# Evolution of saline lakes in Rajasthan

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*Saline lakes are widely distributed in the Thar desert of western Rajasthan. The cardinal factors in the evolution of saline lakes are aridity and the formation of playa depressions, characterized by ephemeral drainage of centripetal type. Most of the large saline lakes are found to have riverine ancestry. Common models suggested for the evolution of saline lakes involve segmentation of stream channels with the onset of aridity. Stream trapping phenomenon is associated with a few saline lakes. The most effective process of stream segmentation was through the formation of linear horsts across the NE–SW trending river channels. Integrated studies based on geophysical, tectonic and remote sensing data indicated control of NE–SW and NW–SE intersecting sets of lineament, particularly the nature of movement along them, in the development of playa depressions. The process of formation of saline lakes can be tied up with the blotting out of the Saraswati and Drishadvati river systems due to drainage disorganization during the Late Quaternary.*

The saline lakes are as much a part of the desert landscape as the sand dunes are. Both the features develop under the conditions of aridity. While the sand dunes form through aeolian process, involving wind action, the major constraint for the evolution of saline lakes is the low to very low precipitation with correspondingly very high rate of evaporation. The saline lakes are widely distributed in the arid western Rajasthan. A few saline lakes, including the Sambhar, the largest one, occur right on the Aravalli mountains. Besides the Sambhar, other important saline lakes are at Didwana, Lunkaransar, Kuchaman, Pachpadra (Panchbhadra), Pokaran, Chhapar, Thob and other places in the plains of the Thar Desert (Figure 1). In addition to these large lakes, there are many smaller saline depressions which occur between the sand dunes. A characteristic feature of most saline lakes in Rajasthan is the NE–SW trend of their longer axis. Topographically, the saline lakes occupy the most depressed part of the isolated basins. Another characteristic feature of the saline lakes is the centripetal drainage system of ephemeral type (Figure 2).

Aridity being the prime factor in the development of saline lakes, it may be pertinent to inquire when actually such a condition had set in. Some crucial information is now available on the time of setting of aridity in western Rajasthan. Thermoluminescence dating of ancient sands in the region suggests that the arid condition prevailed here at least since 1,50,000 years before the present[1]. Detailed sedimentological studies of the Sambhar, Didwana and Lunkaransar lake deposits, however, furnished evidence of transition from extremely arid to sub-humid and wet regimes during the period mentioned above[2-7].

## Origin of saline lakes

Several theories have been proposed in the past to explain the salinity as well as the origin of saline lakes

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in Rajasthan. The earlier concepts, like aeolian transportation of salt particles (like sand) by the south-west monsoon wind[8], or the suggestion that the saline lakes are the leftover saline pools of a former sea that receded from the region, are meant only for historical records. As mentioned earlier, the saline lakes are essential features of the desert regions all over the world. This very fact implies that the aridity must be the prime factor in the evolution of saline lakes. Other than the factor of aridity, the most important component in the evolution of saline lakes is the formation of depressions with the associated centripetal and ephemeral drainage pattern. The saline depressions of western Rajasthan are morphologically similar to the playa lakes, which are broad and shallow depressions occasionally getting inundated with water. Such depressions in western Rajasthan and the neighbouring Kachchh region of north Gujarat are known as *rann*. We should, however, note that the ranns of Kachchh (the Great and the Little Ranns) are not only much larger in size than the Rajasthan ranns, but have formed by a different process. The Kachchh ranns evolved as shallow tectonically subsided areas that allowed transgression of sea water, mainly during the high tides. The Rajasthan ranns on the other hand are typical inland playa depressions, without having any marine connection.

## Formation of playa depressions by aeolian process

There may be several ways of formation of playa depressions. In a desert terrain, the playa depressions of smaller dimensions commonly form by the process of deflation of sand bodies. These depressions turn into ephemeral lakes during the rains. With the onset of dry season, water is evaporated, leaving a thin veneer of salt incrustation. There may be annual repetition of the process. The formation of playa depression by the process of deflation is a very common feature in the sand

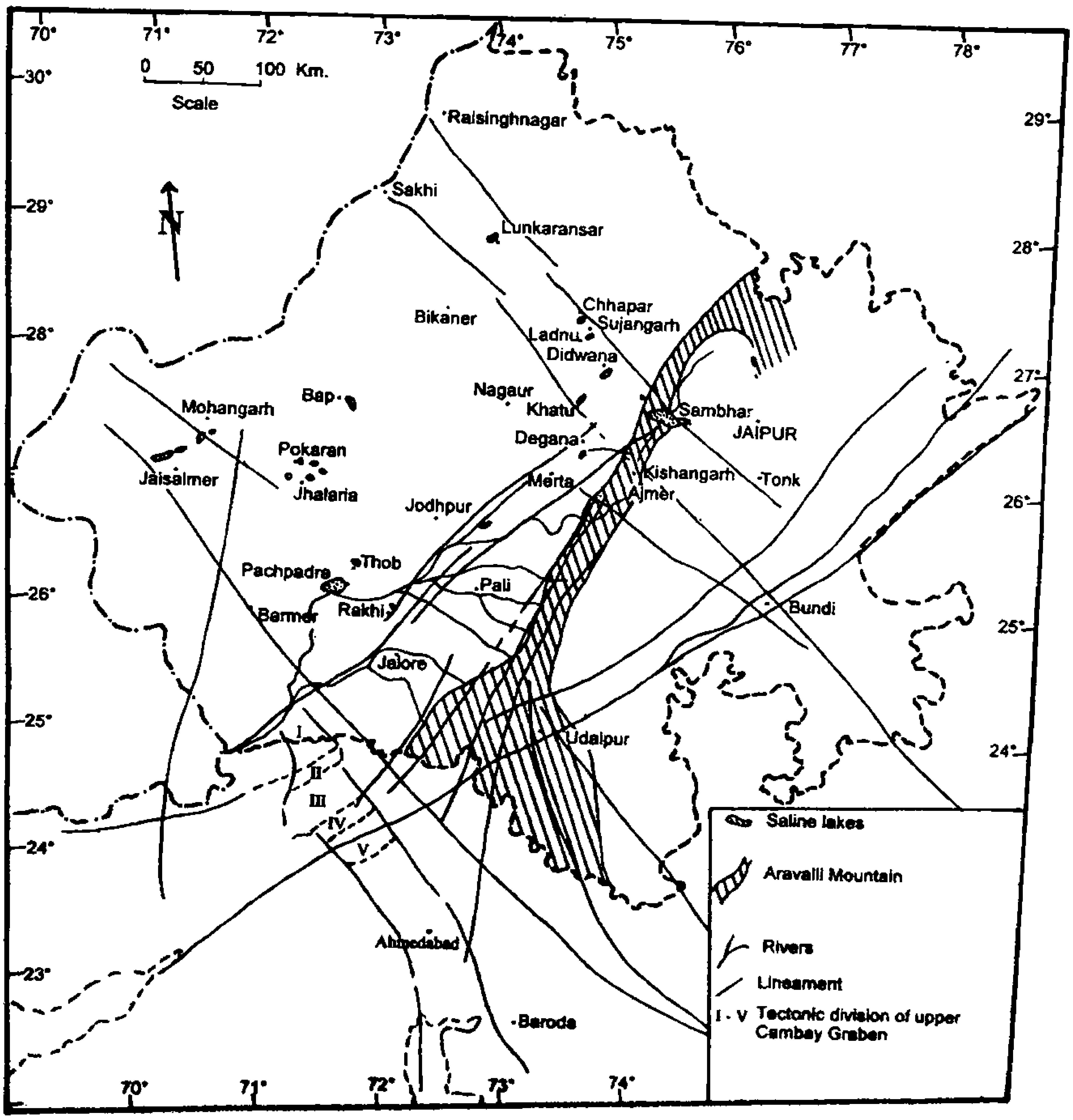


**Figure 1.** Schematic map of Rajasthan and northern Gujarat showing distribution of saline lakes and important lineaments. Noticeable is the occurrence of alternate 'highs' (horsts) and depressions (grabens) between the southern Luni basin and the Cambay graben. I, Sanchor graben; II, Tharad high; III, Paiyak depression; IV, Deodar high, and V, Patan depression.

dune-infested terrain. However, the depressions formed by this process are transient in nature and are subsequently covered with sand dunes. For the initiation of some saline lakes in the rocky tract of Jaisalmer region, Kar[9] suggested a theory of wind scouring of limestone by the quartz-dominated sand-particles, which ultimately created the basins for water accumulation. However, there are indications of riverine connections for almost all the major saline lakes in the region.

## Formation of playa lakes by segmentation of palaeochannels

Majority of the large saline lakes in western Rajasthan have riverine ancestry, formed by segmentation of stream channels. The rows of ranns that occur in the Jaisalmer–Mohangarh area provide examples of segmentation of a former stream. The four major lakes, Kharariwala Rann, Kanodwala Rann, Khara Rann, and Mitha Rann, are aligned in a NE–SW direction (Figure 3). All these seem to have been formed by the process of channel segmentation and the consequent formation of saline lakes due to impounding of water. Pachpadra lake in Barmer district also seems to have evolved by this process. Based on the study of aerial photographs, Ghose[10,11] was able to establish the presence of dead drainage channels in the Pachpadra area.

The Pokaran lake might also have a similar history of evolution. Isopach map of the lake deposits prepared by Rai[12] suggests existence of an east-west running palaeochannel towards the northern end of the present lake. The present NE–SW trending depression of the lake could be an extension of a former rann that developed over an earlier E-W trending abandoned channel.

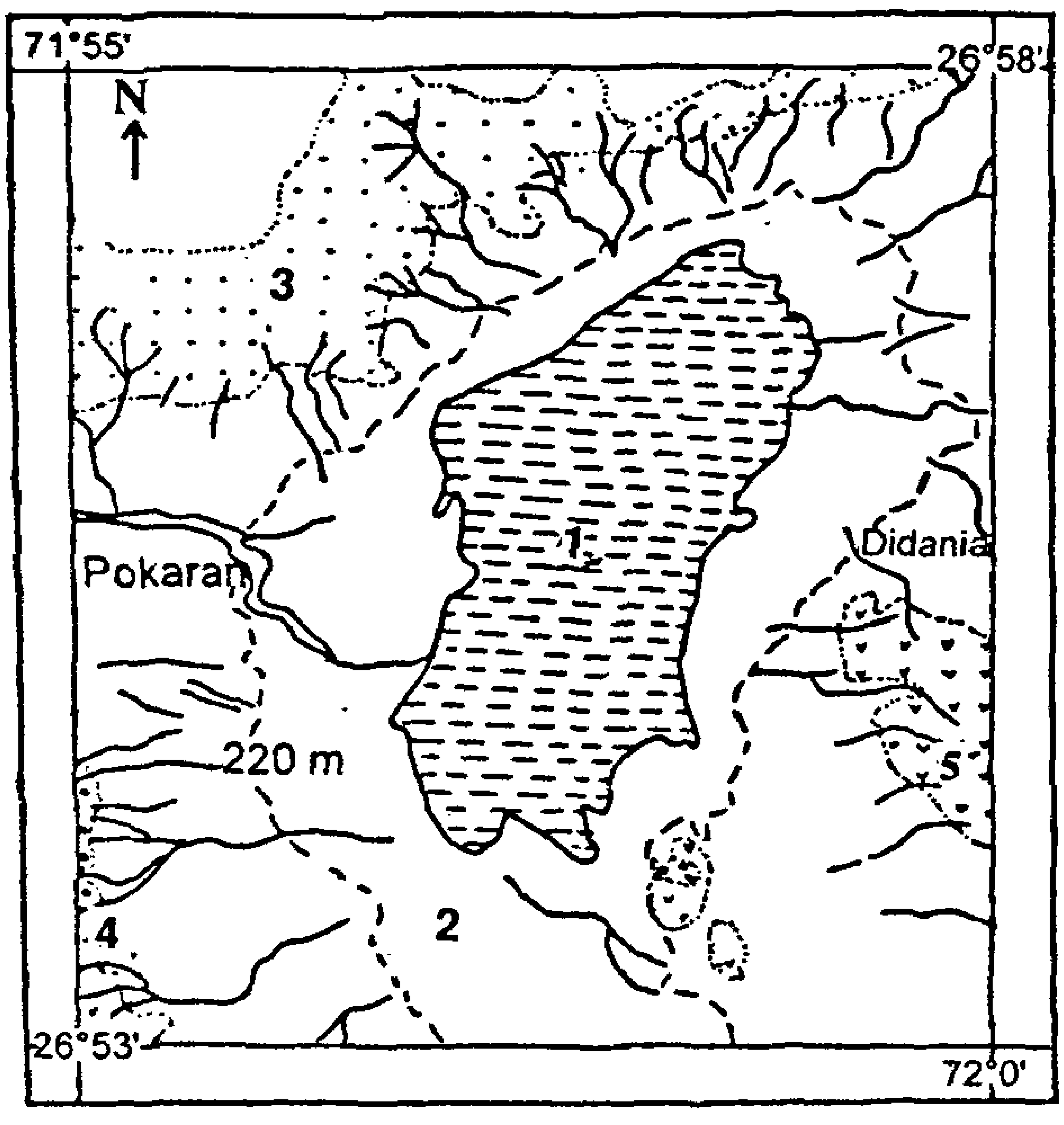


Figure 2. Pokaran saline lake showing characteristic centripetal drainage patterns. 1, Playa deposits; 2, Blown sand/fluvial deposits; 3, Sandstone; 4, Conglomerate; 5, Volcanics.

In the Luni basin, several segments of dead stream channels were identified by Ghose[10,11] and Ghose *et al.*[13] in the form of depressions and isolated channels disconnected from their head water sources.

The segmentation of river channels in a desert region can take place in several different ways. Agarwal[14] was the first to put forth the idea of segmentation of dried river channels by mobile sand dunes. Ghose *et al.*[13], extending an implied support to the sand dune model, further elaborated the process. According to these authors, the onset of aridity during the early Quaternary led to disorganization of the existing drainage system in western Rajasthan. The change over from a dominantly fluvial regime to an arid environment promoted aeolian activities. The dying river channels could not prevent formation of barriers in the form of sand dunes across their courses. The growth of sand dunes astride a river channel appears to be the most simple and effective mechanism of channel segmentation and formation of isolated pools of water but it cannot explain the evolution of many lakes like the Pokaran, which is situated in a virtually dune-free area, bordering a rocky 'hamada'.

An alternative to the sand dune theory is the model of excessive siltation at a river confluence leading to blockage of channels when the head water source is dried up. The evolution of the Pachpadra lake is the case in point. Relying heavily on the interpretation of aerial photographs, Ghose[10,11] proposed that the Pachpadra was a confluence of two flourishing streams that flowed as palaeo-Luni in the south. During the wetter climate, the streams carried enormous volume of silt, a significant part of which was deposited at the confluence of the streams, but the silts were flushed out of the confluence. When the aridity set in, the flow was drastically reduced

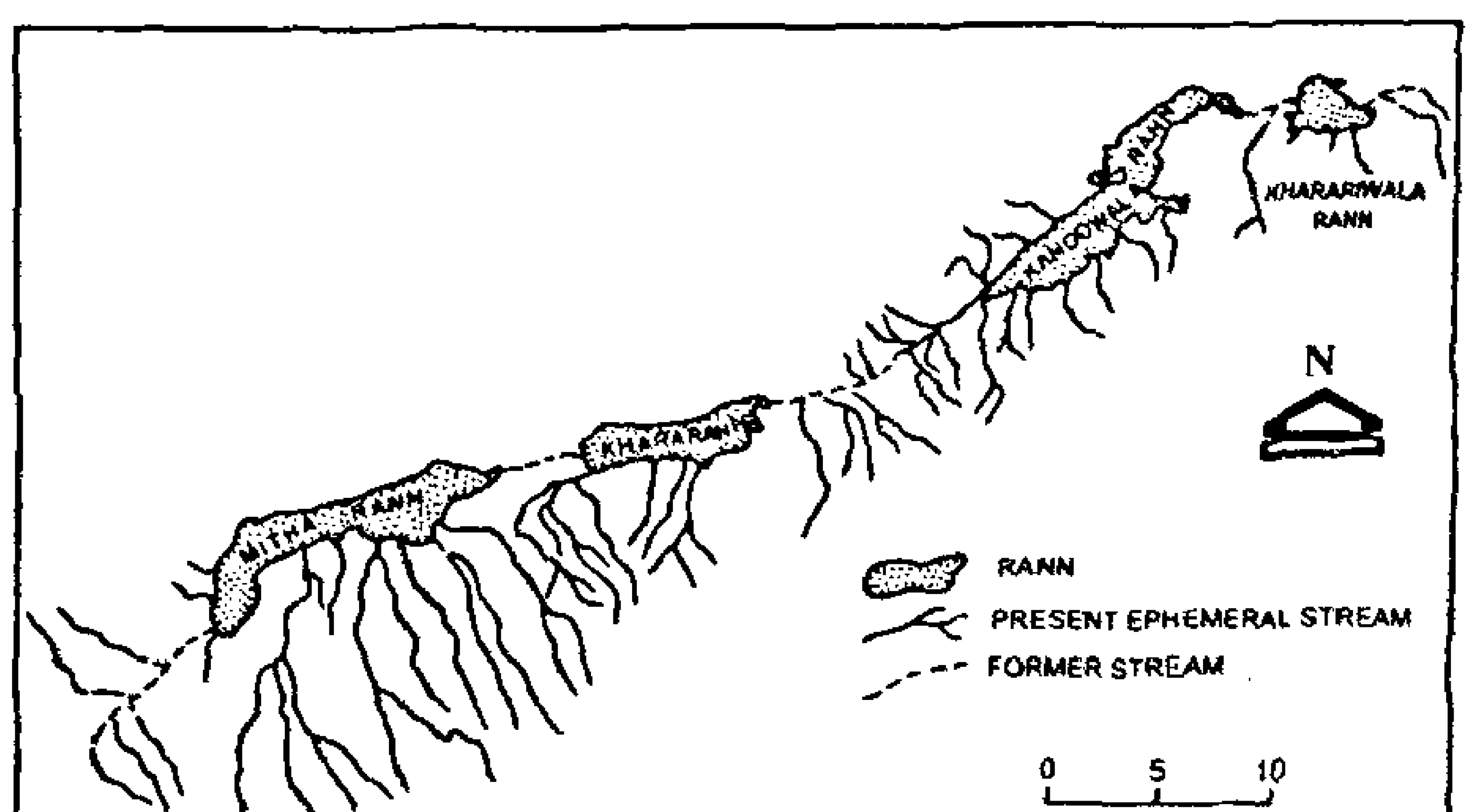


Figure 3. Rows of playa lakes evolved due to segmentation of a stream channel, north of Jaisalmer. (After Singhvi and Kar[1].)

and the silt load could not be carried beyond the confluence. The trapped silts caused total blockage of the river mouth, which eventually turned into a shallow saline depression.

## Stream trap theory of saline lakes

The stream trap theory of Kar[15] depicts the process of formation of stream valleys in between successive longitudinal dunes, which grew as sub-parallel arms from isolated hills that lay astride the dominant wind direction. The gaps between the hills were also filled up by sand dunes. The streams flowing away from the dune-bounded basins were pirated to contribute water in the newly constituted basins. This theory seems to explain satisfactorily the formation of a few saline lakes like the one at Didwana and a couple of others to the south-east of Degana (Figure 4). However, many other lakes of western Rajasthan appear to be due to segmentation of palaeochannels by some processes other than the mechanism of stream trapping.

## Neotectonism and lineament control of saline lakes

Several possible relict palaeochannels of the Saraswati and the Drishadvati river systems as also that of the present Luni follow a NE–SW trend. This is the trend not only of the Aravalli mountain but also of a set of major lineaments in the region, which controlled the palaeo-drainage pattern in western Rajasthan[16,17]. On the other hand, the NW–SE trending lineaments have guided the stream channels that descended from the Aravalli Mountain[16]. Although the tracing of lineaments is highly impeded by the thick cover of sand in the desert region, detailed studies made in northern Gujarat, specially in the Kachchh region[18–22], helped to elucidate the significance of the two lineaments (NW–SE and NE–SW) in controlling the Quaternary geomorphology of the region. In the area between the Luni basin and the Gulf of Cambay the neotectonic movements along NW–SE and NE–SW trending sets of lineaments produced a series of rhomb-shaped alternating horsts and grabens. From south-east of the Luni basin, the structures have been identified as the Sanchor graben, Tharad high, Paiyak depression, Deodar high, and Patan depression (Figure 5). In contrast to the 'highs', the grabens are the zones of very thick Quaternary sediments[23,24]. A very similar situation seems to have developed in the desert region of western Rajasthan. There is a strong possibility that most of the NE–SW oriented saline lakes are situated in the rhombic blocks of grabens bounded by the NE–SW trending lineaments. The isopach map of the Pokaran lake[12] not only indicates presence of a thick E–W trending sediment prism in the north, but also a sharp change of thickness across the NE–SW trending eastern boundary of the lake. This suggests that the Pokaran lake evolved as a graben (or possibly a half graben) between NE and SW trending faults. A striking feature

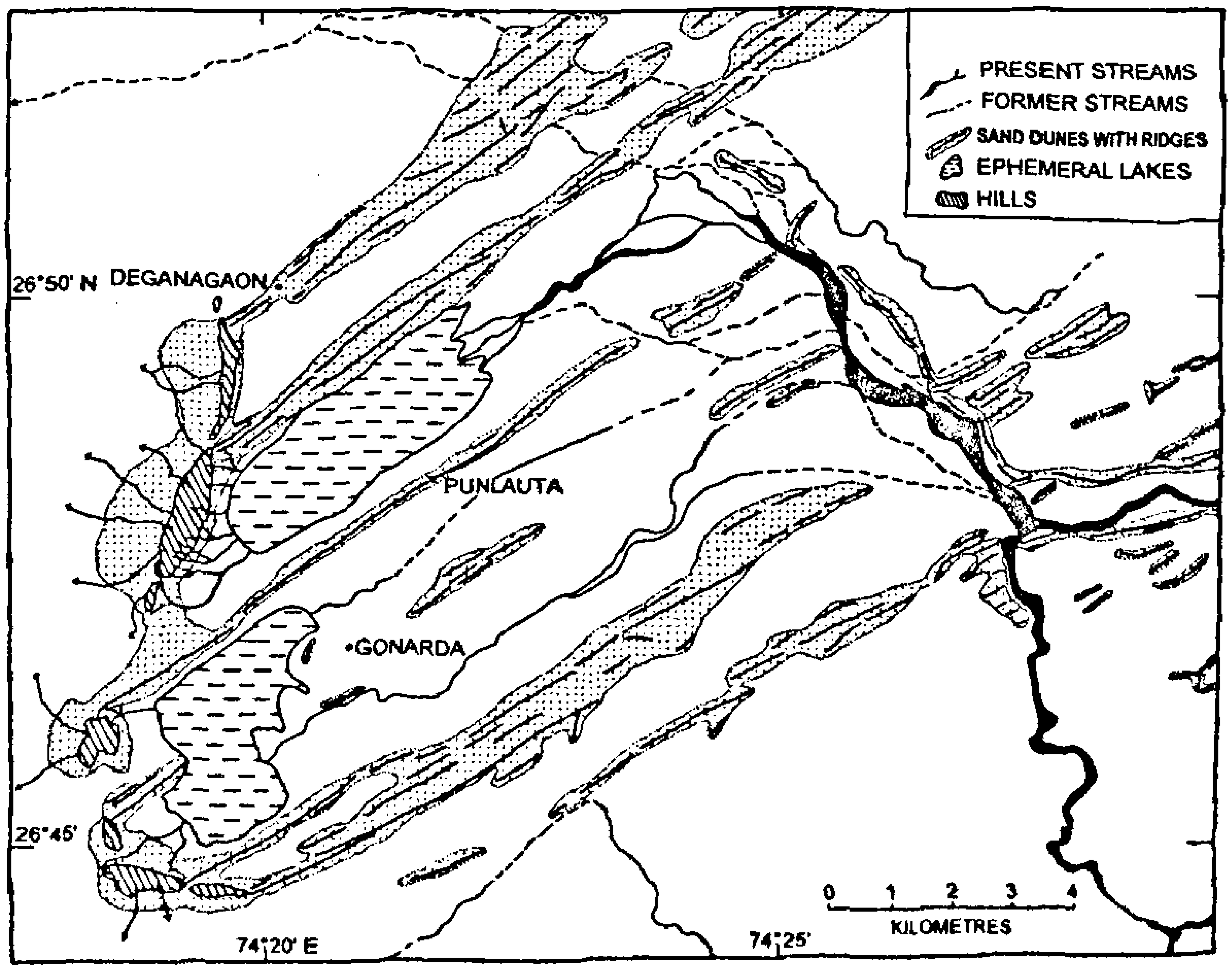


Figure 4. Morphological setting of Punlauta and Gonarda lakes, south of Degana elucidating the stream trapping hypothesis. (After Kar[15].)

in the spatial distribution of major salt lakes at Sambhar, Kuchaman, Didwana, Chappar, Sujangarh and Lunkaransar, is that these lakes are confined within a narrow belt bounded by the NW–SE trending Raisingnagar–Tonk lineament in the north and the Sakhi–Khatu–Kishangarh–Bundi lineament in the south (Figure 1). The narrow lineament bounded strip possibly represents a shallow NW–SE trending depression in the basement rocks, which is further segmented by NE–SW running sets of lineament faults. The discovery of two important NW–SE trending subsurface ridges (or horsts) by geophysical studies (the Delhi–Lahore ridge and the Jaisalmer–Muri ridge) implies the existence of linear grabens subparallel to these structures. Confirmation of the existence of NE–SW trending faults (lineaments) in western Rajasthan also comes from the mapping of a series of NE–SW trending lineaments (showing vertical movements) in the Luni basin by Dassarma[16], Kar[17,25], and Tiwari and Gangadhar[26].

Intersection of two sets of lineaments divided the western Rajasthan crust into a number of rectangular blocks. Differential movements along these blocks seem to have controlled the Quaternary tectonics of the region. Known as 'block tectonics', this type of tectonic movement operated in the same way as in the case of eastern Kachchh region of northern Gujarat, at least during the late Quaternary. Such neotectonic activities have considerably influenced not only development of the land form patterns but also in disorganizing the drainage network. This geomorphotectonic process which was involved in shifting and segmentation of dried stream channels, eventually led to formation of many playa depressions and saline lakes. In addition to the block tectonic model, segmentation of most of the NE–SW trending channels could have been due to movements along NW–SE trending lineaments. Upliftment and tilting of lineament bounded blocks appear to be the most effective mechanism that caused segmentation of channels, drainage reversal and ponding[16,27].

The largest saline lake, the Sambhar which is situated astride the NE–SW trend of the Aravalli mountains, appears to have evolved by a process different from what has been suggested above. According to Sinha-Roy[28], the Sambhar originated as a pull-apart structural depression due to strike-slip faulting along curvilinear planes. According to him, the lake is situated at the junction of two lineaments. Dassarma[27], however, suggested that the pull-apart depression at Sambhar could be due to rotational movements of the fault-bounded blocks.

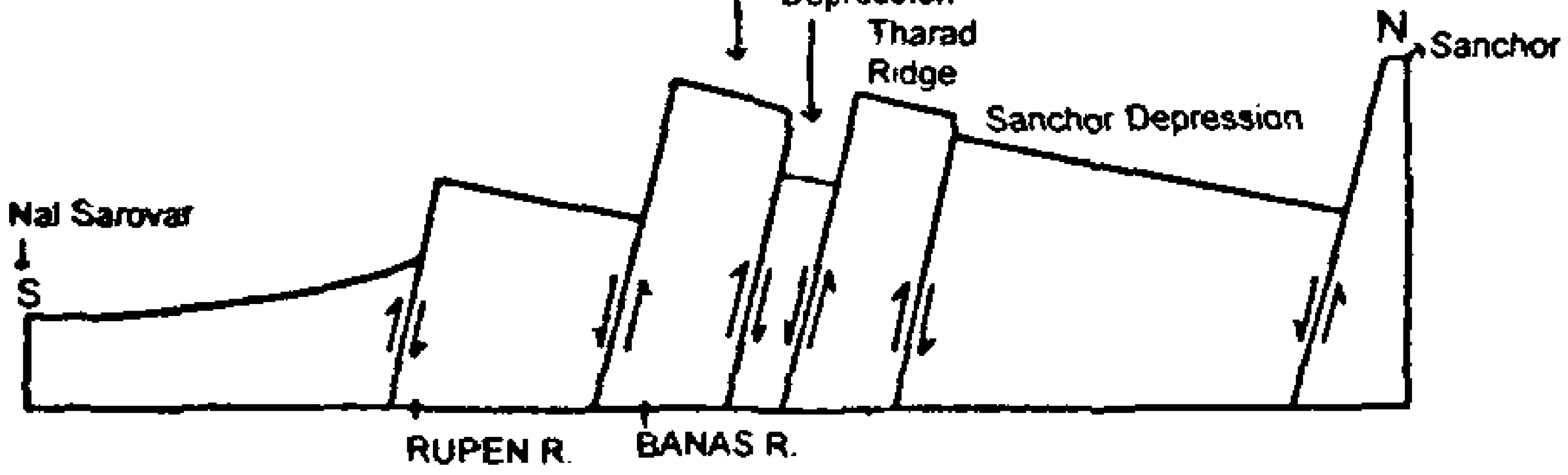


**Figure 5.** Schematic illustration of fault blocks showing alternate horst-graben disposition in the Sanchor–Nav Sarovar region, northern Gujarat. (After Sridhar *et al.*[22])

The pattern of distribution of lake sediments in the Sambhar basin[29] provides indication of deposition in a Recent to sub-Recent graben formed over a fluvial channel. It is, however, difficult to prove whether the down-sagging was due to the formation of pull-apart basin, either due to movements along curvilinear planes, or due to rotation of fault-bounded blocks. Detailed structural studies may be necessary to conclusively prove the actual mechanism of neotectonic movement, which led to the formation of such a large depression. However, the trends of the lineaments as well as the known patterns of neotectonic movements along some of these lineaments, might suggest rotation of a NE–SW trending rhombic depression to the present position.

## Conclusions

Geomorphological studies on the saline lakes of western Rajasthan help in bringing out the different physical causes of segmentation of dwindling stream channels. The process eventually led to the formation of playa lakes. Formation of shallow playa depressions by deflation of sand cover is a common process of formation of small-scale ranns. Most of the larger saline lakes have riverine connections. These lakes seems to have evolved by the process of segmentation of stream channels. Blocking of stream valleys could be due to the formation of sand dunes across declining stream channels. Segmentation of channels could also be due to excessive deposition of sediments at the river mouths, particularly when the channel was active and the river carried a huge load of sediments. There are also a few cases of stream trapping under favourable situations. Nevertheless, the most effective process of stream segmentation was, perhaps, due to the formation of linear horsts (or fault bounded uplands) across NE–SW trending river channels. These horsts successfully blocked the river channels, leading to segmentation and ponding. Concentration of a large number of saline lakes between two important NW–SE trending lineaments not only suggests development of a linear depression or graben, but also its segmentation into blocks by differential movement along NE–SW trending faults. Formation of regional horsts and grabens subparallel to the two trends, NW–SE and NE–SW, seems to have assisted in disorganization and shifting of stream channels. Based on the geophysical studies in the Barmer district in western Rajasthan, Singh and Srinivas[30] suggested that the change in the course of palaeochannel followed the NE–SW and NW–SE trends of major lineaments. According to these authors, the gravity anomaly caused by the major in-homogeneities in the crust might have controlled the direction of palaeochannels. Tiwari and Gangadhar[26], from their study of the Luni drainage system, have also highlighted importance of the aforesaid lineament trends in the process of drainage disruption and the topographic inversion.

There is overwhelming evidence to prove that a great majority of saline lakes (other than the playas formed by deflation) are related to disorganization of stream channels during the late Quaternary period when the aridity had also set in. The use of satellite imageries led to the discovery of a large number of sand-covered palaeochannels and other features, suggesting vigorous fluvial activities in the Luni basin. Also implied in the detailed descriptions of Ghose[10], Ghose *et al.*[31,32] and Kar and Ghosh[33] is the existence of a former Himalayan river, system of the Saraswati and the Drishadvati. Remote sensing as well as field data further provide evidence of riverine connection for the Pachpadra lake, which according to Ghose[10] lies at the confluence of erstwhile channels used by large perennial streams. Existence of five perennial rivers is also implicit in the undistorted name of the place, Panchbhadra, (*panch* means five; *bhadra* stands for five flowing rivers; *cf. Tungabhadra*). Thus, concealed in the name of the lake is the reference that the place was a confluence of five generously flowing rivers (the *bhadras*). One of the five *bhadras* is believed to be the extinct Saraswati river. The large delta that lies at the mouth of Luni river, partly under the Great Rann of Kachchh, was presumable built up by the Saraswati river[34]. It may therefore be rationally concluded that the blotting out of the Saraswati river and its tributaries from the region had set in the process of segmentation of the abandoned river channels, and the consequent development of saline pools. The Sambhar lake might not have any direct link with river Saraswati or its tributaries. However, there are indications of fluvial activities preceding the formation of the graben. The formation of the Sambhar graben may be contemporaneous with the neotectonic processes that led to shifting and effacing of erstwhile rivers.

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