Calcrete-hosted surficial uranium occurrence in playa-lake environment at Lachhri, Nagaur District, Rajasthan, India

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At Lachhri, uraniferous powdery soft calcrete having significant uranium values with high leachability (~90%), is spread over an area of about 300 m × 200 m up to a depth of about 1 m from the surface. The soft calcrete occurs in a playa-lake environment in a local interdunal depression. Both groundwater and meteoric water, under the influence of the evaporite environment, were probably associated with the genesis of this calcrete and mineralization in it. Detailed study has shown a fair amount of continuity and uniformity in grade and thickness of the uranium-bearing calcrete horizon. Chemical assay of 50 grab samples of calcrete indicated total U ranging from 6 to 195 ppm with an average value of 90.66 ppm. At Lachhri, the uranium value in the groundwater sample is 333 ppb. The country rocks around Lachhri are carbon phyllite–quartzite of the Precambrian Delhi Supergroup, granites and metabasic rocks. The present study indicates that approximately 14 tonnes of U can be expected in the powdery soft calcrete. Contained U (in tonnes) is based on contained metal content and at the present stage it does not consider metallurgical, mining or economic aspects. This new find of significant uranium occurrence in calcrete of playa-lake type environment, in addition to being a low-grade uranium-bearing horizon, establishes the potentiality of similar geological set-up. It offers a type model and guide for prognostication of calcrete-hosted uranium occurrences in other areas, especially in Rajasthan, for further exploration.

Keywords: Calcrete, Lachhri, metal content, playa-lake environment, surficial uranium.

SURFICIAL uranium deposits are generally defined as young (Cenozoic), near-surface uranium concentrations within sediments and soils, although they also occur in peat bogs and karst caverns[1–3]. Uranium mineralization is typically in the form of carnotite ($K_2(UO_2)_2(VO_4)_2{\cdot}3H_2O$) and is commonly cemented by secondary minerals, including calcite, gypsum, dolomite, ferric oxide and halite[1–3]. Uranium deposits in calcrete (calcium and magnesium carbonates) are the largest of the surficial deposits. These usually form in regions where deeply weathered, uranium-rich granites occur in a semi-arid to arid climate. Examples from Western Australia occur in valley-fill sediments along Tertiary drainage channels (palaeochannels), e.g. Yeelirrie and in playa-lake sediments, e.g. Lake Maitland[1–3]. These overlie and are adjacent to Archaean granite and greenstone basement of the northern Yilgarn Craton that serves as a source of vanadium necessary to form carnotite. Subsequent to the discovery of the Yeelirrie deposit in Australia in 1972, 'calcrete' uranium deposits are continuing to receive attention. Numerous similar uranium deposits have been located in various parts of the world, viz. Namibia (Langer-Heinrich deposit), South Africa, Mauritania, Somalia, Botswana, Tanzania and China. Major regional controls on the distribution of uraniferous calcrete are climate, geomorphology and provenance[1,3]. If climate, geomorphological development and provenance of a region are favourable, uraniferous calcrete occurrences are likely to be found in a wide range of valley, deltaic and lacustrine settings. Groundwater transport and shallow subsurface precipitation of uranium, vanadium and potassium in association with authigenic carbonate in an oxidizing and chemically complex regime typify the calcrete environment[3]. In uraniferous calcrete, the ore mineral is carnotite. Introduced carbonate cement ranges from sparse to dominant. Reworking of both ore and gangue minerals may be extensive[3]. The processes involved in the fixation of uranium in calcrete-related environments include one or more of the following[2]: dissociation of soluble complexes, for example, uranyl carbonate species through loss of CO_2 to the atmosphere or precipitation of a carbonate mineral; evaporative concentration of solute species in near-surface groundwater and change in valence state of vanadium or uranium which decreases the solubility of the ore mineral.

The physiography and climate of western Rajasthan along with the geological setting make it the prime target area for exploration of calcrete-type uranium deposit. Physiographically, Rajasthan can be divided into the western plains, the Aravalli hill ranges and the eastern plains[4]. The western plains are further divided into desert plains and dune-free plains. The dune-free plains are characterized by generally rocky pediments, flat buried pediments and older and younger alluvial plains. The genesis of these alluvial plains is linked to the extinct Saraswati–Dishadvati river and the Luni river system[4]. The most recent fluvial landforms are the narrow younger alluvial plains. These are formed along the major streams in the Luni Basin and along the dry valley of Saraswati. The alluvial plains form the target areas for the search of calcrete–uranium deposits. A few restricted drainage systems feeding the salt playas are also present (e.g. at

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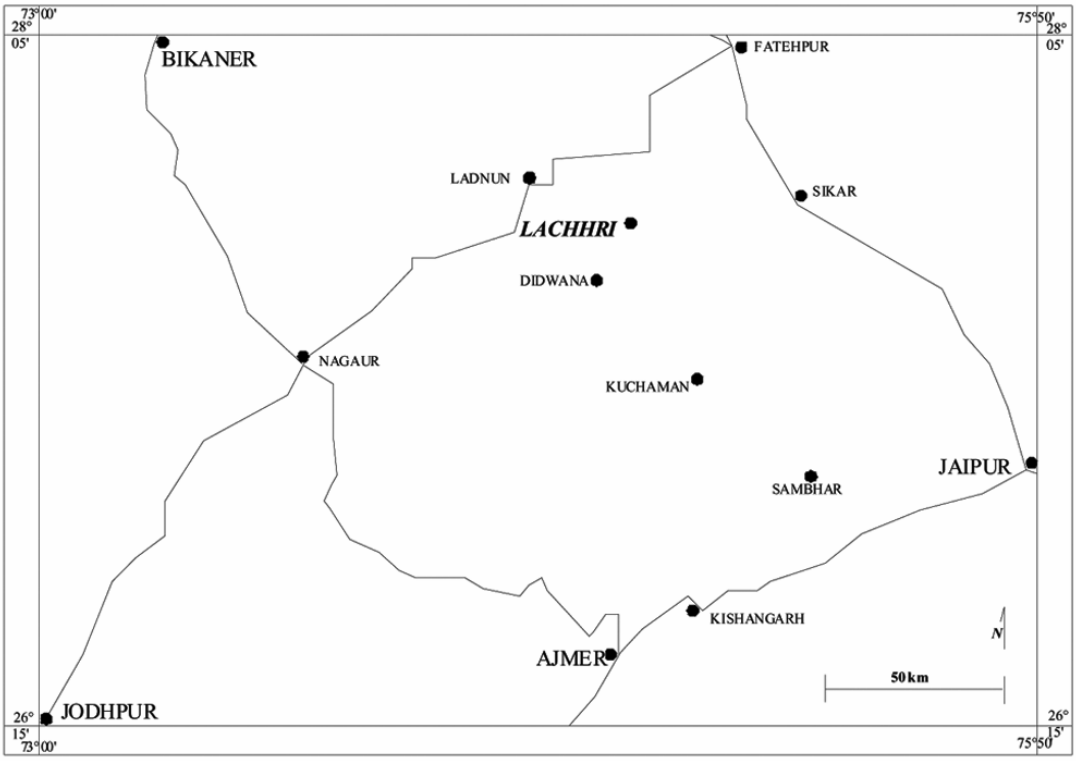

Figure 1. Location map of Lachhri.

Sambhar, Kuchaman and Didwana). These playas (Ranns) are topographic depressions, forming closed basins, fed by streams and groundwater where salt accumulated due to evaporation (similar to Lake Maitland and Lake Austin, Western Australia where these playas are the main sites of calcrete–uranium mineralization). In the desert region, the basement configuration of intracratonic basins and sedimentary formations is represented by the Precambrian Delhi Supergroup, the Late Proterozoic to Early Palaeozoic Marwar Supergroup, the Mesozoic sedimentary rocks and the Cenozoic shallow marine–deltaic formations. These formations have had an influence on the creation and spatial distribution of Neogene continental aggradational domains[5].

In the area under study (Figures 1 and 2), well-developed calcrete horizons are present at several localities. The basement and provenance for calcrete in this region are chiefly metasediments of the Delhi Supergroup, the Malani Igneous Suite (MIS) and sandstones of the Marwar Supergroup. The acid extrusive and intrusive rocks – rhyolites and granites – of the Malani Igneous Suite have in general higher uranium content (1–17 ppm and 3–20 ppm respectively). Metasediments of the Delhi Supergroup are associated with metabasic rocks which could be a good source of vanadium in groundwater of this area for the precipitation of carnotite. The areas underlain by these rocks form the prospective targets for the search of calcrete-hosted uranium deposits. Geographically, the area lies between latitudes 26°00′N and 29°00′N. Incidentally, all the world's major calcrete-hosted uranium deposits have been located between latitudes 26°00′S and 29°00′S.

The Atomic Minerals Directorate for Exploration and Research has carried out reconnaissance radiometric surveys, regional and detailed hydrogeochemical surveys and exploratory drilling in various phases in the western parts of Rajasthan and exploration is still continuing.

Lachhri village (27°33′00″ lat.; 74°41′52″ long.) is located about 20 km NE of Didwana, a town in Nagaur District, Rajasthan, which is well connected to Sikar, Nagaur, Ajmer and Jaipur by all-weather metalled roads (Figure 1). The regional topography is fairly even. General slope of the land is towards west. The southeastern extremity is marked by small scattered hillocks whereas the north, northwestern and northeastern parts constitute a part of the Thar desert. The climate is semi-arid to arid.

A large part of the area studied (27°15′–27°45′ lat.; 74°00′–74°45′ long.) is covered by aeolian sand and alluvial sediments. The area exhibits a hummocky topography due to the formation of sandy undulating plain. The aeolian sand cover often forms sand dunes. Below the sand cover at some places, the Quaternary sequence comprising aeolian and fluvio-lacustrine sediments, viz. clay, silt and fine sand generally rich in carbonates are present. Well-developed calcrete horizons are present at several localities. Regionally, the metasediments of the Delhi

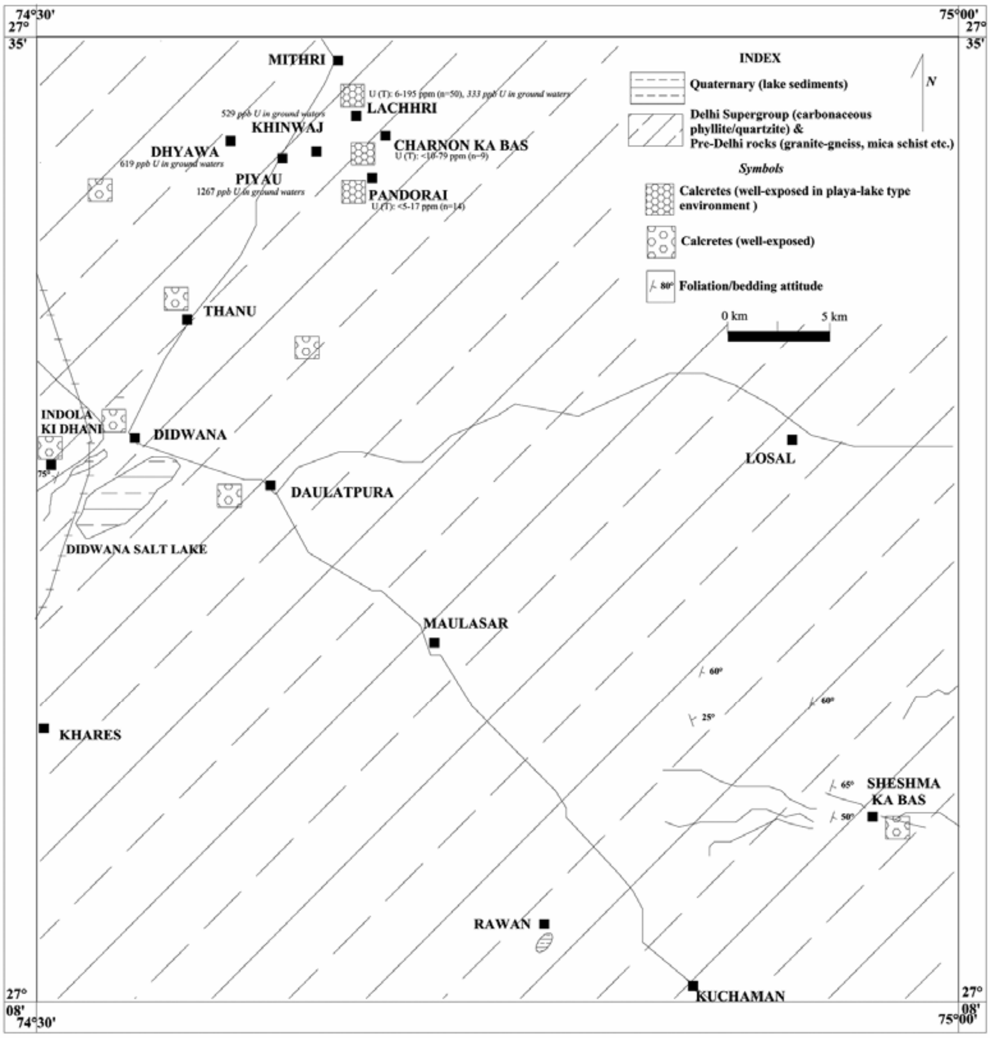

Figure 2. Generalized geological map of Didwana–Lachhri–Kuchaman area, Nagaur District, Rajasthan (T.S. No. 45I). (Geology partly from Pareek[6] and Sinha Roy *et al.*[9]).

Supergroup, Pre-Delhi rocks, rocks belonging to MIS and sandstones of the Marwar Supergroup are exposed at places in hillocks and mounds. Mafic and ultramafic rocks within the Delhi Supergroup are also exposed in some parts.

In the area under consideration, metasediments of the Delhi Supergroup, Pre-Delhi rocks, and intrusive and extrusive rocks belonging to MIS are present. The metasediments of the Delhi Supergroup are exposed at places as hillocks and mounds (Figure 2).

Largely, the metasediments of the Delhi Supergroup chiefly represented by carbonaceous phyllites, phyllites and quartzites, and Pre-Delhi granite–gneiss and schist, form the basement for poorly to well-developed calcrete horizons over them. Minor exposures of MIS granites are present near Didwana[6]. The MIS comprises (i) an extrusive phase – tuff, welded tuff, rhyolite, rhyolite porphyry and mafic rocks; (ii) an intrusive phase – granites and (iii) a dyke phase – felsic, intermediate and mafic rocks. The MIS has been considered to be post-Delhi Supergroup and pre-Marwar Supergroup[6,7]. Towards the western part of the area under consideration, sandstones belonging to the Jodhpur Group of the Marwar Supergroup (Upper Proterozoic–Cambrian) are present. The cross-bedded sandstones are fine to medium-grained. Quarries have exposed deep and wide sections of sandstone overlain by calcrete/calcretized horizons.

Calcretes in the Thar desert, Rajasthan occur in a variety of settings, including piedmonts, sheet-wash aggraded plains, regolith and colluvio-alluvial plains. Calcretes are generally defined as terrestrial, near-surface, secondary calcium carbonate accumulations in soil profiles, bedrocks and sediments. Carbonate is thought to be introduced by replacive, displacive and/or passive mechanisms of precipitation. Sand dunes and sandy plains (dating to < 20 ka) have weakly developed calcretes. The better-developed calcrete horizons occur in piedmonts, interdunes or in areas with sufficient groundwater. The extensive sheetwash plains contain mature calcretes and date to Mid-Pleistocene[4,8]. Calcretes have been described based on the degree of development and morphological appearance[4].

The present study indicates the presence of well-developed calcrete horizons at several localities. Calcrete horizons, representing various stages of development, range from well developed to poorly developed ones. Representative stratigraphic sections showing calcrete horizons have been measured in all the areas with calcrete exposures. A typical stratigraphic section, containing about 4–5 m thick pile of calcrete, shows various types of calcrete/calcretized horizons. Based on field study, it is observed that the unaltered bedrock is overlain by partially altered bedrock with calcareous infillings along weak planes. This, in turn, is overlain by immature calcrete horizons containing unaltered to partially altered boulders of bedrock and ill-formed calcrete nodules containing core of the bedrock. These horizons are overlain by mature calcrete horizons of nodular calcrete containing well-formed (about 2–15 cm across) calcrete nodules. At the top usually a cover of aeolian sand or alluvial sediments is present. Apart from the above-mentioned sequence of calcrete/calcretized horizons, massive sand bodies also contain calcrete horizons at places, and some of the playa-lake areas, viz. Lachhri, Pandorai, etc. contain soft and powdery calcrete horizon on the surface. Figure 3 represents a generalized integrated stratigraphic section showing various types of calcrete horizons present in the region, depicting the different stages of calcrete development.

At Lachhri, uraniferous powdery soft calcrete having significant uranium values with high leachability (~ 90%), is spread over an area of about 300 m × 200 m up to a depth of about 1 m from the surface.

The soft calcrete occurs in the playa-lake type local depression. This seems to have formed an environment

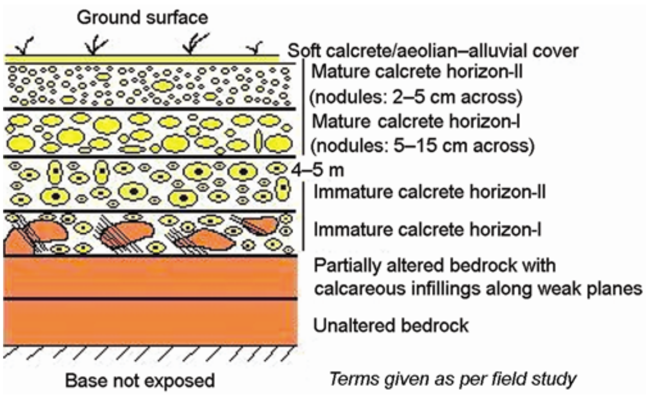

Figure 3. Generalized integrated stratigraphic section showing various types of calcrete horizons present in the region, depicting the different stages of calcrete development.

with a higher water table, in comparison to the surrounding dunal areas. Both groundwater and meteoric water, under the influence of evaporite environment, were probably associated with the genesis of the calcrete and mineralization in it. The calcretre is soft, powdery and white in colour. The country rocks around Lachhri are carbon phyllite-quartzite of the Delhi Supergroup, granites and metabasic rocks.

Detailed study involving sampling by pitting and trenching has shown a fair amount of continuity and uniformity in grade and thickness of the uranium-mineralized calcrete horizon. Chemical assay of 50 grab samples of calcrete indicated U (total) ranging from 6 to 195 ppm with an average value of 90.66 ppm and U (leachable) ranging from 4 to 179 ppm with an average value of 82.12 ppm. These values indicate leachability of about 90% (with 10% HNO_3). Vanadium in the samples ranges from 10 to 30 ppm with an average value of 18.09 ppm ($n = 41$). K_2O ranges from 0.23 to 1.36 wt% with an average value of 0.73 wt% ($n = 41$). At Lachhri, uranium value in the groundwater sample is 333 ppb.

Approximately 14 tonnes of U is expected to be contained in the powdery soft calcrete horizon at Lachhri. The calculation has been done assuming the specific gravity of the clacrete as 2.6. The assumed value for the specific gravity is based on a literature search of powder calcretes found in the Kalahari desert and the lake calcretes of Namibia and Australia. Contained U (in tonnes) is based on contained metal content and at the present stage does not consider metallurgical, mining or economic aspects.

Figure 4 is a representative stratigraphic section showing the soft calcrete horizon present at the playa-lake type local depression at Lachhri.

Whole-rock analyses of soft calcrete samples from Lachhri indicated 6.75–22.31% CaO with an average value of 16.60%, and 2.09–18.70% MgO with an average value of 13.28%. The values for LOI ranged from 7.38% to 37.36% with an average value of 27.72% ($n = 6$).

Powdery soft calcrete as in Lachhri is also present in similar geomorphological conditions at Pandorai and Charnon Ka Bas areas. At Pandorai, approximately 5 km

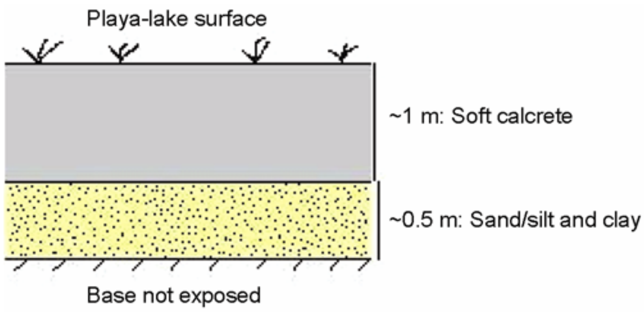

Figure 4. Representative stratigraphic section showing soft calcrete horizon at Lachhri.

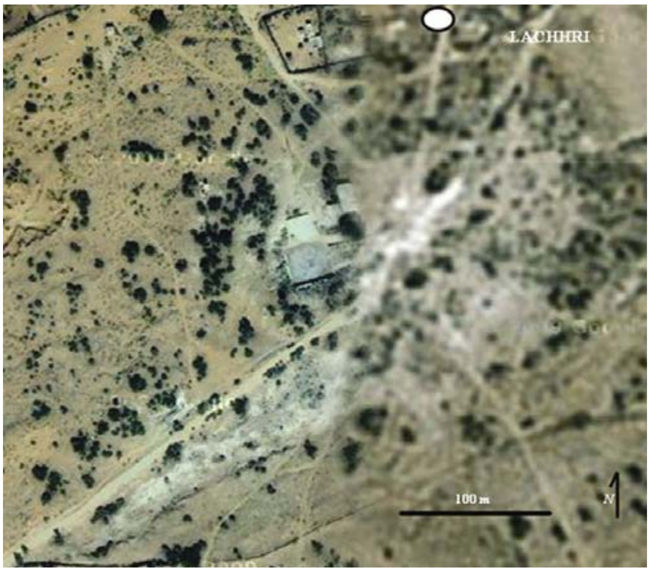

Figure 5. Image showing the extent of soft calcrete of the Lachhri depression (playa-lake environment). (Image source: Google Earth.)

SSE of Lachhri, powdery soft calcrete is exposed over an area of approximately 100 m × 75 m on the surface, with thickness ranging from 0.40 to 1.0 m in 'Lachhri-like' geomorphological set-up. Chemical assay of 14 calcrete samples from nine pits indicated < 5–17 ppm U (total), < 5–14 ppm U (leachable), 15–32 ppm vanadium and 0.54–1.08% K_2O. At Charnon Ka Bas, approximately 3 km ESE of Lachhri, powdery soft calcrete is exposed over an area of approximately 200 m × 150 m on the surface with thickness of about 1 m. Here also the calcrete occurs in 'Lachhri-like' geomorphological set-up. Chemical assay of nine calcrete samples indicated < 10–79 ppm U (total), < 10–71 ppm U (leachable), 12–25 ppm vanadium and 0.49–1.23% K_2O.

The white-coloured powdery soft calcrete areas at Lachhri, Pandorai and Charnon Ka Bas can be seen as rounded white patches in satellite images (Figure 5).

At Lachhri, uraniferous powdery soft calcrete having significant uranium values with high leachability (~ 90%), is spread over an area of about 300 m × 200 m up to a depth of about 1 m from the surface and seems to have formed in the playa-lake environment in a local depression (interdunal) with signatures of relatively higher water table in comparison to the surrounding sand-dune areas. Both groundwater and meteoric water, under the influence of evaporite environment, were probably associated with the genesis of the calcrete and mineralization in it.

Detailed study involving sampling by pitting and trenching has shown a fair amount of continuity and uniformity in grade and thickness of the uranium-mineralized calcrete horizon. The calcrete indicated U (total) ranging from 6 to 195 ppm with an average value of 90.66 ppm and U (leachable) ranging from 4 to 179 ppm with an average value of 82.12 ppm (n = 50). These values indicate high leachability of about 90%, which makes the occurrence significant.

According to the present study, approximately 14 tonnes of U is expected to be contained in the powdery soft calcrete horizon at Lachhri. Contained U (in tonnes) is based on contained metal content and does not consider metallurgical, mining or economic aspects.

The high content of uranium in the groundwater samples from Lachhri and adjacent areas and also in the country rocks around Lachhri presents a favourable scenario for uranium mineralization in calcretes of the area. Further exploration objectives would include a test for the lateral extensions of the present uranium-mineralized horizon at Lachhri and the adjacent areas.

This find of significant uranium occurrence in calcrete of playa-lake type environment, in addition to being a low-grade uranium-bearing horizon, establishes the potentiality of similar geological set-up. It offers a type model and guide for prognostication of calcrete-hosted uranium occurrences in other areas, especially in Rajasthan, for further exploration.

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