Concealed salt range below Punjab Alluvium in Jammu Himalaya, India: Geological and geophysical evidences

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Abstract

The Salt Range is the active frontal thrust zone of the Himalaya in Pakistan. No such frontal thrust zone or discrete topographic salt range is mapped east of Potwar Plateau (Jhelum syntaxis) in north-west Himalaya in India. Salt Range Formation underlies the Potwar basin. The existing understanding about Potwar Plateau is that ductile substrate underlies the basin whereas in India the thrust front lies over frictional substrate. It is a paradox that salt range is shown to terminate abruptly at the eastern boundary of Potwar basin though the equivalent salt beds are exposed north of MBT but no salt range is conceptualized east of Potwar in India. A composite gravity anomaly map covering northwestern India and Pakistan depicts several interesting tectonic features and basement configuration of the area. A major basement fault is identified north of Gurdaspur (throw~1km), Punjab Plains, India and the same fault is traced to the northern flank of Salt Range (basement fault, throw~1km), Pakistan and to the north of Chandigarh in India from the gravity anomaly data. A comparison has been made in the structurisation pattern to the north of this fault in the Potwar Plateau of Pakistan and in the north of Jammu-Pathankot-Dasuya area in India. The continuation of the gravity contours and their magnitude indicates that the anomalous zone of the Potwar basin is not restricted to the geographical area of Pakistan and the basinal limits of petroliferous Potwar Plateau extend to the Indian side. Pre-Tertiary sedimentation might have taken place in the Punch-Rajauri area and also to the north of major normal fault and might have continued in the Jammu-Pathankot-Dasuya graben.

High salinity in the wells drilled close to Himalayan Frontal Thrust(HFT), folding of the subsurface strata in Punjab Plains under the cover of Alluvium, the form of syntaxes and salients in the Himalaya, presence of migratory hydrocarbon in the well and no trace of frontal thrust in Jammu sub-Himalaya etc. are scores of cogent evidences across the international border with Pakistan which strongly suggest possibility of presence of concealed(buried) salt range east of Potwar in Jammu Himalayas in India. These evidences have led to the mapping of trace of HFT and tentative boundary of Salt Range in India. Presence of older sediments makes the area highly prospective for hydrocarbons and paves the way for further exploration.

Keywords: Himalayan Frontal Thrust (HFT), Potwar Plateau, Punjab Plains, Salt Range

Introduction

The Himalaya represents the most extensive, active collision zone in the World, extending westwards from Burma, through northern India, Nepal and southern Tibet, into northern Pakistan (Fig.1). The western part of Himalayan foredeep known as Punjab basin is demarcated by Aravali ridge and its subsurface extension to the east and Jhelum syntaxis (Jhelum Transverse uplift) to the west and north-west. Delhi-Sargodha ridge marks the southern margin whereas the Main Boundary Thrust (MBT) marks the northern extremity of the basin. Tectonically it can be divided into two specific belts. (1) The Tertiary thrust fold belt to the north of

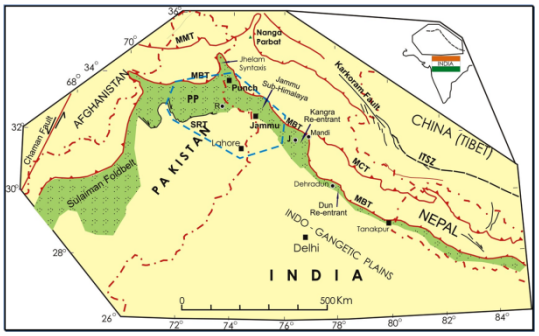

Fig.1 Main structural features of the Himalaya (PP: Potwar Plateau-Study area)

Himalayan Frontal Thrust and (2) The undisturbed homoclinal foredeep below Indo-Gangetic alluvium. The area discussed in the paper includes Jammu Himalayas and Punjab Plains of India and their relationship with Potwar Plateau of Pakistan

The geological and geophysical studies for oil exploration in Pakistan are published by several workers and contributed to the understanding of the tectonics, stratigraphy, and petroleum geology of the area. Similar type of work for oil exploration is also carried out in India in particular by Oil and Natural Gas Corporation Limited. Accumulation of regional G&G data makes it possible to conceptualize the relationship between the main tectonic features of northwest Pakistan and India. A few segments of seismic sections of petroliferous Potwar Plateau of Pakistan are published in technical papers. It is difficult to merge this scanty data for a panoramic picture to understand the continuity of anomalous zones to focus for oil exploration in our adjoining area. Unfortunately, the data of Pakistan Occupied Kashmir (POK) is not available to fill the gap. Subsurface data show that the section beneath the Jhelum Plains, Pakistan consists of Himalayan erosional products, deposited on Cambrian strata while in Potwar Plateau, Eocambrian evaporites rest upon the metamorphic basement of the Indian subcontinent. In Punjab Plains, India, Siwalik molasse is deposited on metamorphic basement. The maximum sedimentary thickness is of the order of 6 km in Punjab Plains (Indian part) and consists of Upper Miocene to Recent molasse-type sediments.

The Salt Range is the surface expression of the leading edge of the foreland fold and thrust belt. On its southern edge, the Salt Range Thrust is anomalous in that, it brings Pre-Tertiary rocks to the surface at the very front of the fold and thrust belt, contrasting sharply with the foreland fold and thrust belt in India, where only Tertiary molasse sediments are exposed. Between the Salt Range of Pakistan (active frontal thrust zone) and the Main Boundary Thrust (MBT) is the Potwar Plateau of Pakistan, which is nearly undeformed south of Soan River but is deformed on its northern and eastern margins. In this region the distance from MBT to the front of the fold and thrust belt is very wide (100-150km). In Pakistan, on the western flank of the Hazara-Kashmir syntaxis, low strength evaporites of Late Precambrian to Early Cambrian age constitutes the zone of decollement (Crawford, 1974). As a result and in contrast to India, the zone of underthrusting extends far out over the foreland (Seeber and Armbruster, 1979), more than 150km south of MBT and has a broad cross-sectional taper (Jaume and Lillie, 1987). The Thrust fold belt in India is between Himalayan Frontal Thrust (HFT) and MBT. In India, strong coupling between sediments and basement is assumed; consequently, the zone of underthrusting is narrow and a high angle of cross sectional taper (Davis et al., 1983; Davis and Engelder, 1985).
The Potwar depression has several features that make it a favourable site for hydrocarbon accumulations. Located on a continental margin, this depression is filled with thick deposits of sedimentary rocks, including potential source, reservoir, and the cap rocks. It contains thick overburden (about 3000m) of fluvial sediments, which provide burial depth and optimum geothermal gradient. The depression has numerous structural traps formed as a result of the Himalayan orogeny. The basin history of the Potwar depression has been favourable, with respect to plate tectonics and geothermics, and several oil discoveries and seeps are found in this area. The Potwar depression has a close proximity with Punch-Rajauri-Jammu area in the Indian side and encourages a comprehensive study of G&G data for finding hydrocarbons.
Presence of hydrocarbons has been known since long, through number of surface oil and gas seepages, but commercial breakthrough is yet to be established in the Indian side. Similarity in structural style and occurrence of hydrocarbons in close proximity of producing Potwar basin of Pakistan further reinforces the hope of early success in this complex area.

The entire area in Pakistan and India is covered with regional gravity data (except POK) which can throw some light on such anomalous areas. Lack of adequate seismic data especially near the frontal thrust makes it mandatory to have a panoramic picture of the distribution of gravity field in the Punjab Plains (Punjab plains of India and Jhelum Plains of Pakistan), Himachal and J& K foothills in India, Salt Range & Potwar Plateau of Pakistan.

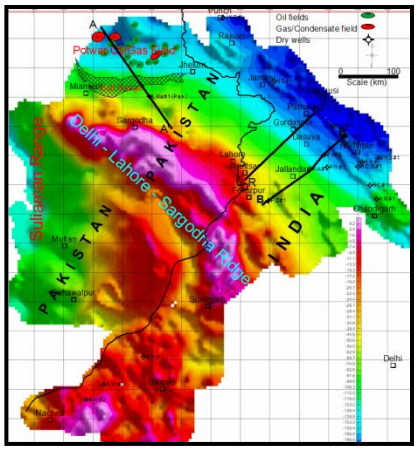

Fig. 2 Gravity anomaly map of Northwestern India and Pakistan

A composite gravity anomaly map covering Pakistan from Rawalpindi in the north to Bahawalpur in the central Pakistan and in India, Himalayan thrust fold belt of Punch-Rajauri area of J&K, from HFT to MBT in Himachal Pradesh, Punjab Plains and Bikaner-Nagaur basin of Rajasthan is studied (Fig.2). (P.Singh, 2005)

The present study describes the analysis of gravity data across the international border with Pakistan. Gravity models one each across the Potwar Plateau and Punjab plains, India are generated. Second vertical derivative map of gravity anomaly data is processed for the interpretation of local features (Fig.3). Refraction sections in the Punjab Plains are discussed in the light of major fault of throw ~ 1km and its continuity on the either side. Analysis of salinity and geochemical data of wells drilled in the area is presented in this paper.

Methodology:

The Bouguer gravity anomaly map of the Pakistan of an area covering around 1,35,000km^2 (Farah et al., 1977) is composited with adjoining gravity anomaly map of NW India to derive a synoptic look with the objective to delineate the major tectonic features, concealed structures and to infer the possibility of extension of the petroliferous Potwar Plateau of Pakistan to the Punch-Rajauri area of India (Fig.2). The boundary of the Salt Range, the present day course of the major rivers, international border are overlayed on the anomaly map. A second vertical derivative map of gravity anomaly data is processed for the interpretation of local features (Fig. 3). Forward gravity model starting from Punjab plains to sub-Himalaya is studied to ascertain the subsurface structure (Fig.4). A refraction section (Fig.5) from Tarantaran to Pathankot in Punjab Plains is also discussed for evaluating and comparing the major fault in India and Salt Range, Pakistan(Fig.6). Well data and geochemical data are also considered for drawing inferences regarding salt range.

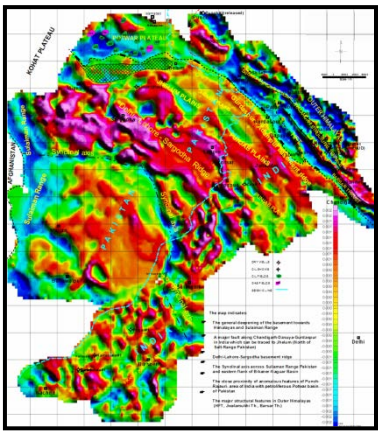

Fig.3. Second vertical derivative map of Gravity anomaly data Northwest India and Pakistan

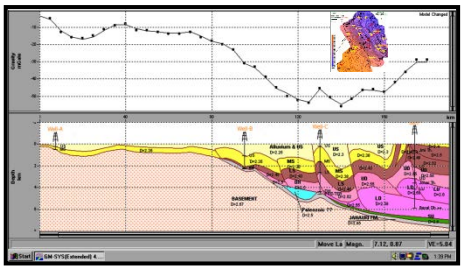

Fig.4 Gravity profile along line AA'

Analysis of the data:

Gravity data:

The Bouguer anomalies of the Rawalpindi-Punch-Chandigarh to Bahawalpur-Bikaner are linear and identifiable in three distinct strips. The nature of gravity contours in the Outer Himalayas, India is not smooth indicating more anomalous zone. The central strip, with a number of positive closures represents the Delhi-Sargodha arch, comprising scattered inliers of rocks of the Purana Group.

From Sargodha northward across the lower Jhelum valley, a negative anomaly gradient is also persistent indicating a plunge of the basement. The Jhelum Plains is the undeformed foreland south of the Salt Range Thrust. The most apparent feature is a large normal fault (throw ~ 1km) in the basement beneath the

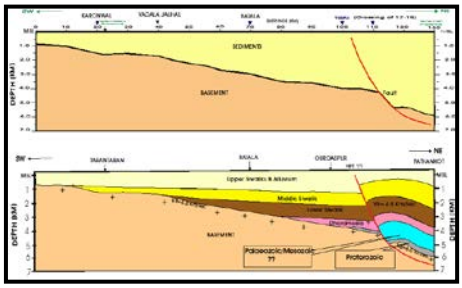

Fig. 5 Depth section along refraction profile16-1R from Tarantaran to Pathankot

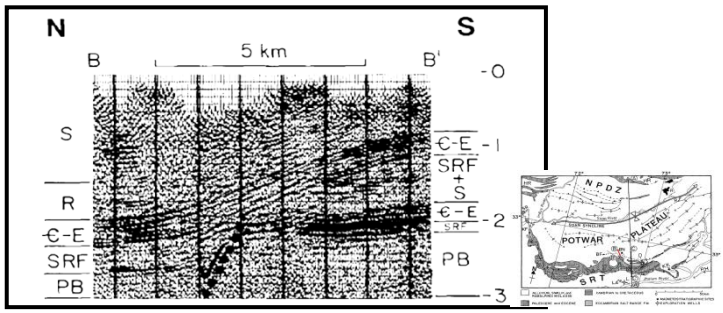

Fig.6 Seismic profile of Pakistan

north flank of the Salt Range that causes the ramping of the entire section (Figs.6 & 6a).
The congestion of the gravity contours north of Salt Range depicts a fault of regional nature. This basement normal fault has been interpreted as being due to flexure of the Indian plate (Lillie and Yousuf, 1986; Lillie et al., 1987; Duroy, 1986). The Salt Range uplift does not significantly interfere with the northerly gravity gradient. This may be examined in the context of large thickness of salt deposits in the Salt Range, which compensates for the excess mass of sedimentary rock in the uplift (Jaume and Lillie, 1988). The Salt Range is a fault bend fold. Loading by the thick molasse sequence within the Soan Syncline is believed to have caused ductile flow of salt toward the south (Gee, 1983), which may have resulted in a salt buildup against the basement buttress.

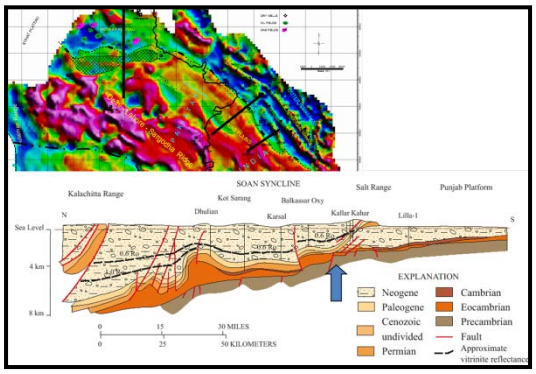

Fig. 6a Generalized cross section Showing structure through the Potwar basin

The main objective of this study is whether the anomalous zone of Potwar Plateau extends to Punch-Rajauri area. The gravity data conveys the regional tectonic setting from which such a model can be conceptualized. It appears that the anomalous zone of the Potwar basin is not restricted to the geographical area of India and Pakistan. The continuation of the gravity contours, their magnitude and less pronounced gravity high just north of Jhelum indicates that Pre-Tertiary sedimentation might have taken place in the Punch-Rajauri area and might have continued in the Jammu-Pathankot-Dasuya graben. The Jhelum tear fault might have not restricted the deposition in the Mesozoic times.

Second vertical derivative map:
For interpretation of local features, a second vertical derivative map of the gravity data is studied (Fig.3). The major local feature is the Adampur ridge which can be traced upto the Gurdaspur fault and a little beyond to the Jhelum town, and then trends NW-SE joining high trend south of SRT(Salt Range Thrust). This suggests that the frontal thrust (HFT) in India runs parallel to Adampur Ridge.

Seismic data:
Oil companies of Pakistan have published some of the seismic data in the eastern part of the Potwar Plateau, but the gap in POK does not allow to correlate the Pre-Tertiary sequence in the Indian side where a few seismic lines exist in Punch-Rajauri area. The seismic data of Potwar and Rajauri-Punch area show similarity of character and seismic thickness suggesting deposition of older sediments in Jammu Himalayas also and continuity of basin towards east of Potwar (Fig.7).

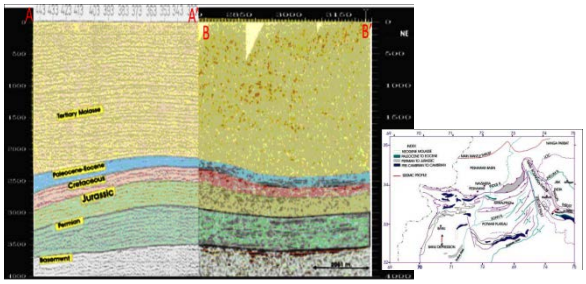

Fig 7. Seismic sections AA' of Potwar Basin,Pakistan and BB'of J&K area

Verma, 2006). A refraction profile from Tarantaran to Pathankot in Punjab Plains, India (Fig. 5) is also studied.
The most apparent feature is a large normal fault (throw ~ 1km) in the basement between Gurdaspur and Pathankot and the same fault can be traced to the northern flank of Salt Range, Pakistan that causes the ramping of the entire section (Fig.6). It is traced from gravity studies up to the north of Chandigarh which indicates it as a fault of regional nature.
A gravity model generated along this profile also conforms with the geological model constrained with the refraction data (Fig.8).The model indicates that the subsurface strata in the Punjab plains is also folded indicating that the fold belt may have extended in Punjab plains and HFT lies further south. It is

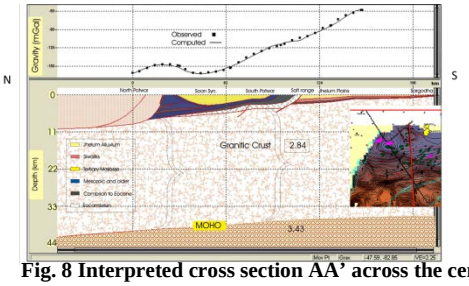

Fig. 8 Interpreted cross section AA' across the central salt Range Plateau. From Bake r(1987) and Lilli et al (1987) the gravity response computed from the geological model matches with the observed gravity values only after combining the model of deepening of the MOHO and sedimentary section encountered in the boreholes.

inferred that this basement fault of big throw might have played a great role in forming of thrust propagated folding of rocks in the Punjab Plains in Pathankot-Jammu area under the cover of Alluvium.

Well data:

Wells drilled near HFT in the outer belt of Himalaya (Fig.5) indicate high salinity (as high as31 gms/litre)(Figs.9&10) in the Tertiary sediments. Since bulk of the Tertiary sediments are non-marine, mixing of deeper level fluids through faults can not be ruled out. Presence of migratory hydrocarbons refers to the possibility of older petroleum system. Both point to the possibility of presence of older sediments in the area.

Well-C
OIL & GAS SHOWS

Year of Drilling 1964-65

Formation	Depth	Remarks
Dharmsala	4000m	Mild gas show during drilling

PRODUCTION TESTING DATA

Formation	Depth	SP (mv)	Resis (ohm-m)	Volume of fluid (m^3)	Nature of fluid	Sali-nity gm/ltr	Remarks
Dharmsala	3999-4005 4297.5-4303.5 4381-4378			$50m^3$/day		1.9 31 7	Self flow recorded

Fig. 9 Oil and gas shows and production testing data from Well -C

Geological data:

Presence of equivalent salt beds all along the MBT in Kangra re-entrant and presence of gypsiferous deposits north of MBT in Hazara district indicates original evaporite basin may have extended substantially further north. There is a striking similarity between salt of Pakistan and Mandi salt of Kangra re-entrant. The difference in salt composition lies in the fact that the salt of India is with a large admixture of earthy impurities and upper surface of salt bed is very gritty. The width of fold belt of Potwar is very large and has broad cross-sectional taper and in comparison to it, the width in India is slightly less (if we consider HFT to be further south) but the impure ductile substrate in India cannot be ruled out. The form of syntaxes and salients in Himalaya also point towards the possibility of evaporite floor in the basin.

Well-B
OIL & GAS SHOWS

Year of Drilling 1961-62

Formation	Depth	Remarks
Mid. Siwalik	2297m 2300m	Gas recorded 100 micro-amp in GLU Gas recorded 2000 micro-amp in GLU Chromatographic analysis shows 0.1-0.6% H_2
Lr. Siwalik		Nil * No OYF in cores

SALINITY DATA

Formation	Depth	SP (mv)	Resis (ohm-m)	Volume of fluid (m^3)	Nature of fluid	Sali-nity gm/lit	Remarks
Up.Siwalik Mid. Siwalik	0-1800 at 1800 at 2200					1.0 2.0 7.0	
Lr. Siwalik	2302m downward at 2302-2313					30.0	Sharp SP anomaly amplitude remaining 100 mv

PRODUCTION TESTING
No zone has been tested
The well was abandoned without testing.

Fig. 10 Oil and gas shows and production data from Well-B

Results:

It appears that the anomalous zone of the Potwar basin is not restricted to the geographical area of India and Pakistan. The continuation of the gravity contours, their magnitude and less pronounced gravity high just north of Jhelum indicates that Pre-Tertiary sedimentation might have taken place in the Punch-Rajauri area and might have continued in the Jammu-Pathankot-Dasuya graben. The folding of the subsurface rocks indicates larger width of the thrust-fold belt in India also and is comparable with fold-thrust belt of Potwar. Presence of 1km down-to-the north fault running from Chandigarh to salt range in Pakistan is established from gravity and refraction data. The continuity of fault indicates continuity of the Potwar basin to the east of Jhelum syntaxis also. Similarity of seismic data of Potwar and J&K indicates continuity of similar stratigraphy in both the areas. High salinity in wells drilled near HFT and presence of migratory hydrocarbons in well lead to the inference that floor of the basin may be composed of ductile substrate. This enhances the probabilities of finding structural traps below Punjab Alluvium around Rajauri-Punch-Jammu area. Primary deduction from these evidences is that the salt range is present in India also.

Conclusions: The signatures of the concealed Himalayan Frontal Thrust (HFT) have been delineated under the Punjab alluvium. The subsurface strata and probably the basement are folded into minor anticlines and synclines and axes of the folds run parallel to the Siwalik range. It indicates that thrusting has not ceased at HFT and may have progressed further beyond HFT which is manifested by the presence of thrust propagated anticlines. The continuity of the gravity contours of same magnitude, continuity of the north of salt range major fault of 1km down-to-the-north throw indicates that the Potwar basin is not restricted to the geographical area of India and Pakistan. This, *inter alia*, means that the Jhelum tear fault might not have restricted the deposition in Mesozoic/older times. In other words, the salt range might have continued east of Potwar Plateau in Jammu Himalayas in India which is now concealed under Punjab Alluvium. Tentative trace of HFT and boundary of salt range in India is mapped (Fig.11).

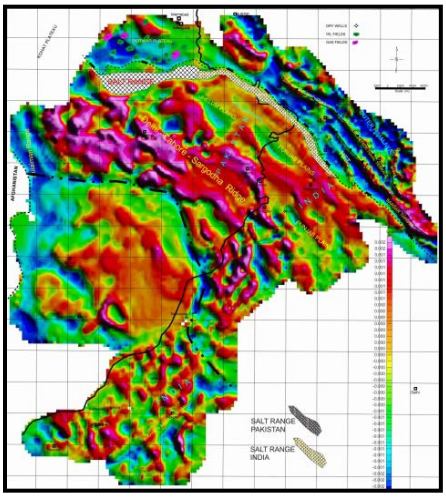

Fig.11: Conceptualised concealed salt range of India

The folding of the subsurface rocks and the presence of salt range in India (and consequently the older sediments) may enhance the probabilities of finding hydrocarbon traps in the Jammu sub-Himalaya. On the basis of analogy of salt range, the study concludes that Punch-Rajauri and Jammu-Pathankot-Dasuya areas are highly prospective and may provide a much sought after hydrocarbon lead in this poorly explored vast area of Himalayan foothills. Conceptualising and tentative mapping of the boundary of salt range in India(east of Jhelum syntaxis) has been the novel contribution of this study.

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