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# Remote Sensing Based Assessment of Neotectonics and Morpho-Structures of Krishna Sub-Basin: A Preliminary Probe for Oil and Gas Occurences

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**Summary**

*Present is the key to the past. Understanding the present day landforms, their genesis and behavior also helps us understand the existence of their subsurface counter parts through time and space, when subsurface samples are encountered in the course of exploration. Thus with this idea a careful study of Krishna delta is conducted to understand the evolution and behavior of the concealed modern delta. It is a covered basin, mere fringe part having some exposures, limiting the conventional geological methods of hydrocarbon exploration. Thus to be competitive and yet effective, Remote Sensing is used for preliminary assessment in this direction.*

*The work is focused to learn the very cost effective method of remote sensing in exploration of oil and gas where in the most recent idea of neotectonics is worked out to probe the signatures of the oil and gas occurrences in the lap of present geomorphological set up so formed by the active neotectonics in the area.*

*The work analyses the satellite data with intensive geomorphological studies based on which lineaments and anomalies were identified with delineations of their corresponding morpho-structures if any. Two major lineaments in the NE-SW and NW-SE directions indicate the influence of the Eastern Ghats and Dharwar trends of which the former is predominant. The dominant lineaments run parallel to the basin margin lineament, however a few major cross trends are also seen. Correlation of observations with the published gravity-magnetic and 2D seismic data (source: DGH website) confirms the delineations by revealing the signatures of their subsurface structural controls. The observations and interpretations were translated into various maps upon which the present lines of possible locales of oil and gas occurrences are precisely suggested subject to further detailing of the areas so identified.*

## Introduction

The Krishna delta falls within 80° 35’ to 81° 05’ east longitudes and 15° 40’ to 16° 30’ north latitudes. It originates from the Mahabaleshwar in Western Ghats and builds a prominent river dominated, bird’s foot delta at the coast of Bay of Bengal in the state of Andhra Pradesh. It lies north of Pennar delta and just south west of Godavari delta intervened by a prominent strand plain and a shallow Machhilipatnam bay. Krishna-Godavari delta complex makes an extensive delta-strand plain complex on the East Coast of India.

Krishna sub-basin within Krishna-Godavari Basin is a continental passive margin pericratonic basin on the East Coast of India. The basin got initiated through rift/syn-rift tectonics between Permo-Triassic to Early Cretaceous and is essentially characterized by lagoonal to fluvial to occasionally brackish water sediments. The northeastern part of the present onland basin was part of an intra cratonic rift set up till Jurassic that constituted the southeastern extension of NW-SE trending continental rift valley sloping northwards.

Krishna in particular is delimited by NE-SW trending Bapatla horst to its eastern side. However, the deltaic system of Krishna falls between Bapatla horst and kaza-kaikalur horst as shown in figure 1.

In the present work the Krishna delta which is a sub basin in Krishna-Godavari sedimentary basin, a major and most attractive exploration target of India, is taken as a separate case for the study.

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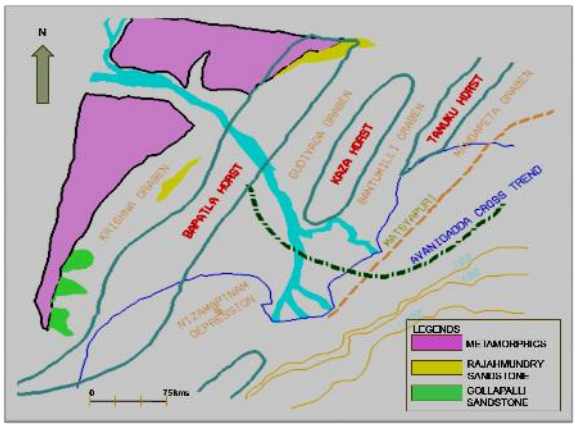


Figure 1 Tectonic map

## Theory and Methodology

Remote sensing works on the basic philosophy that subsurface phenomenon or surface features influence the surface cover. Numerous evidences also exist to support the expression of the subsurface on the surface though exact nature is difficult to define. Thus an understanding of the principles involved in Geological mapping is important in the basic analysis of remotely sensed data.

The main objective of the work was to develop a methodology to integrate geological method of exploration with that of remote sensing and geophysics. Krishna sub basin has long received lesser attention as compared to its Godavari counterpart. Therefore this work aims to identify avenues in the Krishna sub basin too and contribute to the ongoing exploration activities in the area.

The work uses Landsat ETM data which is downloadable for free as it works in international public domain. The work also makes use of published gravity-magnetic and 2D seismic data available on DGH website.

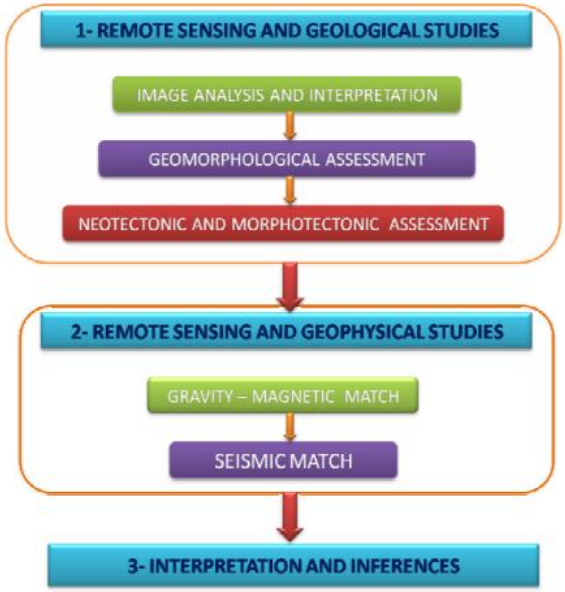


Figure 2 Methodology

## Geomorphological Studies

Geomorphology is the systematic study of landforms and the interpretation of them as records of past-history. This frames the first step in the probe for oil and gas. In most cases, geomorphology mimics the subsurface how-abouts which is also strongly supported by Walther's Law which proposes that the vertical progression of facies should be the same as corresponding lateral facies changes.

Probably, this idea makes the geomorphological studies to be an opening and deciding factor to consider the prospectivity of any basin for any furtherance of oil and gas exploration.

On the basis of the geological associations of the depositional environments with respect to their characteristic signatures in the satellite images used, the complex deltaic system of Krishna has been simplified in the Subaerial delta plain *(Fluvial to Fluvio-Marine Environment)* and Subaqueous delta plain *(Marine environment)* with their corresponding Topset, Foreset and Bottomset deltaic environments. Each of these classes is further subdivided into their geological components which are discussed below.

Fluvial plain is a composite of many landforms viz; natural levees, point bars, channel bars, abandoned channels, mender cutoffs and flood plains. The overall boundary of the fluvial plain is not clear enough to mark it with a confidence but the interpretation tools of remote sensing like tone, texture, association etc. could help mark this with a certain degree of confidence. Thus, this plain is interpreted based on the associations like abandoned channel, palaeo-drainage, tone, texture, colour etc. Typical examples of point bars, in the Hamsaladivipaya distributary; channel bars, in Krishna main channel; and fluvial marsh can be seen in the study area.

The fluvial plain of Krishna river system shows maximum development in the direction of palaeo-drainage course through Gudivada, and development with the south westward margin of the drainage through Hamsaladevi existing as a distributary of Krishna which is at its abandoning stage.

The eastern limit of the fluvial plain is well defined on the basis of palaeo-drainage markings discernible in band 6 of Landsat ETM. However, the western margin is unclear and has been taken till palaeo channel seen south of Tenali and grades with the non-deltaic plains. In the area around Avanigadda, the fluvial plain has buried or destroyed the palaeo beach ridges as is apparent from the obliterated beach ridges in the image.

The deltaic plain of Krishna is wider as compared to its Godavari counterpart. There are larger and extensive mudflats in the Krishna river deltaic plains. This indicates that the Krishna river system has a greater sediment flux, whereby offshore bars are built under the tidal influence, supporting mudflats on the landward side.

The sediments brought by the rivers are discharged into the sea both during the normal and flood times. The action of the sea is to rework these sediments which are then deposited as shoals and subsequently develop into spits and barrier bars. The spits developed towards the west of the mouth of Krishna river are both evolving towards becoming barrier bars as they support a large lagoon on their landward side and are curving landwards to join the coast. There are other examples as well of smaller spits seen at the mouths of distributaries of Krishna which is made of fine sandy material and ending into the sea. From the paleo-drainage and beach ridge developments, it is seen that there are two major depocenter in Krishna delta, one towards Machhilipatnam bay and another towards the Nizamapatnam area.

The delta shows a continuous clockwise drift towards the southwest and in the process covering most of its flood plain with recent deposits. Therefore, the western margin of the Krishna delta is unclear. The maps from figure 3-8, demonstrate five order classification of Krishna delta based on physiographic positions, sedimentary environments and associated landforms.

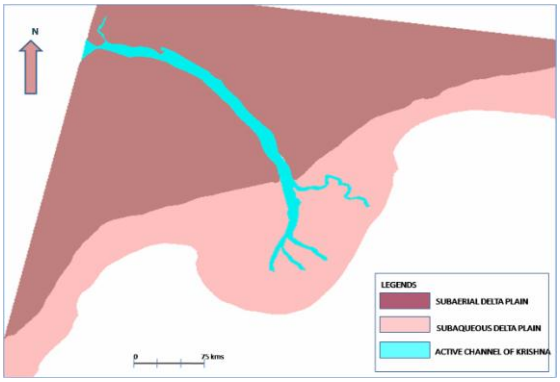


Figure 3 First order delta classification

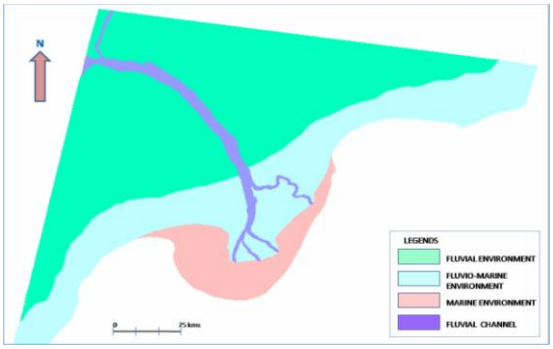


Figure 4 Second order delta classification

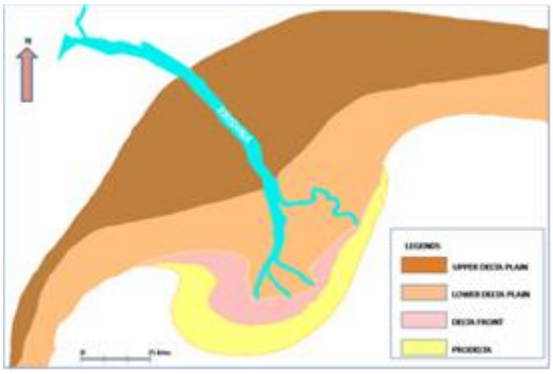

Figure 5 Third order delta classification

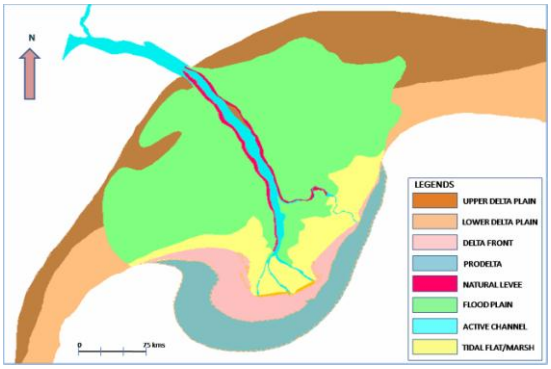


Figure 6 Fourth order delta classification

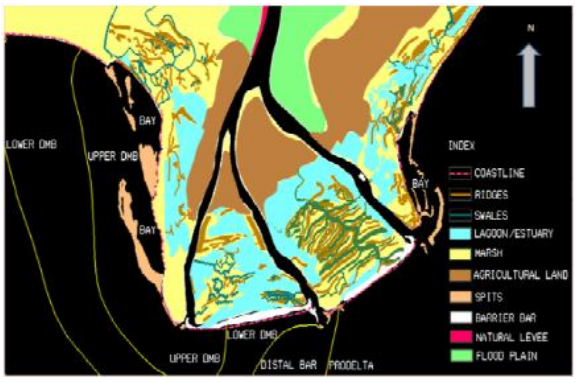


Figure 7 Fifth order delta classification


Figure 8 Sub-aqueous delta components

## Neotectonic Assessment

The structural plan of the Indian subcontinent explains that there are three major structural trends NW-SE, NE-SW and ENE-WSW directions representing Dharwar, Aravalli/Eastern Ghats and Satpura trends respectively. These trends are reflected in the grain of Precambrian rocks where the analysis of the strike of the foliations suggested these trends. These trends are responsible for the physiography of the subcontinent. The present work thus religiously takes this idea of Neotectonics into account and the delineations of such impressions over the surface is keenly investigated on the satellite data which is explained in detail in the further section.

The drainage of Krishna (and Godavari) river shows a south-westerly shift in its course. This is probably indicative of a gradual block tilting towards the south-west along active faults. The distributary arm of Krishna river at Hamsaladevi has been abandoned from the marine course of present day Krishna river. The migration is envisaged to be sudden or through piracy as the palaeo-beach ridges between the two arms are not destroyed. This is an anomaly or a micro high that persisted through time and obstructed the course of the river.

## Morpho-Structural Analysis

Morphostructures refer to the study of short-and long-term superficial evidences of neotectonic activity. The surface expression of endogenous mechanism driving the tectonic activity is always represented by relative movements such

as uplifting, subsidence and translation of the crust. The most sensitive parameter is the drainage and its relationship with structures which control the courses. The continuous processes of weathering and erosion lead to the formation of landforms manifesting the control of tectonics. Multi-sensor and multi-date remotely sensed data and advanced digital image processing techniques are extremely useful to observe and map morphotectonic features.

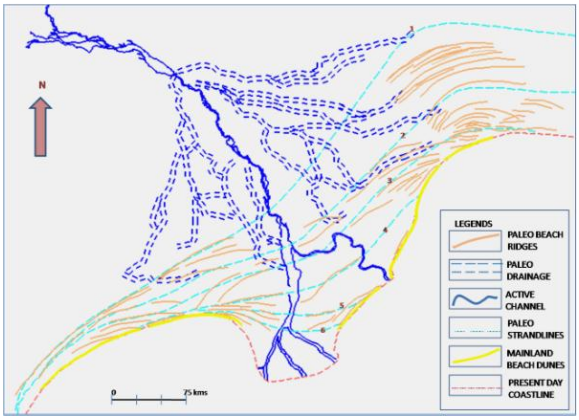


Figure 9 Map representing paleo landforms

In areas where rate of present day tectonism is considerable, several field indications can be directly observed. However, in other cases where rate of tectonism is mild or very slow, evidences mainly comes from morphotectonic investigations, which may demarcate the areas for detailed field investigations.

Morphostructural study of Krishna delta is based on the interpretation of lineaments, anomalies, geomorphology and their relationship with the subsurface set up.

***Anomalies***

Anomalies are primarily marked on the Geomorphological characteristics of the area. The river course migration, piracy, channel abandonment, channel shift etc. These entire phenomenon are dependent on the topography, sediment load and water supply and most surprisingly and never the less very important phenomenon i.e. neotectonic activities. The identification of anomalies calls for the possible reasons for their existence and thus leads to better derivation of the ideas mentioned above to give an appropriate explanation to the problem. In the light of these facts the anomalies are recognized on the satellite data mainly by the tonal contrasts (marked with yellow starred arrows) and drainage anomalies (marked as 1 & 2).

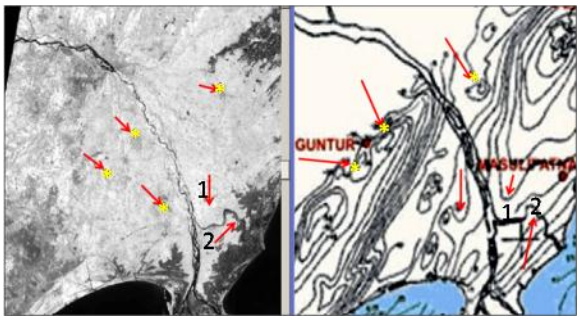


Figure 10 Anomalies and their signatures in the gravity data (source: DGH website )

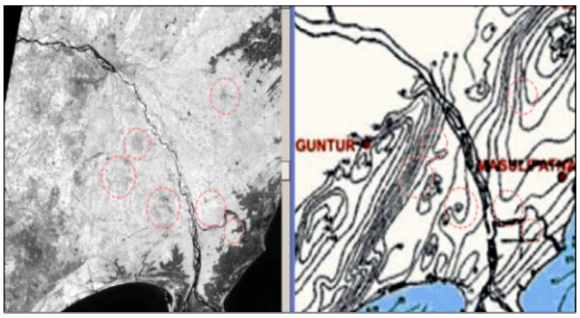


Figure 11 Anomaly correlation with gravity data (source: DGH website )

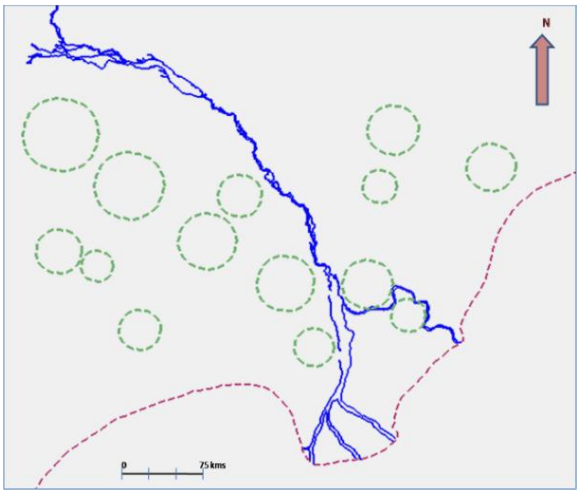


Figure 12 Interpreted geomorphic anomaly map

The correlation of the anomalies with their signatures on gravity has been done on the basis of the qualitative analysis of the contour patterns. For example, the distributary arm of

Hamsaladevi marks a paleo-relief or paleo high around which the river is deflected. Its signature in the gravity data can be assessed by anomalous nosing and notching of contours at the anomaly site on gravity map. This adds to the confidence level in demarcation of the anomalies. The anomaly map is given in figure 12 for peruse.

***Lineaments***

Lineaments are the linear feature present in the area. These could be exposed faults, fractures, weak zones, subsurface ridges, horsts etc. These features to a larger extent control the behavior of geological agents like rivers, lakes, lagoons, bays etc and thus control the depositional system in an area. For example, a partially exposed ridge or horst will control the course of the river channel making it characteristically parallel to the ridge. This may have become a palaeochannel course in the present picture. Thus identification of the lineaments may indicate about the paleo drainage based on the present day river morphology and may lead us to concealed depocentres in the area.

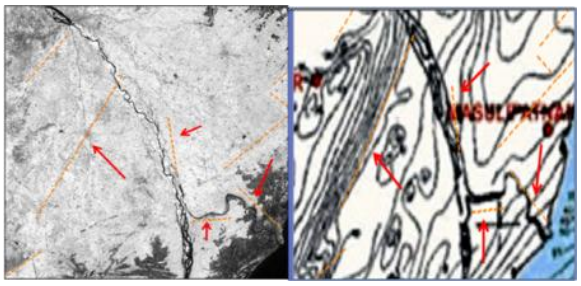

Figure 13 Lineament correlation with gravity data shown with arrows (source: DGH website)

Lineaments also control the accumulations of oil and gas in the basin, Saunders et al. 1973; Collins et al. 1975. In the satellite data the lineaments are marked on the basis of tonal contrasts, contour patterns and association.

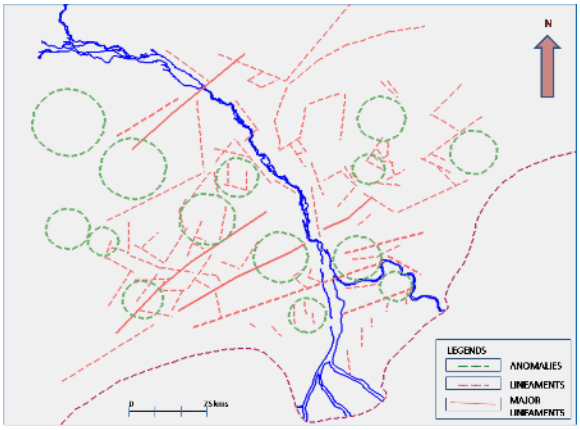


Figure 14 Anomaly and Lineament map represented by circles and lines respectively

The lineaments and the anomalies so marked in the area are consistent with the contour patterns of the gravity and magnetic data as can be seen in the figures 10, 11 & 13. The anomalies are matching with the anomalous contour patterns like nosing, notching and divergence, convergence patterns of the gravity data. The lineaments trend in almost parallel to sub parallel contours on gravity-magnetic data.

Major lineaments have been mapped from the Landsat ETM satellite data as shown in figure 14 & 15. The lineaments of the basin margin of Krishna-Godavari Basin are oblique to the strike of the Eastern Ghat rocks. Lineaments across the basin margin lineaments are also identified and marked. Lineaments extending from uplands to deltaic plains are also observed. A prominent cross trend namely Avanigadda cross trend marks the south-westerly shift of the delta lobe shown in figure 1 of tectonic map.

In this study an attempt has been made to correlate rather integrate the remote sensing observations with the already interpreted seismic data so as to correlate the marked lineaments with their subsurface signatures. Two of the prominent lineaments could be identified to be extending in the subsurface too as reflected in the interpreted seismic data of Krishna subbasin by Ravi Bastia, RIL as shown in figure 16. However, other lineaments identified do not fall on the sections provided by Bastia. Probably, other seismic lines along dip and along strike would definitely reveal subsurface signatures of other lineaments marked on the surface so far.

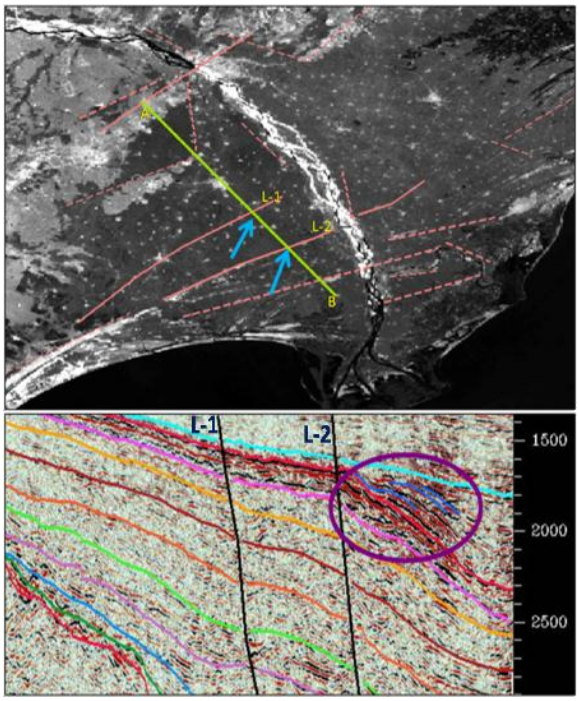


Figure 15 Lineaments' correlation with its expression on 2D seismic (source: DGH website )

## Conclusions

The Morphostructural study reveals a good intensity of river course migration on both the flanks. The paleo-drainage course of the river and beach ridge development, indicate two major depocentres, one towards Machhilipatnam bay and another towards the Nizamapatnam bay. Six palaeo-strandlines are seen as discontinued but aligned, curvilinear, regionally extended morphostructure in upland.

The Krishna delta shows a continuous clockwise drift towards the southwest and in the process covering most of its flood plain with recent deposits. Therefore, the western margin of the Krishna delta is not clear.

The distributary arm of Hamsaladevi marks a paleo-relief or paleo high around which the river is deflected, marking a prominent geomorphic anomaly.

Two major lineaments in the NE-SW and NW-SE directions indicate the influence of the Eastern Ghats and Dharwar trends of which the former is predominant. The dominant lineaments run parallel to the basin margin lineament, however a few major cross trends are also seen.

In the light of the neotectonic setup and the morphostructural analysis, it is idealized that the hydrocarbon accumulations might have migrated from their original place of generation. This explains why some of the mapped structures were probed dry. Probably the reason behind is the neotectonics. This has led to the newer prospects in the area *(marked with circles in figure 16)* which can be identified on the basis of the lineaments so marked in the work.

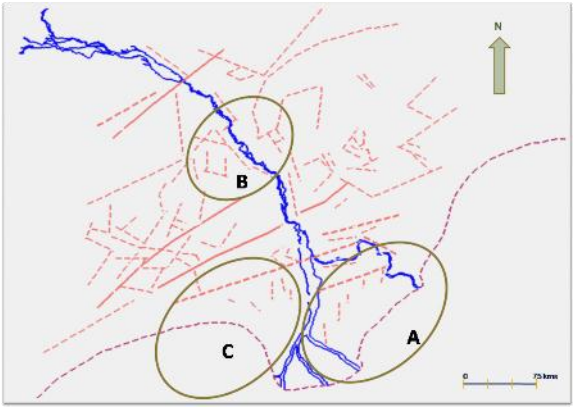


Figure 16 Probable locales (in circles) for HC occurrences subject to further detailing

In the light of the fact that present channels have been shifted along lineaments, the trend remain active throughout the geologic past and act as conduits for the hydrocarbons migration in the area in case of structurally controlled migration. Southwest progradation of delta indicates southwestward slope leaving areas 'A' and 'C' as areas for up dip migration in case of stratigraphically controlled migration through such conduits. Similar is the case with northwestward depocenter. Area 'B' also holds the similar idea with the occurrence of major lineaments which may apply the former principle. A good number of gas seepages have been reported at these places various times over the years during drilling of bore wells for water and, by other agencies like ONGC (during seismic shot hole drilling) and AMD (while exploring for heavy minerals). Some of these gas seepages have been investigated by ONGC *(Kamaraju et. al, 2008)*.

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