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Drainage Mapping-Supplementary tool to Seismic for Detecting Buried Structures

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Summary

In most hydrocarbon bearing covered basins structures can be delineated easily in the deeper horizons, no such structural features are apparent in the shallower horizons of the basin in conventional seismic data. To overcome this problem drainage based geomorphic analysis had been used as an tool to define faults in the surface that had been correlated with sub surface faults from seismic data to decipher structures in the shallow sediments where seismic signatures are absent. This procedure had been tested successfully in four blocks of Himalayan Foreland in West and East ganga Basin, Purnea Basin and Bengal Basin and this tool can be used as an effective and low cost complementary tool to conventional seismic exploration as well as it can serve as a guideline for seismic reinterpretation of a basin.

Introduction

In any particular basin, alluvial rivers are very sensitive to tectonic events that may produce longitudinal and lateral changes in stream gradients resulting in channel pattern shifts and diversions. Most of these tectonic events are recorded and reflected in drainage characters and imply the presence of active subsurface structural elements (Burrato et al, 2003). As such the study of drainage morphology supplements geophysical investigations in delineating sub surface structures especially in cases where the sub surface data is not available or its quality is not proper.

In this paper an attempt has been made to correlate structures interpreted from sub surface data extracted from seismic studies with the structures interpreted from morphotectonic data that are limited to the surface. Drainage analysis based on anomalous drainage behavior and drainage patterns with respect to terrain slope had been used to delineate micro faults or micro geomorphic linears that can be joined as per their trend to define surface faults.

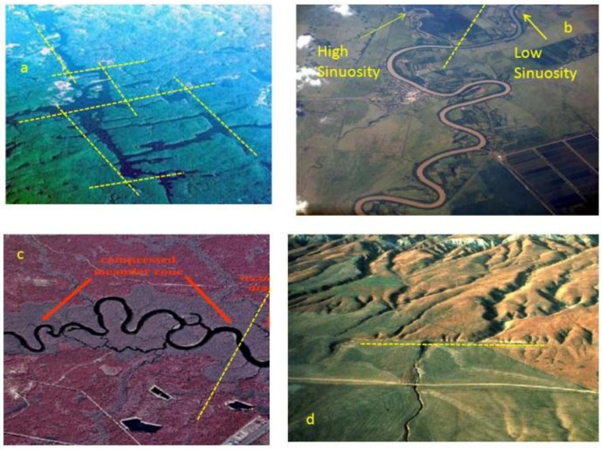

Fig1: Satellite images showing relationships of surface drainage with faults (marked in yellow) generating different structure controlled anomalies like a) rectangular drainage, b) sinuosity variations c) compressed meanders and d) drainage offsets.

Though in a section, faults are defined as surfaces with an appreciable displacement, in plan they can be identified based on their relationship with drainage. Such relationships are manifested as drainage characters like Rectangular Drainages, Drainage Offsets, Sinuosity Variations and Compressed meanders and conversely these features could be identified to delineate probable faults affecting the terrain (Fig 1).

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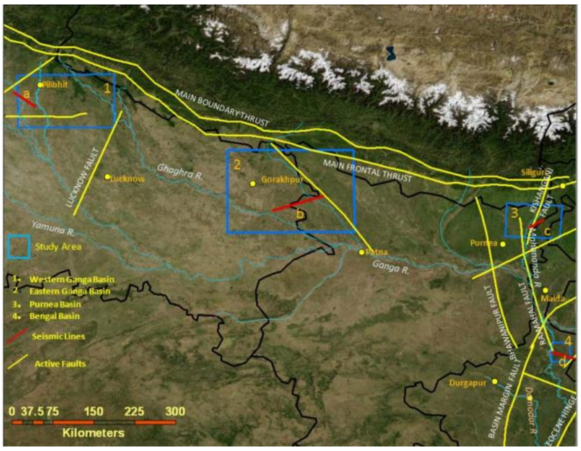


Fig2: Study area showing different blocks of study 1) Western Ganga basin 2) Eastern Ganga basin 3) Purnea basin 4) Bengal Basin with major drainage in the area as well as tectonically active faults. The seismic lines a, b, c, d of the above basins are the lines of study.

Four areas had been delineated for the study, all of them lying in the foreland part of the Himalayas in the Indo Gangetic Plains and are alluvium covered with no direct indications of structures visible on the surface. However all these covered areas are found to be neotectonically active with abundant evidences (Shukla & Raju, 2008, Jain & Sinha, 2003, Parkash et al 2000, Singh et al, 1996 for Ganga Basin, Agarwal, 1986 for Purnea basin, Agarwal, 1991 and Babu, 1976 for Bengal basin) suggesting the presence of reactivated buried structures below the terrain.

Additionally it is observed from seismic data available in these areas that though structures can be delineated easily in the deeper horizons, no such structural features are apparent in the shallower horizons of the basin which might be due to water saturated unconsolidated lithology or due to structures below seismic resolution (Fig 3).

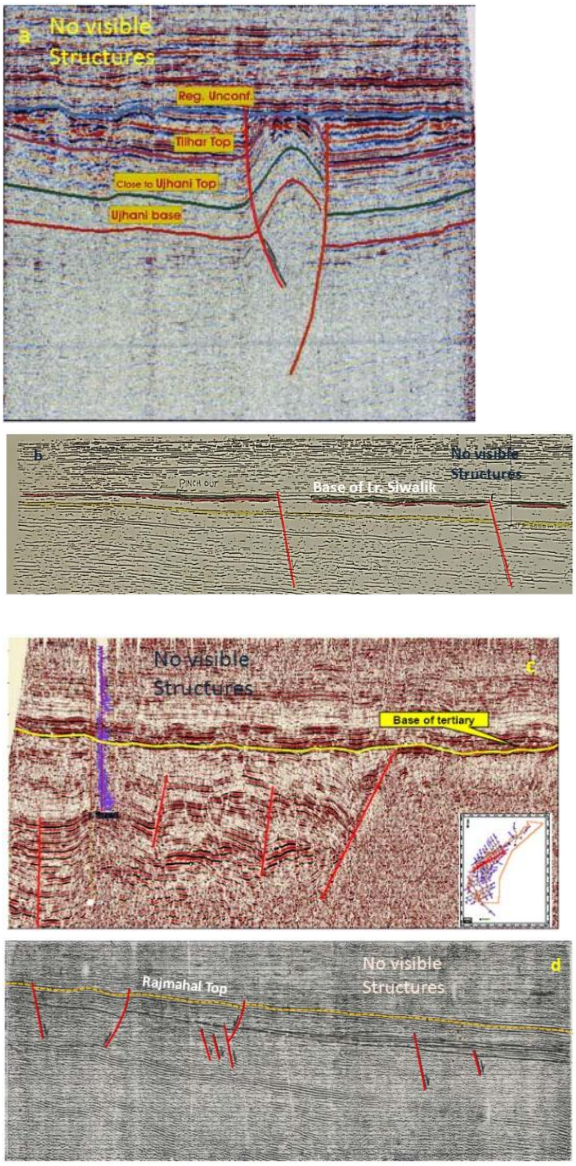


Fig3: Seismic sections along line a, b, c and d in Western Ganga basin, Eastern Ganga basin , Purnea basin and Bengal Basin respectively showing no visible structures in younger sediments though deep seated structures are visible.

Such drainage based geomorphic studies can help to delineate structures in terms of faults and highs in the surface and a positive correlation between these interpreted structures in the surface and the deep seated sub surface structures suggest that these structures are basically penetrative and continuous from surface to their interpreted sub surface extent implying their existence even in shallower sub surface levels. This premise had been applied to all the areas of study mentioned above to define structures in shallow sediments.

Study Area & Tectonic History

The area for the study consists of four blocks (Fig 2) namely, the Western Ganga Basin, Eastern Ganga Basin, Purnea Basin and Bengal Basin in a grossly similar geological setting with their terrains drained by Ganga and its tributaries.

1. Ganga Basin: The Ganga Basin developed as an Intra-Cratonic Rift during Meso-Protertozoic in extensional settings and subsequent to the collision of India with Eurasian Plate at 45Ma changed to a convergent geotectonic setup forming an Active Foreland Basin. The Faizabad Ridge that represents the northeastward subsurface projection of the Bunelkhand Massif further subdivides the Ganga Basin almost equally into a Western Ganga Basin with Sarda Depression and an Eastern Ganga Basin with a Gandak Depression.

2. Purnea Basin: Purnea Basin located in eastern part of Bihar and North Bengal, also developed initially as an Intracratonic Rift basin during the Permian Gondwana fragmentation and then as a result of tectonic overloading during Himalayan orogeny culminated into a foreland setting.

3. Bengal Basin: Bengal Basin is located in the Himalayan Foreland at the junction of Indian, Eurasian and Burmese plates that forms the western part of the Assam-Arakan Fold Belt. The tectonic evolution of Bengal Basin initiated as a Divergent Basin with the development of rift related grabens formed in response to the breakup of Gondwana during Permo-Carboniferous. However, Post-Eocene till now, collision of the Indian Plate with the Eurasian and Burmese Plate in the north and northeast respectively converted it into a convergent margin basin causing it to be neotectonically active.

Thus all these four basins are found to have suffered at least two phases of deformation with an initial extensional setting followed by an ongoing compressional episode. This implies that deformation structures produced as a result of the initial tectonic episode and confined to older sediments must have been affected by the later phase of compression related stresses leading to their reactivation. As this compressional phase is in continuous even in the present day it is probable that the reactivated faults might even deform the surface sediments exercising some amount of structural control over the drainage.

3. Geomorphic Analysis & Correlation

3.1 Study area **Block 3** falls in the Purnea Basin drained by the Mahananda River and its tributaries with a regional south-south easterly slope of the terrain resulting in a dendritic pattern of drainage. A detailed study of the block based on the drainage characters revealed a number of structurally controlled drainage anomalies especially in the lower order tributaries of these trunk drainages.

These structurally controlled drainages had been identified from anomalous drainage patterns classified into (a) Drainage Offsets (b) Rectangular Drainages (c) Rectilinear Drainages (d) Compressed Meanders and e) Sinuosity Variations and on basis of these anomalies, microgeomorphic linears had been identified on the surface. These microgeomorphic linears had then been joined as per their prevalent trends and earthquake epicenters in the area which also acts as another evidence of neotectonic reactivation to reconstruct probable regional scale faults affecting the surface of the terrain (Fig 4 A & B).

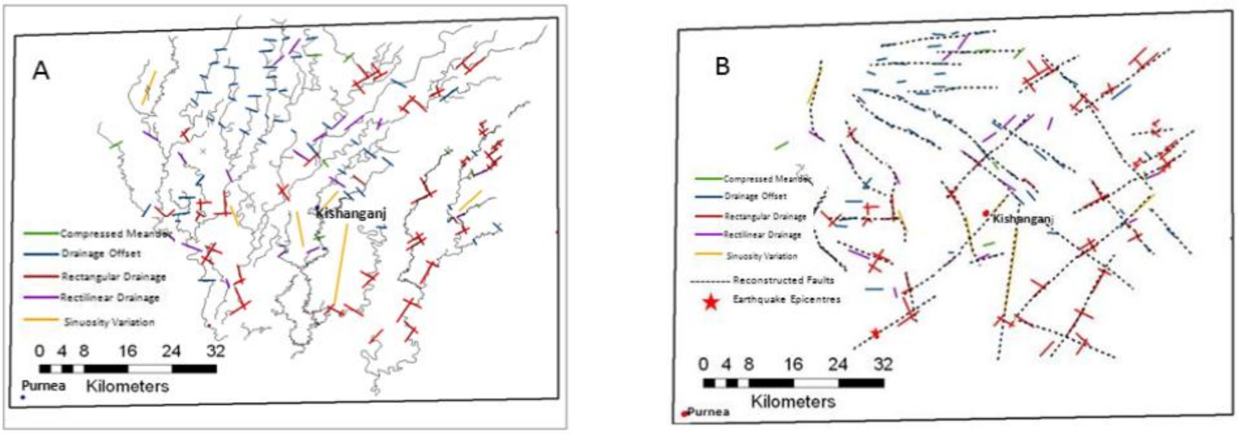


Fig4: A. Microgeomorphic linears defined on basis of structure controlled drainage in study area of Purnea Basin **B.** Microgeomorphic linears joined to define regional faults in the study area.

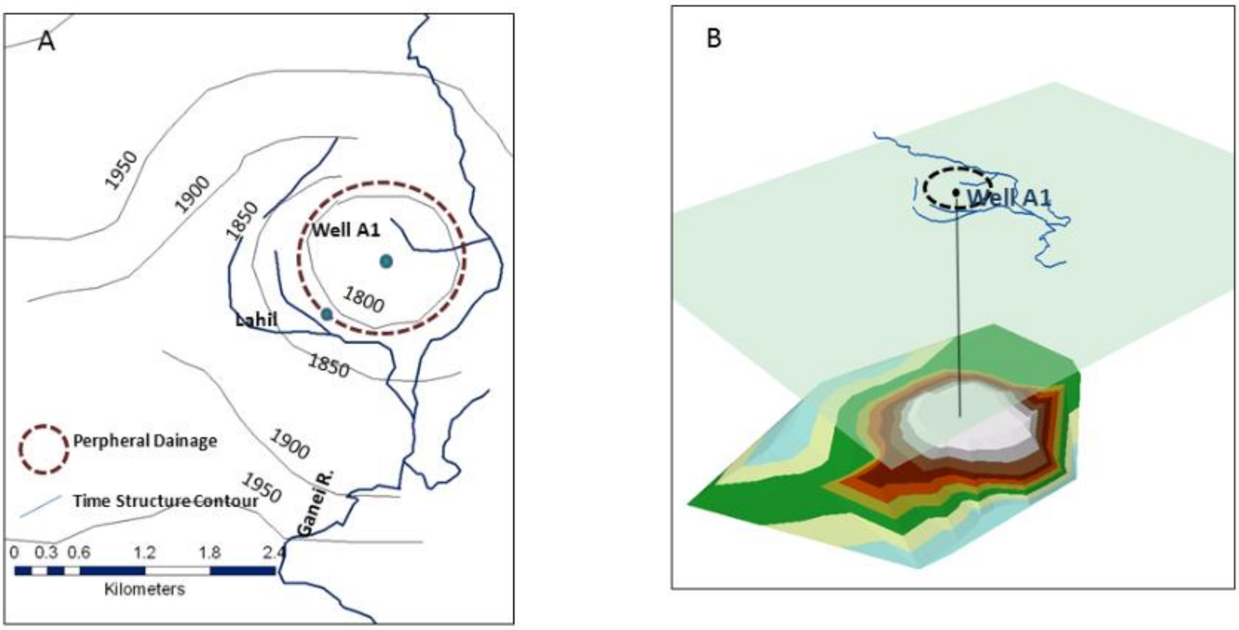


Fig5: A. Peripheral drainage near Lahil with the channels of drainage trending almost parallel to the structure contours in Lower Gondwana **B.** 3D representation of peripheral drainage overlying structural high

Also, near Lahil, based on drainage pattern, an area of peripheral drainage had been delineated suggesting some subsurface structural high causing the channels of drainage to diverge from each other. This area of peripheral drainage when overlain on a structure map of Lower Gondwana at an approx. depth of 2000m shows a structural high just underlying it with the channels of drainage trending almost parallel to the structure contours of the high (Fig 5 A & B).

The reconstructed regional scale faults when correlated with faults identified from seismic data at the top of base of Tertiary approximately at a depth 1200m, it is found that both these sets of surface and subsurface faults depict a good amount of correlation in both their trends as well as disposition (Fig 6A). Also when these faults are correlated in section, the extrapolated extents of these faults confined to the deeper horizons, i.e. below the Tertiary are found to match the reconstructed faults on the surface suggesting their continuity all through (Fig 6B).

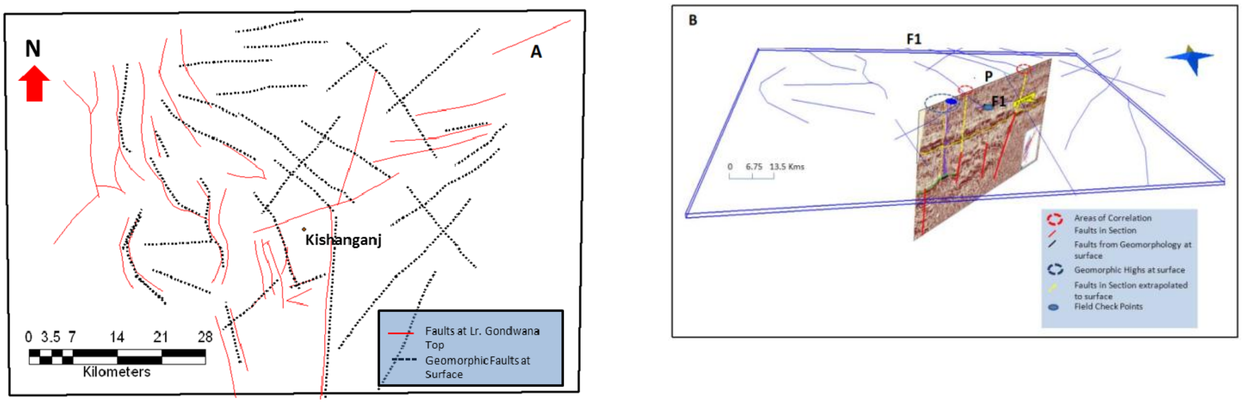


Fig6: A. Regional faults correlated with faults interpreted from seismic at the top of Lower Gondwana Top (Permian) in map (after Mishra et al, 1993)**B.** Reconstructed faults from geomorphic data correlated with faults interpreted in seismic section (after inraline.com) along with field check points for verification.

For a further level of verification, the faults reconstructed from geomorphic data that had been correlated with faults interpreted in seismic section (Fault F1F1 in Fig 6) had been verified using field checks at point P at Bhoidhar near Kishanganj. Here incised banks (IB) are found to be developed in a 1st order channel at suggesting neotectonic faulting along trend FF (Fig 7)

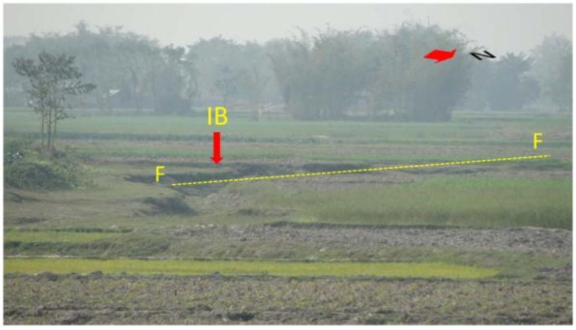


Fig7: Field verifications at Pt P at Bhoidhar near Kishanganj showing incised banks (IB) in a 1st order drainage along fault trend F1F1 that matches fault FF in Fig 6

In a similar procedure regional scale faults had been reconstructed based on geomorphic data in the different areas of study pertaining to the different basins discussed above. These faults had then been correlated and compared in both map and section views to define the continuity of deep seated faults in shallower sediments. The results had been depicted below.

3.2 Block 1: West Ganga Basin

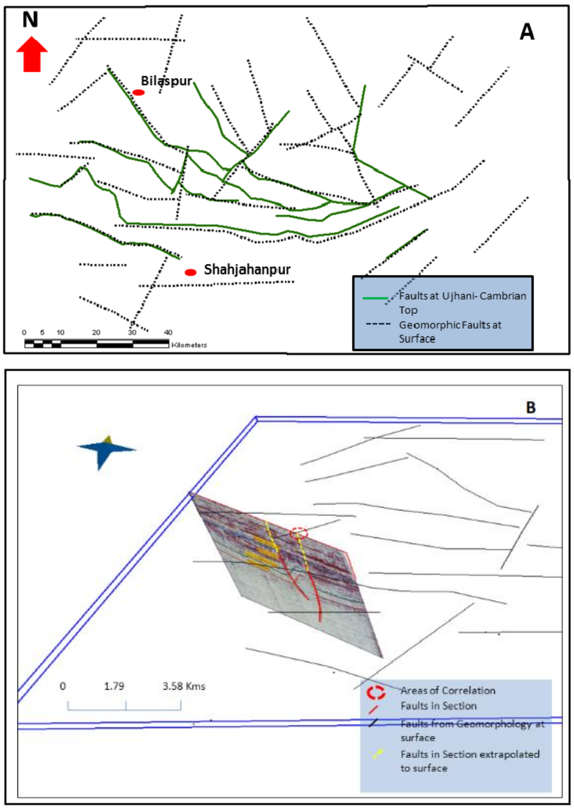
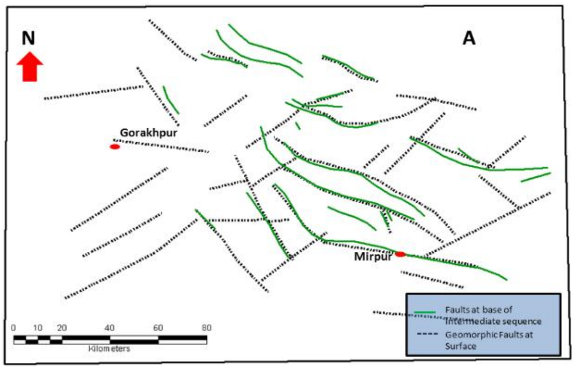


Fig8: A. Regional faults correlated with faults interpreted from seismic at the top of Ujhani Formation in map in Western Ganga Basin **B.** Reconstructed faults correlated with faults interpreted in section that had been extrapolated to surface showing the continuity of faults defined in shallower horizons (marked in yellow)

3.3 Block 2: East Ganga Basin



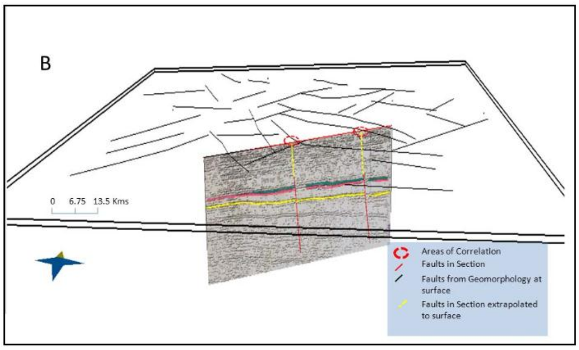
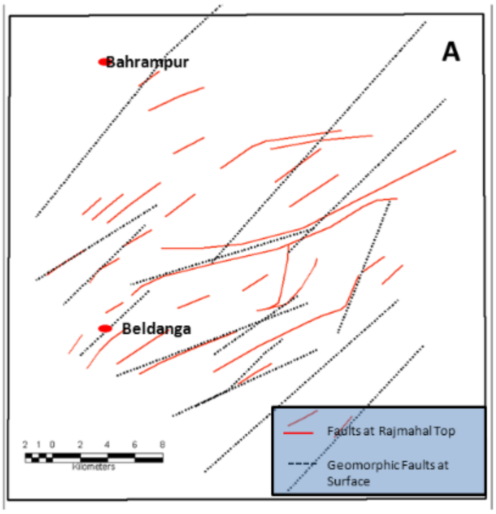


Fig 9: A. Regional faults correlated with faults interpreted from seismic at the base of Intermediate Sequence in map in Eastern Ganga Basin (after Chatterjee et al, 1990)**B.** Reconstructed faults correlated with faults interpreted in seismic section(after Chatterjee et al, 1990) limited to base of Lower Siwalik that had been extrapolated to surface showing the continuity of faults defined in shallower horizons (marked in yellow)

3.4 Block 4: Bengal Basin



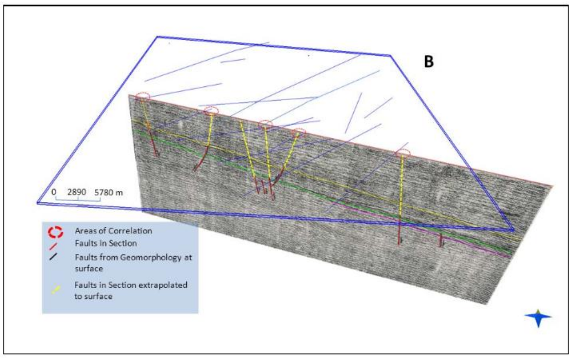


Fig 10: A. Regional faults correlated with faults interpreted from seismic at the top of Rajmahal Volcanics in map in Bengal Basin (after Barua et al, 1995) **B.** Reconstructed faults correlated with faults interpreted in seismic section limited to Rajmahal top that had been extrapolated to surface showing the continuity of faults defined in shallower horizons (marked in yellow) (after Barua et al,1995)

4. Discussion and Conclusions

In all the above case studies in the different blocks belonging to the different basins, it is found that a drainage based morphotectonic analysis might help to define faults in shallow horizons where it is difficult to decipher any structures from conventional seismic methods. Hence such type of analysis in a similar type of geological and tectonic setting might serve as an effective complimentary tool to seismic studies for exploration of shallow and subtle structures. Secondly such geomorphic analysis also might serve as a guideline to define sub surface faults or in reinterpreting sub surface data to update structure maps. All these advantages of drainage based geomorphic analysis can help to open up a new frontier in hydrocarbon exploration defining new pathways of migration as well as new locales for accumulation.

The opinions expressed by the authors are not necessarily that of the organization that they represent

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