.2H_2O$], occasional sylvinite (KCl.NaCl) and sylvite (KCl), localized langbeinite ($K_2SO_4.2MgSO_4$) and traces of carnallite ($KCl.MgCl_2.6H_2O$). Through drilling data the thickness of HEG has been estimated to be between 100m to over 652m in different parts of the basin. It contains several halite zones, whose cumulative thickness vary from a few cm to over 488m. A study of the bore hole profiles demonstrates seven halite cycles, in which each halite unit is separated from the other by intervening zones of clay and/or anhydrite and/or dolomite. Each halite cycle has at the base a non-halite intervening zone. This cyclic pattern is repeated several times. Several sub-cycles within halite cycle have been identified by sudden changes in the bromine concentration in halite.

Based on bore hole data and core analysis, the GSI scientists have subdivided HEG into eight formation and 17 members on the basis of lithological characters and order of superposition. These subsurface formations containing halite and non-halite members have been correlated with three different formations of Bilara Group of carbonate, exposed in the sedimentary basin. These halites contain potash minerals in variable quantity. Total probable and possible reserves of potash is 2476 Mt with an average of 4.70% K or about 5% K_2O in three sub-basins of. Satipura, Bharusari & Lakhasar. Similarly, 6 trillion tonnes of halite with over 80% NaCl have also been estimated in this evaporite basin.

Halite occurs in close association of dolomite and clays in the Hanseran bed. These sedimentary precipitates were closely investigated for petrographic characteristics in order to establish the mode of their emplacement and origin. Supersaturation and precipitation of halite was possible in these barred basins in which isolation was apparently achieved by topographic barriers represented by tectonic highs. These tectonic elements accompany rifted, step-faulted blocks of region dimension. Repeated rifts provided accommodation for the thick evaporate deposits to form over a long period of Earth history. These barriers allowed periodic inflow of seawater in the isolated basin, represented today as dolomite filled inlets distributed all over the basin boundary, without any specific plan or order.

Petrographic studies show growth bands in thick halite beds which originated during the temperature variations in the basinal waters which in turn controlled the rate of growth of halite crystals and the brine composition. Most of these tend to produce tiny fluid bubbles entrapped within the sediments and inside the halite crystals. These inclusions are tiny brine filled cavities that formed during the crystal growth and reflect the geochemical environment prevailing at the time of their entrapment. Nearly all subsurface evaporite texture is secondary and is diagenetically modified. Pore water imprints on the primary matrix of mud and carbonate sand are all pervasive. In spite of this, the evaporates retain relicts of primary texture in the form of alignment of anhydride nodules, halite cheverons floating in matrix of halite spar (Fig. 1) or zoned crystals in anhydrite matrix (Fig. 2). Although recrystallized to various degree, primary lamina with impurities define the depositional fabric.

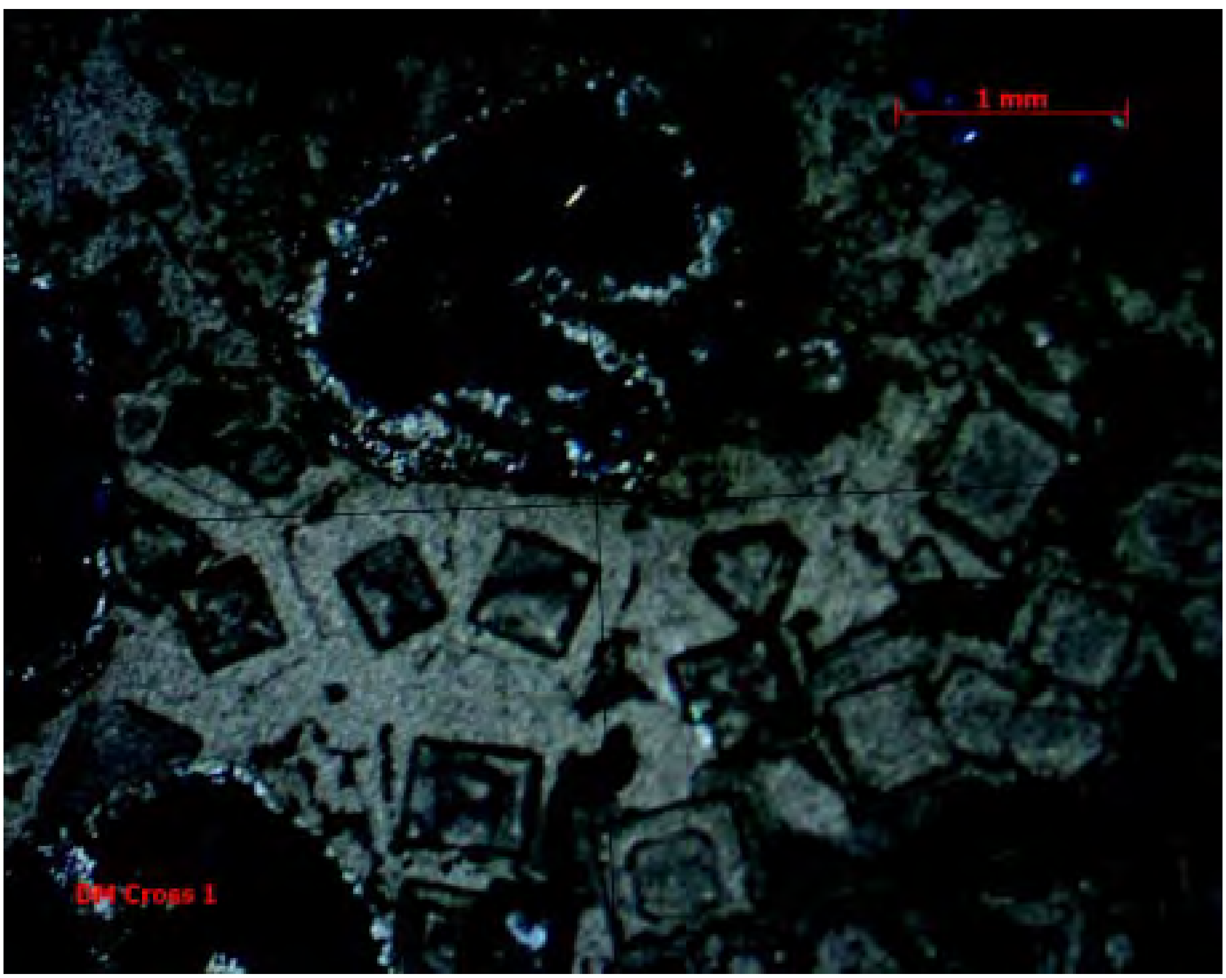

Fig. 1: Halite crystals in anhydrite matrix with fine grained potash minerals entrapped in dark organic matter as seen in the upper end of the photograph

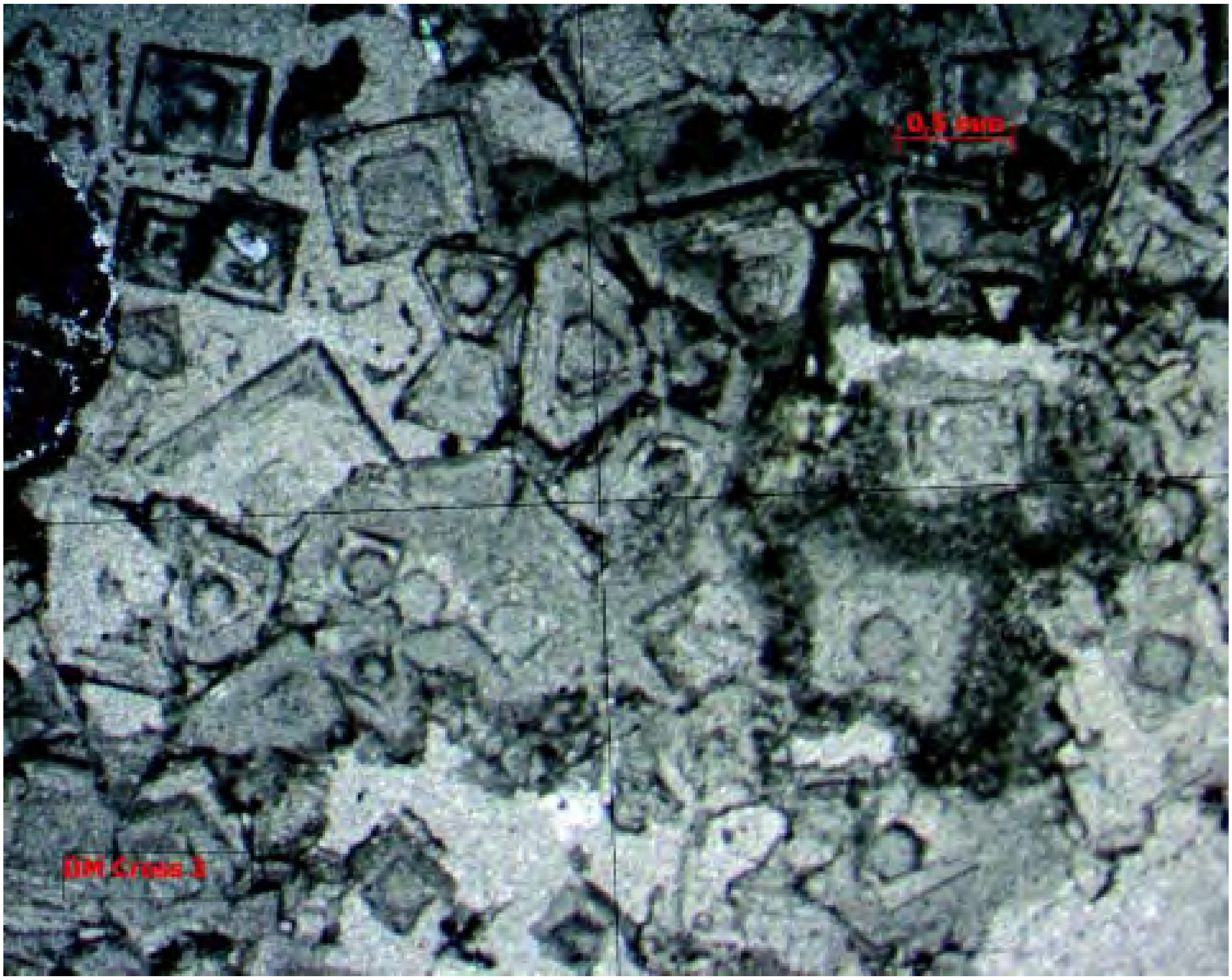

Fig. 2: Halite crystals with zoning as a result of repeated dissolution and recrystallization

Fluid inclusions (Figs. 3,4) in the halite recovered from the GSI drilled Borehole Nos.P/4 and P/12 were studied for measuring the homogenization temperature with gas phase and sylvite daughter crystals. These were measured under a microscope with heating and freezing chambers. For this purpose, halite plates 1-2 mm thick and approx 5mm x 5mm in area were cut which contains as many inclusions as possible for simultaneous homogenization. Fluid inclusions (20-70 µm) from each salt plate were heated in a step-wise fashion until homogenization was achieved. For three phase inclusions temperatures measured show a considerable variation from 55 to 100^{o}C. Gas inclusions in the halite showed high pressure values. During dissolution in water, gas inclusions in halite crystals exploded with cracking sound. Four types of fluid inclusions were identified: Monophase liquid (L), Liquid-rich (L+V), Multiphase solid (L+S±V) and Multi-solid (L+S1+S2±V). During heating of the halite slide with three phase inclusions, sylvite crystals dissolved at 60-62^{o}C and subsequently the gas phase disappeared at 110^{o}C.

Bromine Analysis with XRF Technique Show Variable Concentration Between 20 and 650 ppm

It is logical to ask what prompted the production and preservation of bed of salt in this sedimentary succession. Like any other evaporite succession, the Hanseran basin satisfies all basic requirement for halite preservation which include (1) Availability of near-surface brine body which is compatible with its location in the arid desert setting with characteristic hydrological drawdown of brine to specific level, (2) Availability of accommodation space in sedimentary depressions and within the beds of semi-permeable carbonate mud and, (3) Ideal conditions for burial with virtual sealing of the under saturated flow by

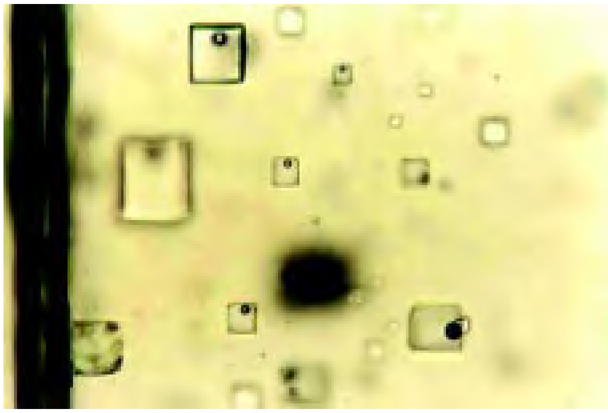

Fig. 3: Halite crystals with distinct fluid inclusions

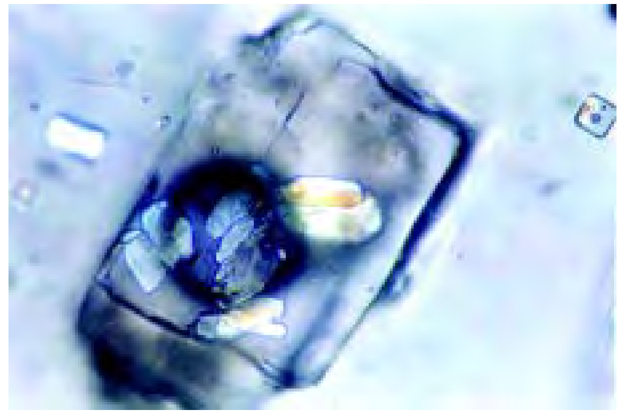

Fig. 4: Halite crystal with clay and quartz inclusions formed during diagenesis

intervening clay sedimentary layers. Supersaturation and precipitation of halite was made possible in these barred basins, isolated due to topographic barriers. Geophysical logs by the Geological Survey indicated structural features like rifted, step faulted blocks extending over a very large area going across the Indian geopolitical border.

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