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Sedimentologic studies of Upper sands of Lower Goru Formation based on well cuttings and wireline logs from wells of X Field in the subsurface of Sindh Monocline, Southern Indus Basin, Pakistan.

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Abstract: Detailed studies of lithologic successions of upper sands of Lower Goru Formation in the subsurface of X Field of Sindh monocline were investigated by Zoom Stereo Binocular examination and thin section study of well cuttings in conjunction with the wireline log and core analysis to understand the depositional environment.

The sedimentological studies of the well cuttings samples of each of the main bodies resolved into various lithofacies based on their textural signatures (Grain size, shape, and sorting) wireline log and core analysis. Within A, B and C-sand distinct coarsening and fining upward sequences have been identified which reflect frequent sea level fluctuations. Textural investigations, particularly of those samples composed predominantly of sand size fractions, show that the mean grain size in studied field is fine to medium grained and range between 1.8φ and 2.5φ. The samples are moderate to well sorted and well rounded to sub-angular in shape. Mineralogically, the samples comprise mostly of quartz grains and occasionally feldspar grain. Only the fine grained sandstones of studied field exhibit a slight increase in the amount of feldspar. A few grains of dark colored minerals can occasionally be seen in thin sections. The results further indicate that the sandstones are fairly mature. The strongly coarse skewness determined in some of the facies, in particular the lithofacies of B sand indicate the progressively increasing competence of flood flow at near shore areas. Based on overall results it can be interpreted that the Upper sands of Lower Goru Formation of Lower Cretaceous age in Sindh monocline were deposited in moderate to high energy near shore sedimentary environment largely influenced by frequently fluctuating sea level.

Keywords: Lower Goru Formation in the subsurface of X Field, Monocline, Southern Indus Basin

1. INTRODUCTION

The uses of lithofacies identification and analysis have a greater importance in terms of clues towards the interpretation of depositional environments of sedimentary rocks. A succession of sedimentary strata should be described first in terms of distinct lithofacies units reflecting different processes of depositions. Then the facies can be grouped in the lithofacies associations, which can be interpreted in terms of depositional environments on the basis of the combinations of physical, chemical and biological processes which have been identified from analysis of the facies (Nichols, 1999). **(Fig. 1).**

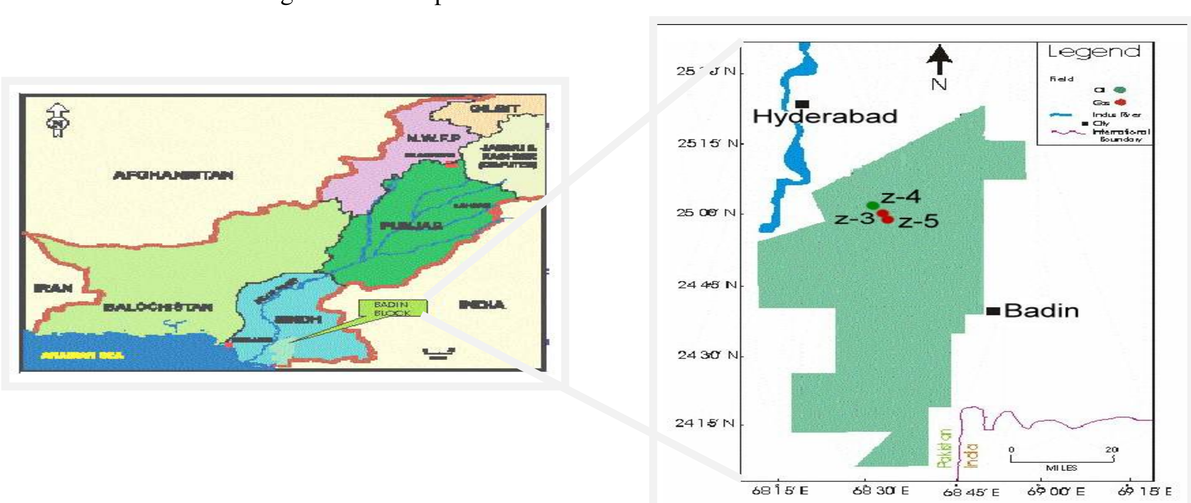


Fig.1. Location Map of the Badin Block showing the wells included in the present Studies

The main objectives of lithofacies analysis are to determine the environment of deposition of successions of rocks in the sedimentary record. The sandstone commonly occurs in regular successions that are characterized by vertical changes in texture and composition. These ordered sequences reflect the processes that transport sand and the conditions under which the sand was deposited. When observed in vertical sequence, the succession of rock properties permits the interpretation of sedimentary processes and may allow a prediction of size and shape of the sandstone body. Further more, the interpretation of sedimentary processes may permit an estimate of reservoir properties throughout the local extent of the sandstone (Berg, 1986).

This research is mainly based on the sedimentological and mineralogical analysis of well cutting samples and wireline logs of Z-3, Z-4 and Z-5 well and core analysis of Z-5wells of X Fields of Sindh monocline (Fig. 1). Attempts have been made to identify and analyze lithofacies and describe the depositional environments of Upper Sands of Lower Goru Formation in the sub surface of Sindh monocline. Sindh monocline is a eastern part of Southern Indus Basin situated on the Indian plate. Sindh monocline is the main oil and gas producing area of Pakistan where a large number of oil/gas and condensate fields have been discovered in the tilted faults traps, formed as the result of extensional tectonics.

2. STRATIGRAPHY/GEOLOGICAL SETTING

Geological setting

Badin Rift Basin, characterized by extensional tectonics, came into existence while India started breaking away from Madagascar about 127 million years ago. However the major Horst and Graben structuration, which forms the main entrapment mechanism, took place about 100 million years ago. During this period the source rocks of Sembar Formation and the reservoir rocks of Lower Goru were deposited. This was followed by major unconformity, which in turn was followed by a wide spread transgressive event of Upper Goru that provides the regional seal to the Lower Goru reservoir units .

Goru Formation

The term Goru Formation was introduced by (William, 1959) for the Upper most part of (Oldham's, 1892) belemnites beds, and included by (Hunting Survey Corporation, 1961) in Parh group. The type section of Goru Formation is located near Goru village on the Nar River in the Kirthar range (Lat: 27° 50' 00" N Long: 66° 54' 00" E). The Goru formation has conformable Lower contact with Sembar and Upper contact with Parh Limestone at type section. **(Fig. 2).**

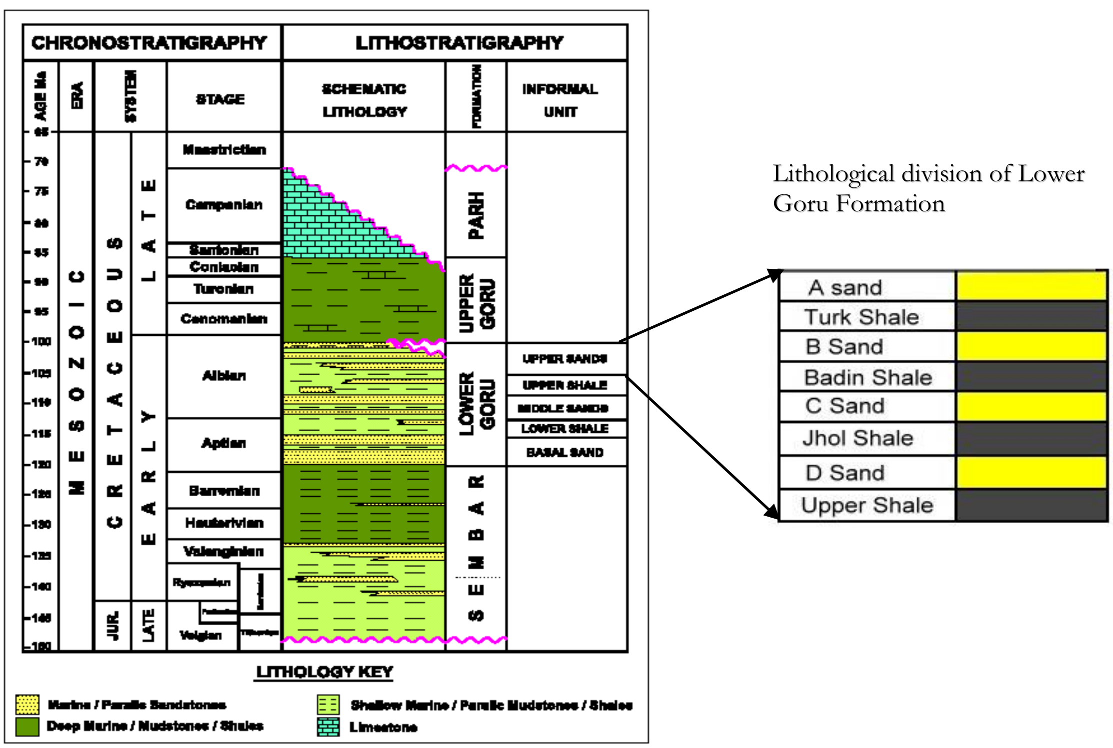


Fig. 2. Stratigraphy of Badin Block

The Upper Goru is dominantly composed of shale or clay and marl, and has no reservoir potential (Quadri and Shoaib, 1986). However, it forms a thick protective cover for oil and gas reservoir in the Lower Goru sands of the Thar slope platform. The upper Goru decreases in thickness in all the directions from the south –central part of the Southern Indus Basin. Its thickness is greater than 1,540m in the southwestern part of the Thar slope platform. The Lower Goru is mostly interbedded sandstone and shale in different proportions and is confined primarily to the southern area of the Thar platform and the adjoining offshore (Quadri and Shoaib, 1986). The wells drilled in Badin area exhibit a lateral facies change from east to west, from producible sand/shale sequence in Lower Goru to non reservoir sand /shale facies, which in turn is entirely represented by shales further west (Kadri, 1995). The zone of facies lateral change, from sand to shale, has been an area of major interest to oil companies as it bears all the hydrocarbon potential in Badin area and further north wards at least up to Kandhkot. The Lower Goru Formation is primarily composed upper sands, middle sands, and basal sands separated by upper and lower shales. Most of the hydrocarbon producing horizons lies in the upper sands, which are further divided into A, B, C and D sands separated by Turk shale, Badin shale and Jhol shale shown in **(Fig. 2).**

3. MATERIAL AND METHOD

Well cutting samples of three wells of X field were analysed for this study. Initially washing of the samples was carried out with water in association with few drops of hydrogen per oxide for cleaning and disintegration of grains. Later a detailed study under Zoom stereoscope was performed for the determination of texture and optical properties. Lithological logs were prepared after the identification of different lithofacies. To avoid mixing of interbedded lithology and samples interval some prilimnary steps must be taken, specially two types of interbedding caused problems when working with well cuttings, thin interbedding and major two or more lithologies within the sample interval. Thinly interbedded lithologies commonly occurred as pairs of rock types in the sample interval with individual beds being blow the resolution of the logging tools which then gives and average value for the thinly interbedded units. Unless one lithology has distinctive log signature, individual lithologic units that are smaller then the sample interval which again require distinctive log signature to relocate**.** When these could not be differentiated in the logs there was no way to determined the actual succession of lithlogic units in the sample interval. Gamma ray logs of some wells of X field were used to reflect the vertical profile of grain size. Correlation of Stratigraphic cross section with wire line logs of Z-3, Z-4 and Z-5 well is constructed using the Geological software, GeoGraphix. For the correlation of wireline logs with lithologic logs were constructed on Corel Draw, 9 version. Core samples of B-Sand of Z-5 well were examined for the lithofacies identification, sedimentary structures, bioturbation and their environment of deposition. These can also be calibrated with and interpreted from Wireline log data. Grain size analysis was performed using standard sieving. Sands size fraction were analysed using the standard sieving techniques described by (Krumbein and Pettijhon, 1938), and (Folk, 1966). A set of British standard sieves number 8 to 240 with an aperture interval of 0.25ϕ was used. The thin sections were prepared of cutting chips for detailed mineralogical study with the help of polarizing microscope.

4. RESULTS

Binocular analysis and interpretation of well cutting samples.

Z-3 Well

In Z-3 well the total depth (TD) is 6970 feet, seventy seven (77) samples were washed, dried and preserved for investigation. The binocular study reveals that the sandstone are predominantly composed of Quartz particles of fine to medium grained size. Some grains of heavy minerals were also seen in the samples. The sandstone facies contain moderately to well sorted. The grains are rounded to sub-rounded and at some places sub-angular to sub-rounded. The grains are generally colorless, off white, transparent, brown, light brown, grey-dark grey. The coarse grained sediments have been generally found in B sand unit of the Upper Sands.The lithological logs, cumulative frequency curve graph for Z-3 well has also been constructed **(Fig. 3).**

Z-4 Well

In Z-4 well total depth of the well is 6900 feet, seventy four (74) samples were washed, dried and preserved for investigation. The binocular study reveals that the sandstone are predominantly composed of Quartz particles of fine-medium grained size. The sandstone facies contain generally moderately to poorly sorted. The grains are rounded-sub rounded and at some places sub angular-sub rounded. The color is generally grey to light grey, white, off white. The medium to coarse grained sediments have been generally found in B sand unit of the Upper Sands. The lithological logs, cumulative frequency curve graph for Z-4 well has been constructed **(Fig. 4).**

Z-5 Well

In Z-5 the total depth of the well is 7000 feet, seventy two (72) samples were washed, dried and preserved for investigation. The binocular study of well Z-5 samples reveals that the sandstone are predominantly composed of Quartz particles of fine to medium grained with some heavy minerals grain. The sandstone facies are generally poor to well sorted. The grains are rounded to sub-rounded and at some places sub-angular to sub-rounded. The grains are generally transparent, brown, light brown, grey-dark grey in color. The coarse grained sediments have been generally found in B sand unit of the Upper Sands. The lithological logs, cumulative frequency curve graph for Z-5 well have also been constructed (**Fig. 5**).

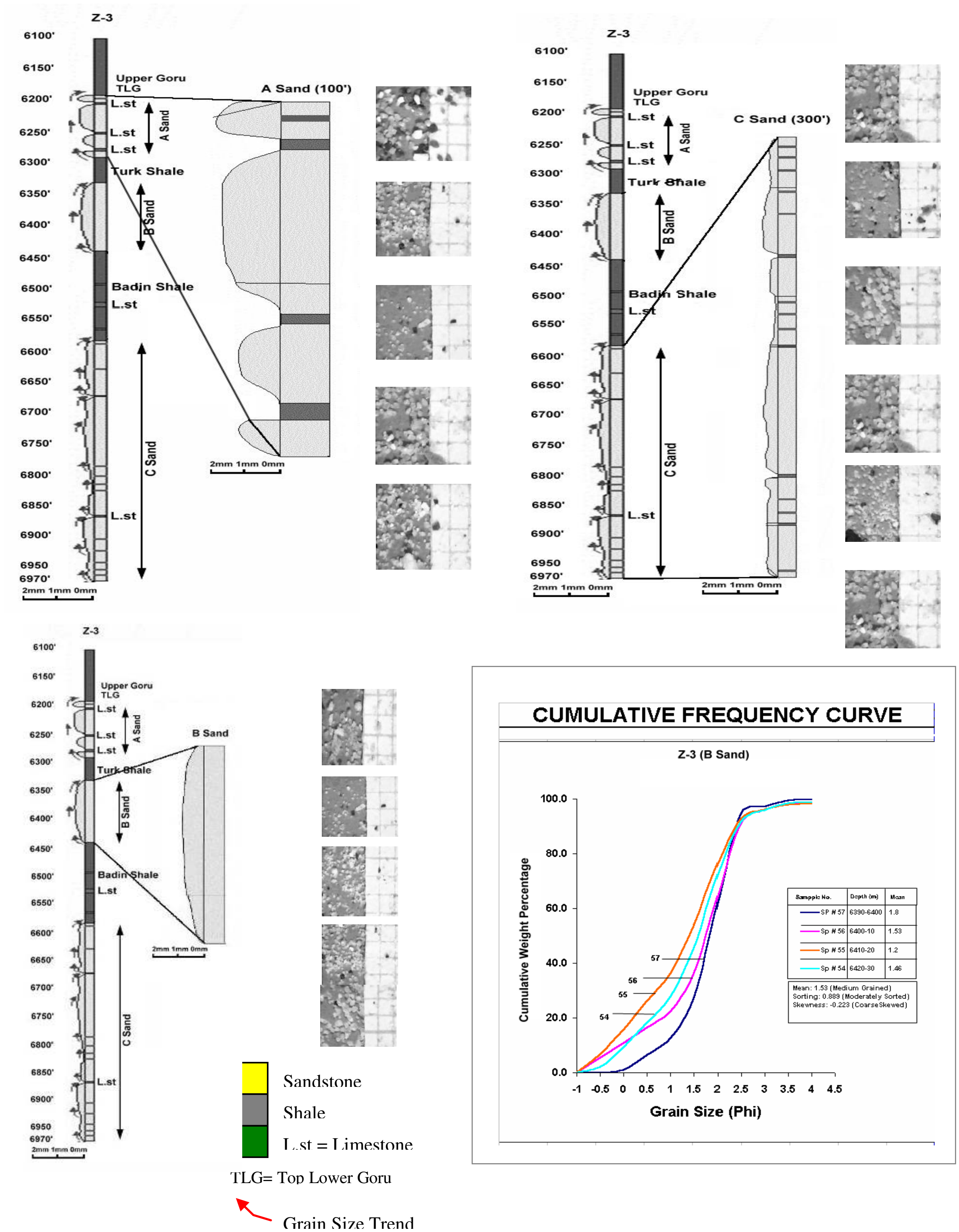


Fig. 3. Z-3 Well Lithological section with A, B, C, Sand lithofacies and Grain size curves

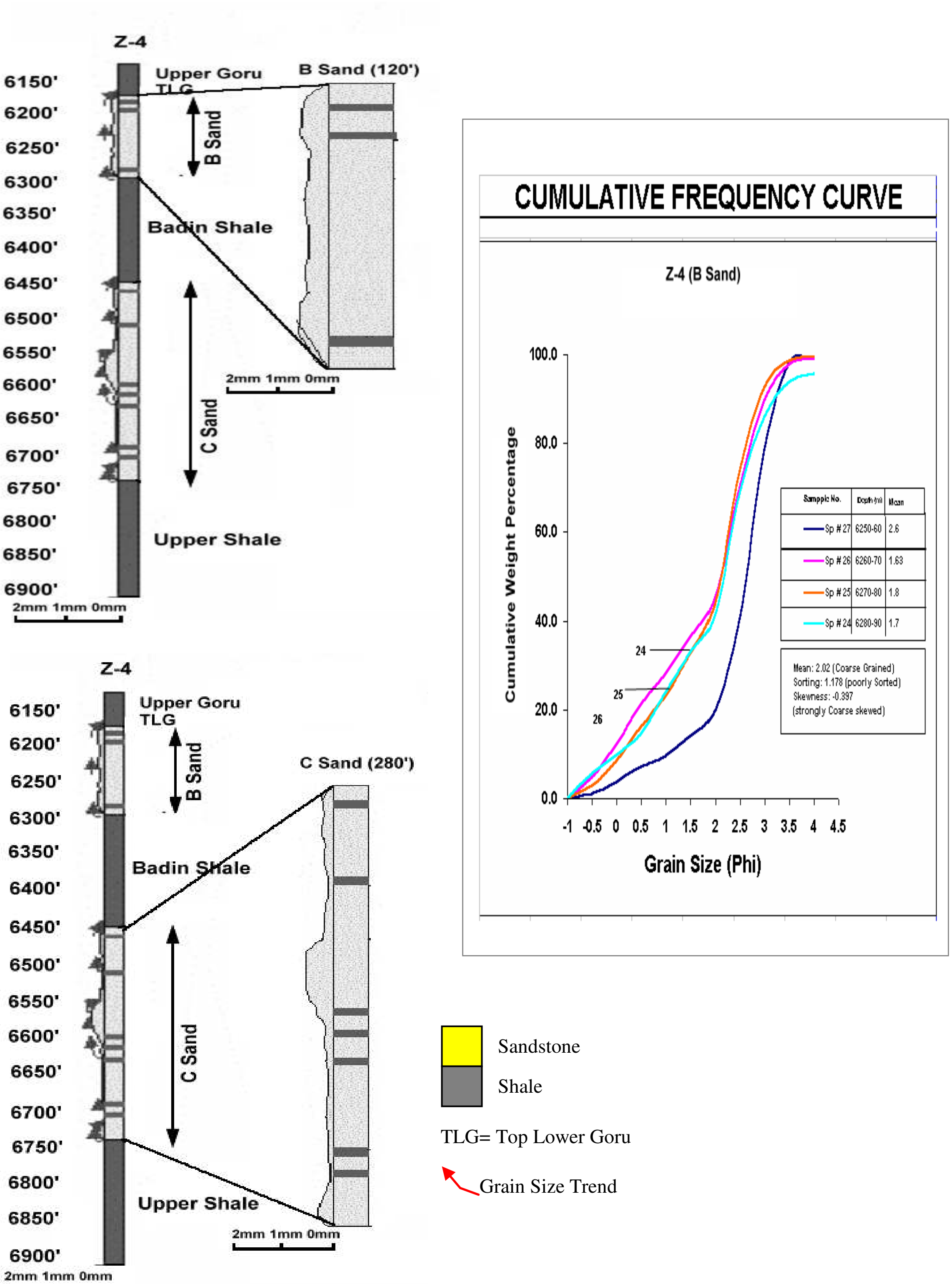


Fig. 4. Z-4 well Lithological section with B, C, Sand lithofacies and Grain size curves

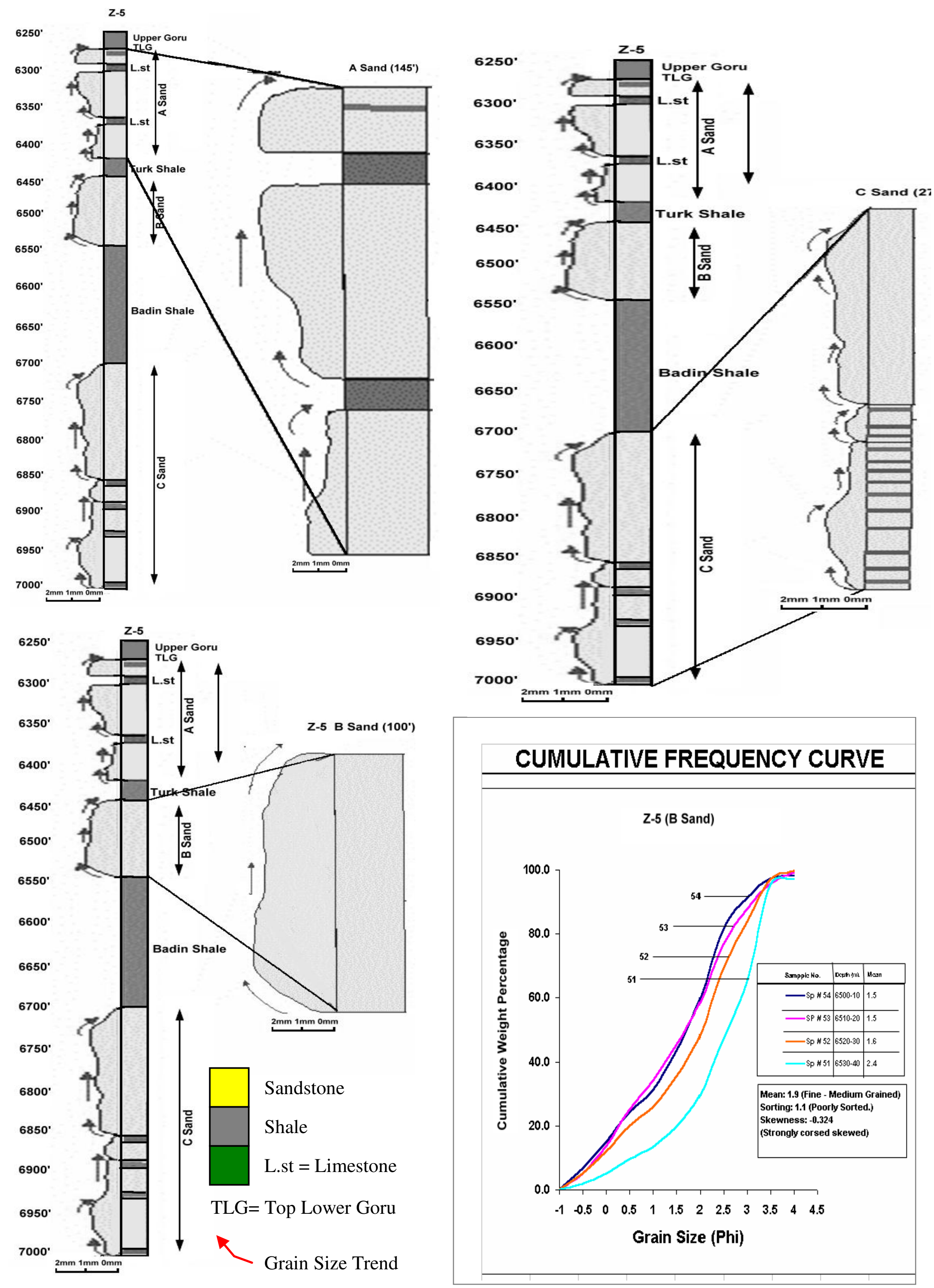


Fig. 5. Z-5 well Lithological section with A, B, C, Sand lithofacies and Grain size curves

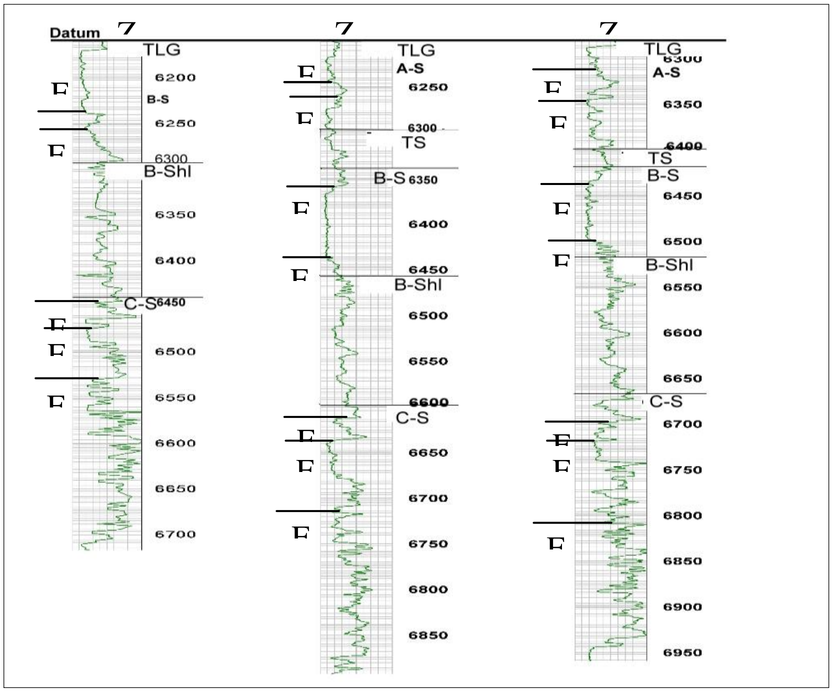


Fig. 6 Wireline log responses of z-3, z-4, z-5
TLG= Top Lower Goru, A-S= A-Sand, T-S= Turk Shale, B-S= B-Sand
B-Shl= Badin Shale, C-S= C-Sand, F1= Facies-1, F2= Facies-2, F3=Facies-3,
F4= Facies-4, F5= Facies-5, F6= Facies-6.

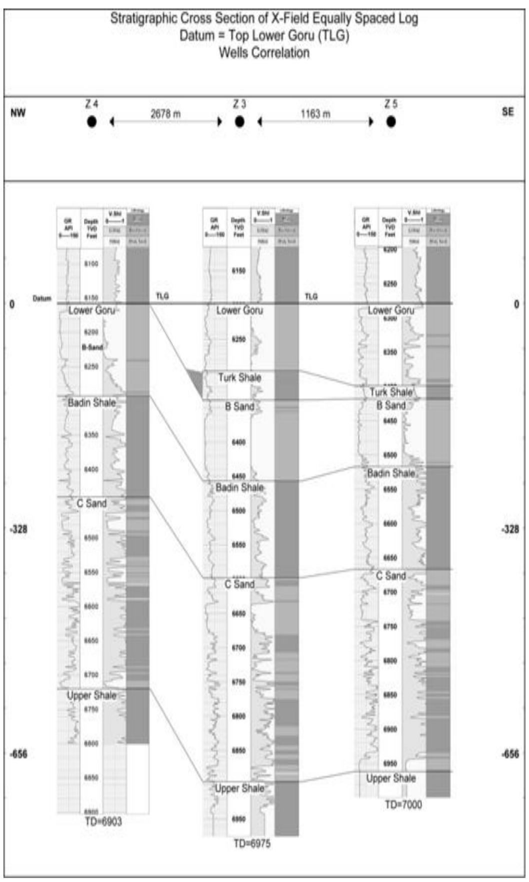


Fig. 7. Correlation of Stratigraphic cross section with wire line logs.

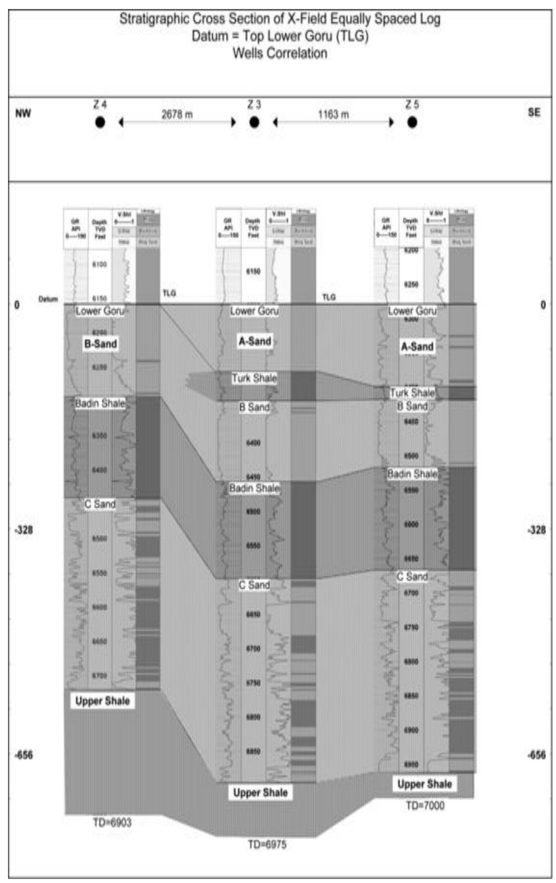


Fig. 8. Correlation of Stratigraphic cross section with wire line logs

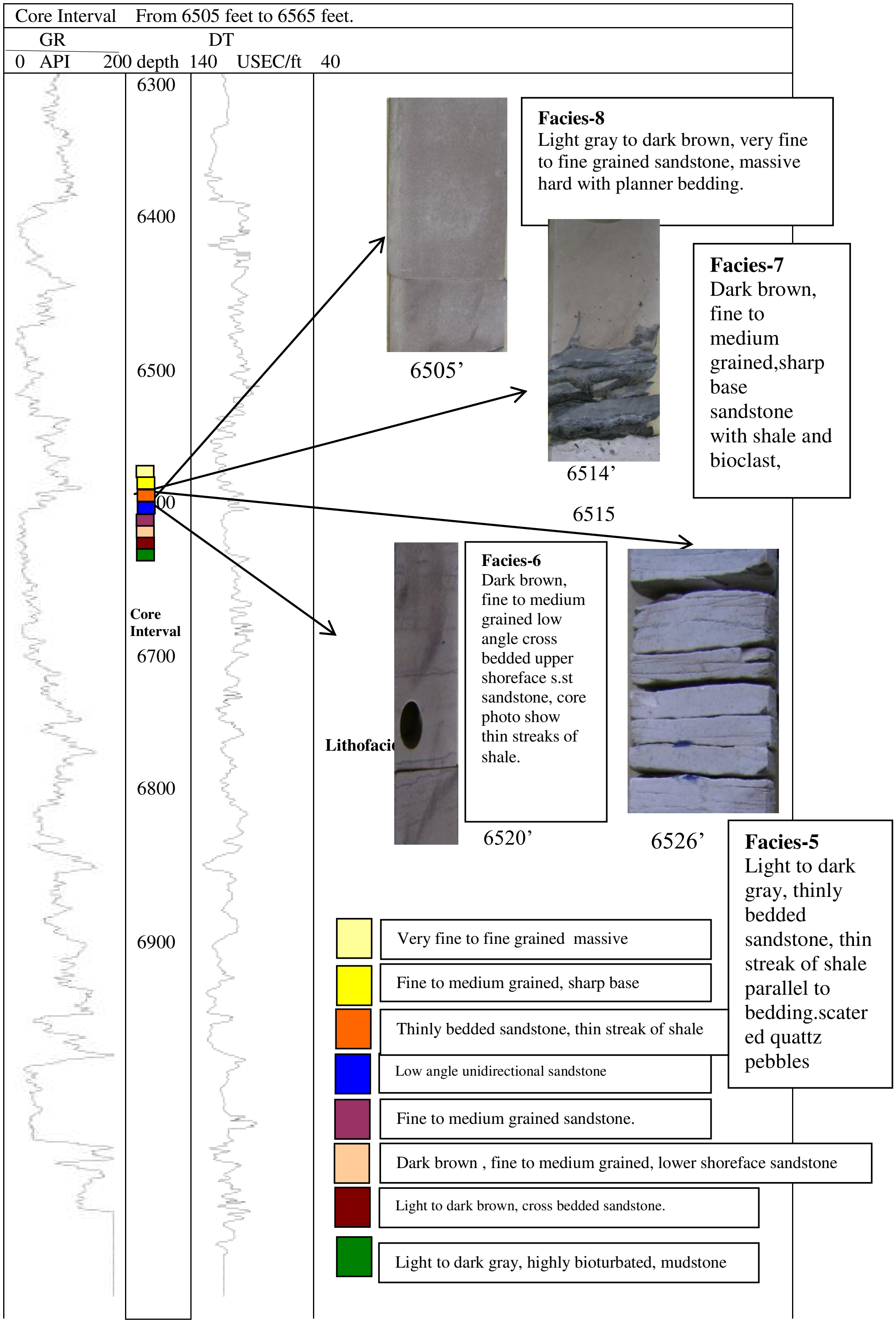


Fig. 9 contenue second on page

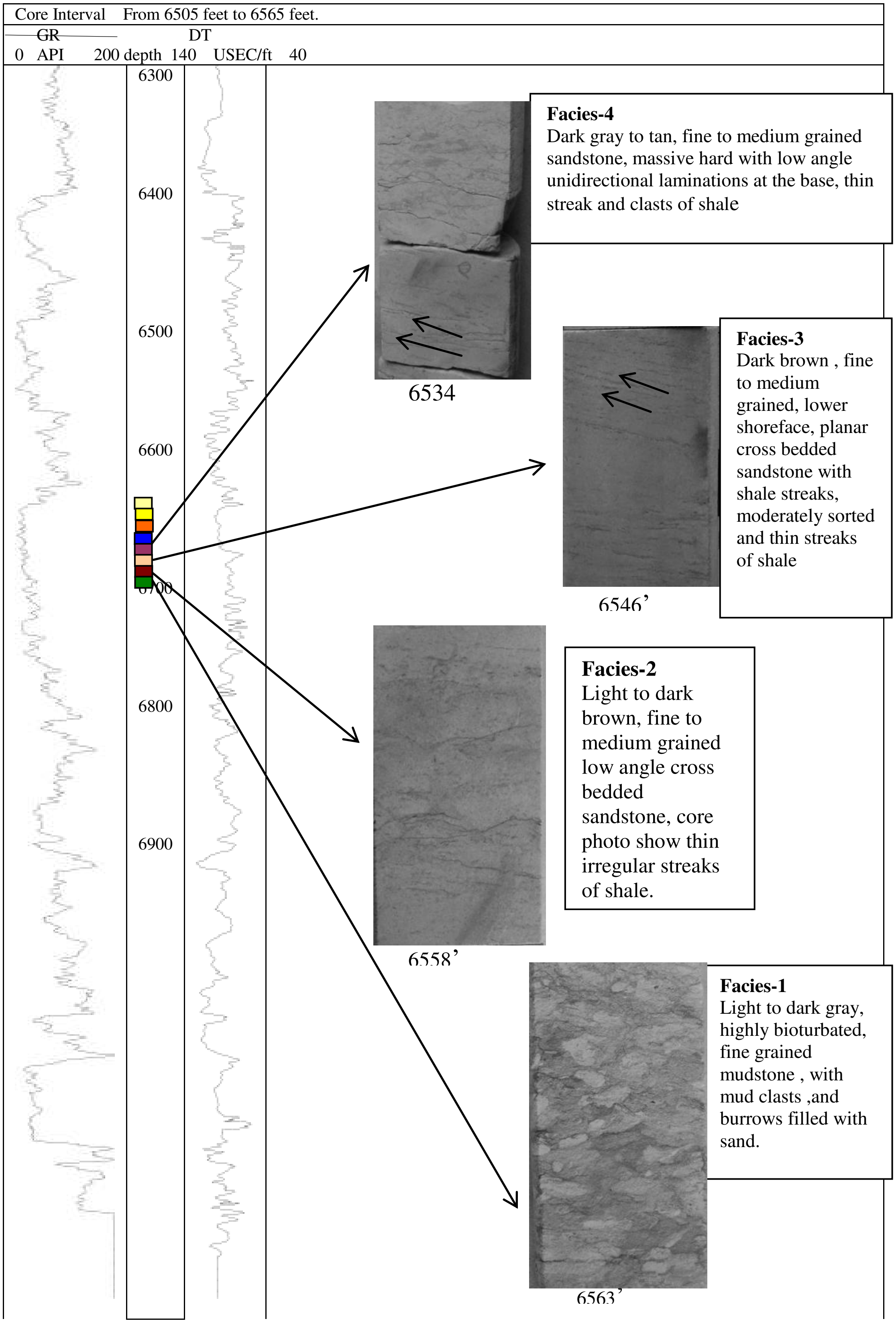
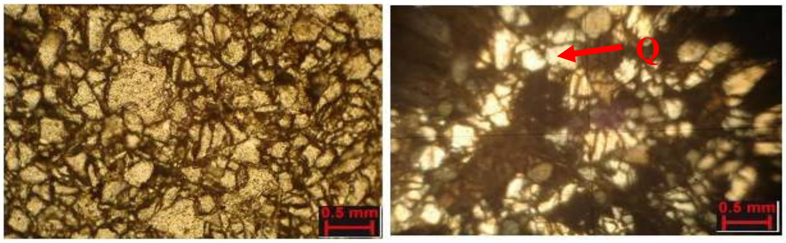


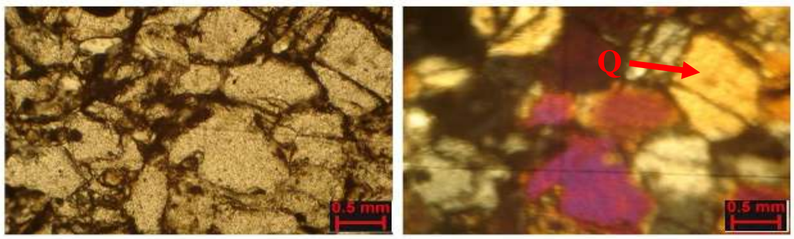
Fig:9 Lithofacies identified from Core Samples of well z-5 Petrographic examination of Well cutting samples

Plate. No.-1
It is mainly composed of Quartz (Q) mineral and traces of iron ore.



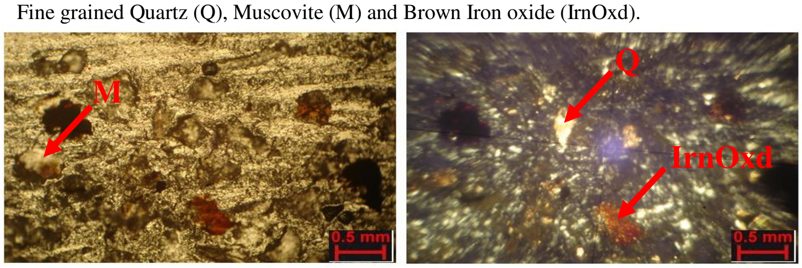
(PPL) Z5- A Sand 6300-6310 ft (XPL)

Plate. No-2
Medium to coarse grained Quartz (Q).



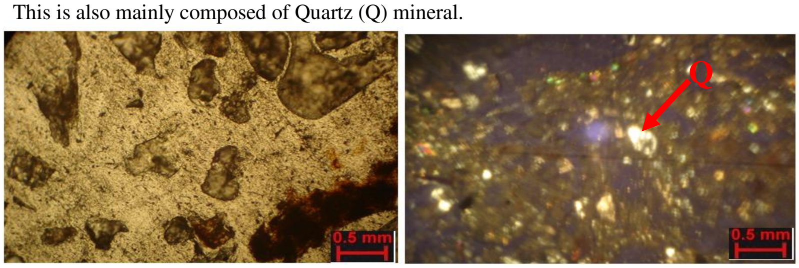
(PPL) Z5- A Sand 6390-6400 ft (XPL)

Plate. No. 3.
Fine grained Quartz (Q), Muscovite (M) and Brown Iron oxide (IrnOxd).



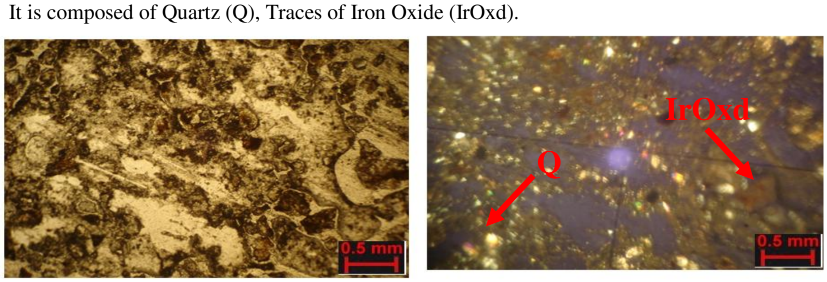
(PPL) Z5- B Sand 6450-6460 ft (XPL)

Plate.No. 4.
This is also mainly composed of Quartz (Q) mineral.



(PPL) Z5- B Sand 6480-6490 ft (XPL)

Plate.No. 5.
It is composed of Quartz (Q), Traces of Iron Oxide (IrOxd).



(PPL) Z5- B Sand 6520-6530 ft (XPL)

Fig. 10: Thin section plates showing the microfacies

5. CONCLUSION.

The detailed studies carried out on well cuttings samples taken at 10 feet interval of three wells and core analysis of one well and wireline logs of these wells of Badin block provide valuable information on texture and lithology of Lower Goru sandstone. Based on these results different lithofacies have been identified from Upper sand of Lower Goru Formation. In A, B and C sand units which are separated by shale intervals, different coarsening upwards (shallowing upwards) and fining upwards cycles are identified**. (Fig. 4, 5 and 6).** This is due to temporal fluctuations in sea level. The results indicate that the sand grain size in the studied field ranges from 1.8 φ to 2.5 φ (fine-medium sand) but some facies are also identified which ranged in between 0.9 φ to 1.5 φ (medium -coarse sand). The sand grains are well sorted and sub-angular to well rounded. Particularly in the B sands strongly coarse skewness (-0.223 to -0.324) indicates increasing flood flow competence in near shore areas. Petrographic analyses show that the upper sands including A, B and C units of the Lower Goru Formation are adequately mature as most of the samples comprise of quartz grains and rarely contain feldspar grains, the absence of the feldspars is probably due to intense chemical weathering in hot and humid climate and the feldspars are less likely then quartz to survive several episodes of recycling. Few grains of iron oxides and muscovite can occasionally be seen in thin sections.

The GR log response of the A and B Sands were used to interpret environment of deposition. According to (Wasimuddin *et al.,* 2002). if the log response is a serrate funnel shape this is due to clay and silt interbeds.

In A sand facies which shows coarsening-upwards and fining upwards profile on log are interpreted as upper shoreface sands intercalated with lower shoreface shaly sand. The GR curve shapes of A sand generally exhibit a serrated combination of funnel-bell appearance. Based on these characteristics the A sands are classified as beach and barrier bar sands, but some of the A sand facies consist of lower shore face facies.

Based on textural studies similar conclusions have been drawn by (Ahmed *et al.,* 2004), Ebdon *et al.* (2004) has also proposed shallowing upwards cycles in A sand while studying core data. Lithofacies of B-sand comprises of mature sand, medium to coarse grained, rounded to well rounded and well to very well sorted. Some of the facies are very fine to fine and silty sands. Medium grained barrier bar sand appears on GR log as a blocky log motif (Ahmad, 2003). In the study area B sand has blocky log motif **(Fig.7)** and it's also confirmed from the grain size analysis study of the B sand in which grain sizes ranges between 0.5 φ and 1.75 φ. Lithofacies identified from C-sands on the basis of textural signatures indicate that the C-sands are texturally immature due to shaly intercalation, containing matrix, moderate to poorly sorted and sub angular to sub rounded characteristics. Therefore, the C-sands are interpreted as transgressive marine sands, because whole sequence represents increasing water depth through out geologic time.

The upper sand in Lower Goru Formation consists of a number of coarsening upward (Shallowing upward) and fining upward sequences, interpreted and indentified from the correlation of GR log response against grain size analysis, and 60 feet core from B sand of well Z-5 have been examined and eight lithofacies identified which were used for the interpretation of depositonal environment. Upper sand was deposited in transgressive marine to shallow marine shelf environment and barrier bar and distributaries channel deposits. Identified facies photos are shown in (**Fig. 8, 9**. **10.)** In studied field the sandstones are varied in nature, i.e. silty, shaly , locally bioclastic and ranges in size from very fine to coarse grained, moderate to well sorted, and formed shallowing upwards (coarsening upwards) successions. The core show bioturbation in its basal part demonstrateing diminishing trend moving upward The bioclats are fragmented and sharp based shale material, interpreted as storm event beds and they pass into bioclastic cross bedded sandstone. Besides, large and small scale cross bedding, horizontal stratification, and parallel lamination has been observed.

This study of well cuttings and Wireline logs core analysis is helpful to improve the knowledge of internal architecture of Lower Goru sandstone reservoir and shale layers and the relationship to the environment of deposition.

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