

Facies Analysis and Sequence Stratigraphy of Cambrian Sandstone, Eastern Potwar and Khewra Gorge, Punjab, Pakistan

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ABSTRACT: The Khewra Sandstone is a prolific reservoir producing hydrocarbons in different oil and gas fields in the Potwar basin, Pakistan. To exploit the potential of the Khewra Sandstone, there is a great need to identify the facies and devise a sequence stratigraphic framework. The present study was conducted for facies analysis and preparation of sequence stratigraphic framework. Outcrop section was measured at type locality of Khewra Gorge and public domain well logs data of four wells from eastern Potwar were used for this purpose. Outcrop section measurement, and petrography of samples collected was conducted to achieve the objective. Four litho-facies were recognized, i.e. i. Red clays with thin bedded siltstone, ii. Red clays with fine grained sandstones iii. Medium grained thick bedded sandstone with laminated sandstone and minor red clays, iv. Medium to coarse grained sandstones. These facies were then grouped into three facies association for the analysis of depositional environments. These facies associations are Pro-Deltaic clays, Distributory Mouth Bars/ Delta Front and Fluvial Amalgamated Channel sandstones. By using these facies associations, the sequence stratigraphic framework was prepared. Basal part of the Khewra Sandstone consists of Transgressive System Tract (TST), middle part is High Stand Systems Tract (HST) and upper part deposited in Low Stand System Tract (LST). The contact of the Khewra sandstone with the Kussak Formation has been recognized as a Transgressive surface (TS).

KEYWORDS -Potwar Basin, Facies Analysis, Sequence stratigraphy, Sandstone, Sedimentology

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I. INTRODUCTION

The Khewra Sandstone is a prolific reservoir in many oil and gas fields of Potwar basin in Northern Pakistan. Many workers have worked on the Khewra Sandstone to delineate its depositional environments, provenance studies and reservoir potential on the basis of outcrop studies in its type locality at Khewra Gorge, Eastern Salt Range. The workers mainly focused on outcrop studies and interpretation of depositional environments. No significant attempt was made to correlate with subsurface data. Even, there is controversy among the researchers about the depositional environments of the Khewra Sandstone. Earlier workers interpreted the depositional environments of the Khewra Sandstone as either Deltaic or Aeolian. This study was conducted to review the existing interpretations, correlation of surface outcrop to subsurface wireline logs data in order to identify the facies in the Khewra Sandstone and interpret depositional environments of each facies in a sequence stratigraphic framework.

Tectonics and Regional Geology

The study area is present in eastern Potwar and Eastern Salt Ranges of Pakistan. Pakistan is present in the world's most magnificent tectonic framework, where three plates converge i.e. Indian, Eurasian and Arabian. Major plate boundaries are, Magmatic arc-continental collision between Eurasian Plate and Kohistan Island arc, another Magmatic arc-continental collision between Kohistan Island arc and Indian Plate, Transform plate boundary along Chamman-Ornach Nal fault system between Indian and Eurasian plates and subduction zone between Arabian plate and Makran block of Eurasian plate. These tectonic elements are responsible for the present tectonic framework of Pakistan.

The emergence of Himalayan Fold and Thrust Belt was a result of the collision between Indian and Eurasian plates. In Cretaceous, after rifting between Indian plate and Madagascar Indian Plate started drifting towards Eurasian Plate.

Potwar Plateau is present between the Main Frontal thrust fault, locally known as the Salt Range thrust (SRT), and the Main Boundary thrust (MBT) (Fig. 1) to the northeast (Drewes. H, 1995). Recorded deformation of the Potwar Plateau area is mostly Neogene, deformation continued at least into late Pleistocene and most likely it is ongoing. This period of major north-south compressive deformation closed the Tethyan seaway during or after Eocene time, which is the time in which the plate collision began.

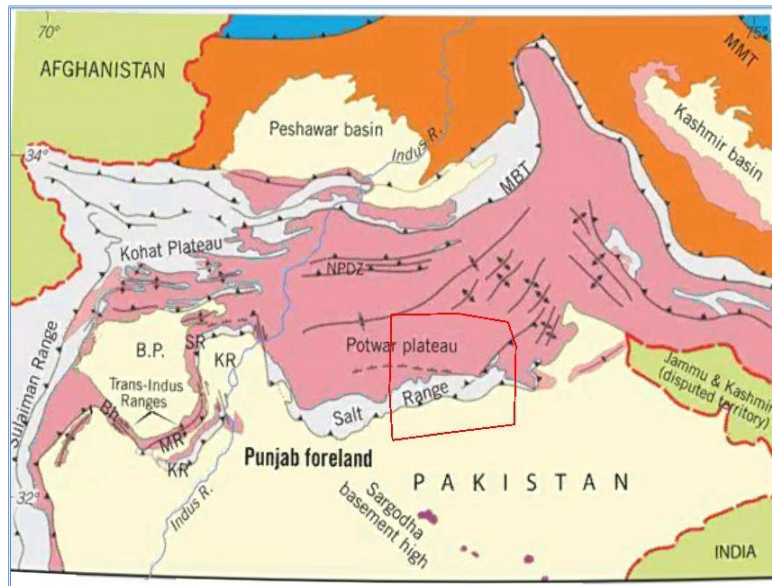


Fig 1 Tectonic map of Northern Pakistan (Mpdified after Kazmi & Rana 1982)

II. METHODOLOGY

Outcrop data acquisition included section measurement, sampling, sedimentary structures and paleo current data, and this data was acquired at type locality of Khewra Sandstone at Khewra Gorge. The results of these data interpretation were integrated to build depositional and sequence stratigraphic model of the Khewra Sandstone.

III. RESULTS:

Lithology of the Khewra Sandstone:

The Khewra Sandstone is well exposed with markable top and bottom at its type locality i.e. Khewra Gorge, near Khewra town, Jhelum District. Thickness measured during present study in the Khewra gorge is 128.85m (Fig. 2).

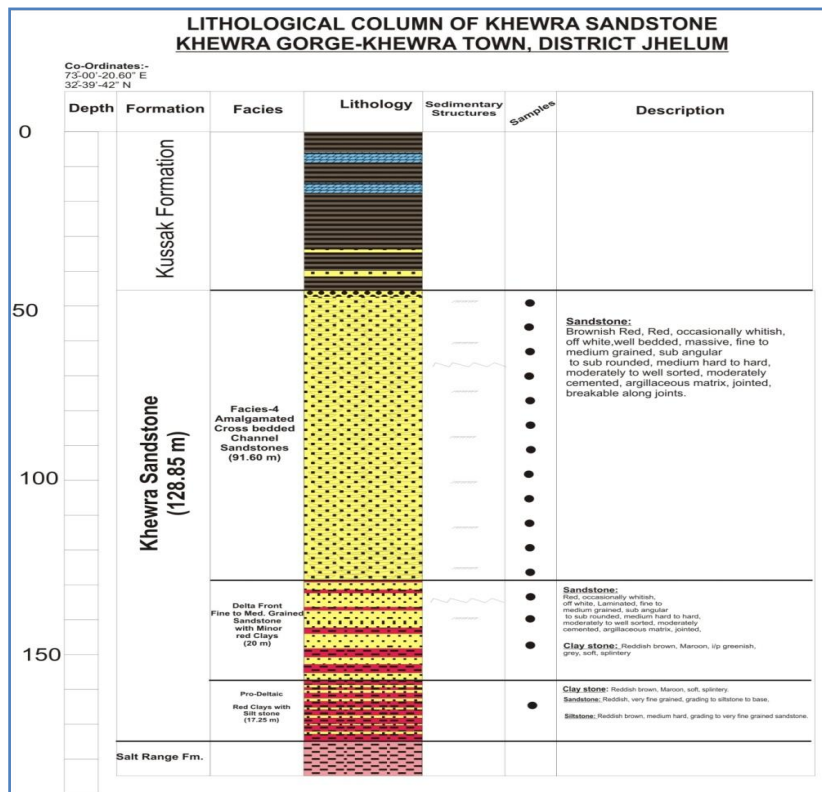


Fig.2 Lithological column of the Khewra Sandstone in Khewra Gorge

The Khewra Sandstone, on the basis of lithology, texture, color and sedimentary structures can be divided in 04 lithofacies, which are as follows:-

- i. Facies-I: Red clays with Thin Bedded Siltstone
- ii. Facies-II: Red clays with fine grained sandstones
- iii. Facies-III: Medium Grained Thick bedded Sandstone with Laminated sandstone and minor red clays
- iv. Facies-IV: Medium to coarse grained sandstones

i. Facies-I: Red Clays with thin Bedded Siltstone

These facies mark the basal contact of the Khewra Sandstone with Salt Range Formation. These are red to maroon colored clays with no sandstones (Fig.3). Clay is reddish maroon colored, soft, sub fissile, splintery and poorly indurated. Siltstone is reddish brown, medium hard, micaceous and grading to very fine grained sandstone.

ii. Facies-II: Red clays with fine grained sandstones

These facies are comprised of red, maroonish clays with sub ordinate fine grained sandstones. The sandstones thickness increases upwards.

iii. Facies-III: Medium Grained Thick bedded Sandstone with Laminated sandstone and minor red clays

These sandstones are red, brownish, in places white and pale yellow, cross bedded, hard, soft sediment deformation structures present laminated sandstone, moderately sorted, quartzose, rounded to well rounded grains. Sedimentary structures found in this facies are cross bedding, laminated, interbedded with red, maroonish clays. The sandstone to clay ratio increases upwards .

iv. Facies-IV: Medium to coarse grained sandstones

This facies consists of predominantly of red, maroon, in places pale yellow medium to coarse grained and cross stratified sandstones. The sandstone is red, maroon in places pale yellow, medium hard, thick bedded sandstone, moderately sorted, quartzose, rounded to well rounded grains.

These channel sandstones are 91.60m thick. At the base and top of amalgamated sandstones, green colored thin clay laminations are present.

The upper contact of The Khewra Sandstone with Kussak formation is marked by a 75 cm thick bed of conglomerate bed in between The Khewra Sandstone and basal black, grey shales of Kussak formation.

IV. DISCUSSIONS:

The interpreted facies associations are as follows:-

- I. Facies Association-I: (Pro-Deltaic: Red-Maroon Clays with thin siltstones)
- II. Facies Association-II: (Distributory Mouth Bar/ Delta Front Facies: Sandstones with red Clays)
- III. Facies Association-III: (Fluvial: Amalgamated Channel Sandstones)

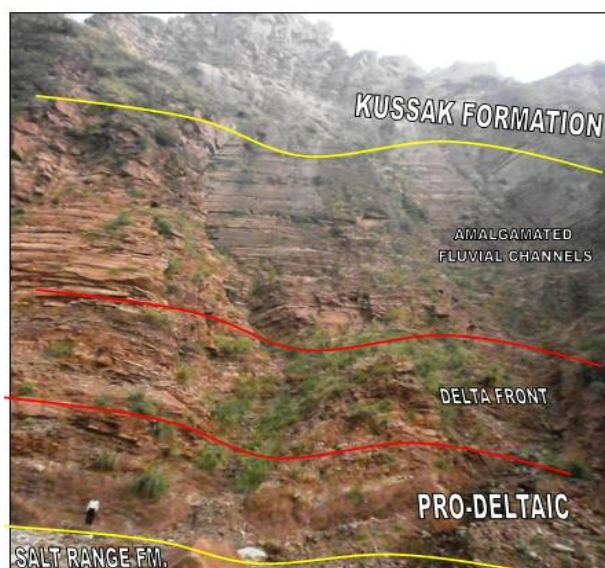


Fig.3 Facies of the Khewra Sandstone

1. Facies Association-I: Pro Deltaic Clays

These pro-deltaic clays mark the basal contact of the Khewra Sandstone with Salt Range Formation. These clays are red, maroon and splintery. These facies association is interpreted to be deposited in Pro-deltaic settings as

thick clays and dirtying upward trend of GR log confirms this behavior that these facies deposited in marine settings.

2. Facies Association-II: Distributory Mouth Bar/ Delta Front Facies

These facies association are recognized by upwards decrease in GR API values, which shows fall in sea level. Thin bed of siltstone and fine grained sandstone grade upwards in medium grained sandstone, as shown by decreasing GR.

At outcrop, sandstone thickness increases upward, also petrographic analysis confirms it. Overall all coarsening upward trend shows that, this strata deposited in progradational behavior of delta (Delta Front setting). Facies-II is interpreted to be deposited in a distal part of Delta Front while Facies-III may have deposited in Proximal settings (Distributory Mouth Bars).

3. Facies Association-IV: Fluvial Facies: (Amalgamated Channel Sandstones)

This facies consist of thick bedded red, maroon, pale yellow, off white, cross bedded, cross stratified, fine to medium grained, hard to very hard, moderately to well sorted, weakly to moderately cemented, rounded to sub rounded sandstones with argillaceous matrix and jointed. Sandstone is characterized by amalgamated channels with lack of flood plain deposits. On GR logs of the surrounding wells, this facies shows cleaning upwards behavior i.e. shallowing upwards. This facies association is interpreted to be deposited in fluvial setting during base level rise.

This portion of the Khewra Sandstone is designated by decreasing upward trend of GR showing the increasing in sandstone content. The log behavior and outcrop studies show that these are migrating channel deposits. Isopach map shows that its thickness is increasing towards SE of the study area.

On the basis of lithological and electrical log characteristics, depositional environments of recognized three facies associations has been interpreted as follows:-

Sequence stratigraphic framework of the Khewra Sandstone

On the basis of outcrop data, petrography and well logs different facies associations were interpreted and recognized that lower part of the Khewra Sandstone was deposited in Deltaic depositional environments while fluvial environment was designated for upper part. This data and interpretation also helped to interpret the sequence stratigraphic framework of the Khewra Sandstone. On the basis of outcrop lithological characteristics, petrographic data and well log curve shapes, the sequence boundaries (SB), flooding surfaces and system tracts were identified which are explained as follows:-

Maximum Flooding surface (MFS):-

Maximum flooding surface separates Transgressive System Tract (TST) below to Highstand System Tract (HST) above and is marked when fining upwards trend changes into coarsening upwards. Maximum flooding surfaces in the Khewra Sandstone has been identified in GR log curve in surrounding wells, which shows upwards GR increasing (alternatively fining upwards trend). On the contact of the Khewra Sandstone and Salt Range formation, entering into the Khewra Sandstone, the GR start increasing showing transgressive behavior. This behavior changes when the GR starts decreasing after making a bow shape. At the maximum curvature of this trend, MFS was marked. This surface marks contact between pro-deltaic clays and delta front facies, as in pro deltaic facies the siltstone thickness upwards decreases while in delta front facies above MFS, fine grained sandstone bed thickness increases upwards.

Sequence Boundary (SB):

Sequence boundary is the surface of erosion or non deposition created during base level fall by sub aerial processes of fluvial incision, wind degradation, sediment bypass or pedogenesis (Catuneanu.O, 2006). In the Khewra Sandstone, SB is marked at the top of delta front facies and at the base of Fluvial amalgamated channel sandstones. Presence of fluvial amalgamated channels sandstones above delta front facies shows that sub aerial unconformity occurred due to fluvial incision as a result of relative sea level fall and then incised valley was filled by these fluvial channel sands when base level was increasing in early stages during Low stand conditions.

Transgressive Surface (TS):

The contact of the Khewra Sandstone with Kussak Formation has been marked as Transgressive surface (TS). 75cm thick bed of conglomerate marks the contact of the Khewra Sandstone and Kussak Formation. At the basal part of Kussak formation, red colored sandstones which thin upwards and thickness of flood plain clays along with shale increases upwards, which is a sign of transgression. Keeping in view these evidences, transgressive surface (TS) is marked at the contact of the Khewra Sandstone and Kussak formation, while basal part of Kussak formation has been included in transgressive systems tract (TST) (Fig. 5 & 6).

System Tracts:-

On the available data and recognition of surfaces, following system tracts were identified:

Transgressive System Tract (TST):- TST has been interpreted at the base of the Khewra Sandstone (contact between the Khewra Sandstone and Salt Range formation) and MFS. GR curve shape in the surrounding wells

along with outcrop section shows fining upwards behavior which is designated as a behavior of TST. During this system tract, pro-deltaic clays (Facies association-I) was deposited with maroonish clays along with thinning upwards siltstones.

Highstand System Tract (HST):- During HST, the overall grain size behavior is coarsening upwards. HST is bounded at top by composite surface of sub aerial unconformity, basal surface of forced regression and regressive surface of marine erosion while lower surface is maximum flooding surface (Catuneanu.O, 2006). In the Khewra Sandstone, HST has been identified with MFS at base and SB at top. Thickening and increasing grain size upwards with decreasing clay content shows a progradational behavior of delta. During this system tract, delta front facies were deposited showing coarsening upwards trend .

Lowstand System Tract (LST):- Lowstand system tract (LST) is bounded at its top by Transgressive surface (TS) and at base by sub aerial unconformity (SB). LST is formed during early stages of base level rise. During LST, sedimentary deposition occurs in every setting from fluvial to deep marine (Catuneanu.O, 2006).

In the Khewra Sandstone, the coarsening upwards behavior of logs, fluvial amalgamated channels sandstones at outcrop and increasing grain size in petrographic photomicrographs suggest that, this strata belongs to Lowstand Systems Tract. At the top of Delta Front facies (HST), the presence of SB marks the base of LST and TS at the contact of the Khewra Sandstone and Kussak formation is the top of LST. The amalgamated fluvial channel sandstones without floodplain fine sediments show that these channel sandstone deposited in Lowstand Systems Tract settings, during early rise of base level.

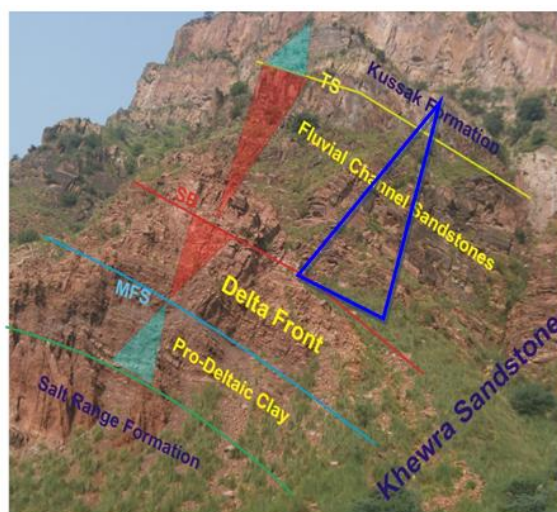


Fig. 5 Outcrop sequence stratigraphy of The Khewra Sandstone

This type of deposition of fluvial amalgamated channel sandstones in LST without floodplain fine sediments has been described by Shanlay & McCabe (1994). The fluvial amalgamated channel sandstones deposits of LST is bounded at base is sub aerial unconformity and at top by first flooding surface/ Transgressive Surface (TS). After Lowstand amalgamated channel sandstones deposition, the transgression occurs and the floodplain fine material starts deposition while the amalgamated channels start isolating from each other (Shanlay & Mc Cabe, 1994). At the type locality of the Khewra Sandstone in Khewra gorge, the amalgamated channel sandstones have almost 91m thickness and these red medium grained channel sandstones with missing floodplain fine material suggests that it is the product of early rise of base level during Lowstand Systems Tract.

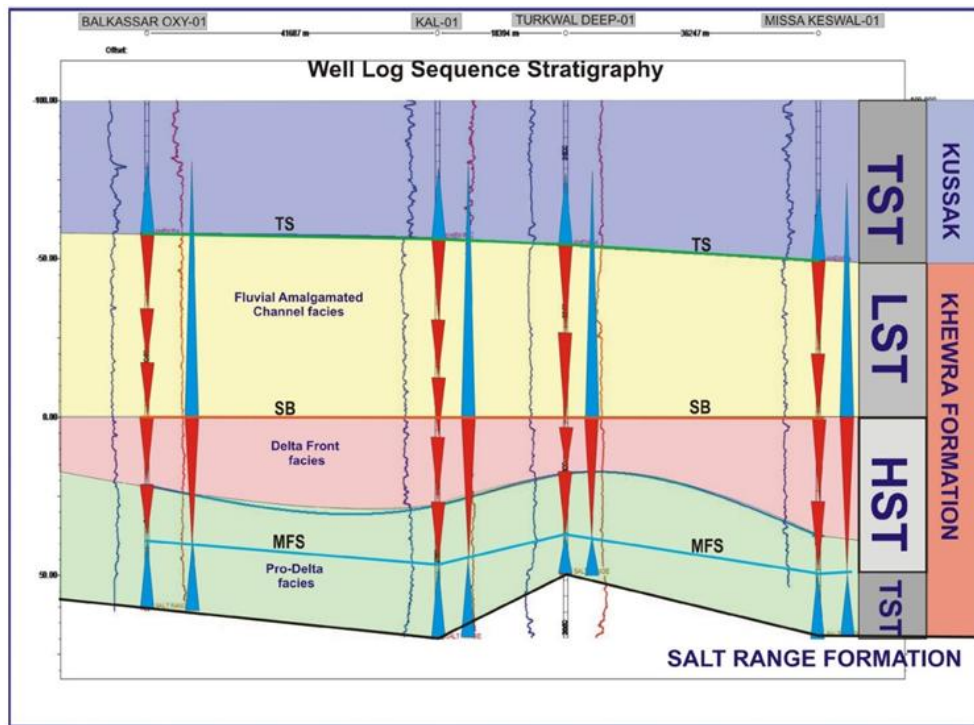


Fig. 4.41 Correlation for Well Log sequence stratigraphy of The Khewra Sandstone

When the Base-level falls i.e. accommodation space creation available for the sediments to deposit is less than sediment supply, it is more likely that Low Stand Systems Tract deposits will be preserved in sedimentary record, because these are deposited in stratigraphically low lying area i.e. incised valleys. Low accommodation to sediment supply rate ratio results in the migrating channel systems producing a succession which have erosion surfaces and then strata deposited in fluvial setting preserved as amalgamated channel deposits. Sedimentary strata preserved in these fluvial settings consist of channel lags and cross-bedded channel fills sandstones with very minor amount of flood plain fine grained material. These sandstones have sheet like geometry. When the base level rises i.e. accommodation space creation rate exceeds sediment supply, vertical distance between successive lateral migration paths of fluvial channels increases. During this process, the channel sandstones along with levee and flood plain material is also preserved. During Highstand settings, fluvial sediments are also deposited as channel fills and flood plain but these are more exposed and subject to removal by subsequent cycles of erosion. After HST deposition, the subsequent erosion by falling base level and associated sequence boundary, the HST strata of fluvial settings is removed (Shanlay & Mc Cabe, 1994). At the base of Kussak formation, the channel sandstone thin out and individual channel sandstones get isolated upwards and increase of clays and dark grey colored shales. This basal part of Kussak formation marks the Transgressive systems tract. Therefore, the boundary between TST succession at the base of Kussak formation and amalgamated channel sandstones (LST) of the Khewra Sandstone may be designated as first flooding surface or Transgressive surface (TS).

V. CONCLUSIONS AND RECOMMENDATIONS

Conclusions:-

Followings are the main conclusions of the present study:

1. Main facies of the Khewra Sandstone are,
 - i. Red clays with siltstones
 - ii. Red clays with thin bedded sandstones
 - iii. Medium Grained Thick bedded Sandstone with Laminated sandstone and minor red clays
 - iv. Medium to coarse grained channel sandstones
2. Three (03) facies associations were identified:-
 - a. Pro-Deltaic Clays
 - b. Delta Front facies/ Distributory Mouth Bars
 - c. Fluvial channel sandstones
3. On the basis of depositional environments, the Khewra Sandstone can be divided in two parts, i.e.
 - a. Lower Part: Deltaic

b. Upper Part: Fluvial

4. Basal Part i.e. Pro-Deltaic clays has been identified as Transgressive system tract as GR log of the surrounding wells also suggests it. On the top of these clays Maximum flooding surface (MFS) has been marked.
5. GR log behavior and photomicrographs show upwards increasing trend in grain size which is a behavior of progradational patterns. This portion (Delta front) of the Khewra Sandstone was included in HST.
6. At the top of HST a sequence boundary (SB) was marked.
7. Upper part of the Khewra Sandstone having amalgamated channel sandstones which deposited in fluvial setting has been identified has Low Stands System Tract (LST).
8. The contact of the Khewra Sandstone with Kussak Formation was recognized as transgressive surface (TS).
9. The lower part of Kussak formation consists of red channelized sandstones thinning upwards and along with upwards increasing flood plain fine sediments. Which suggests that, this part was deposited during Transgression, therefore it has been identified as Transgressive systems Tract (TST).

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