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# Flow zone indicator: A tool for Facies analysis & identification of zones for fracturing by integrating core, production & log data in low porosity & low permeability reservoir of KG Basin, India: A case study

B. S. Haldia, V. L. N. Avadhani, Shilpi Ray, Lt. Col. (Dr.) K. J. Singh

CEWELL, ONGC, Makarpura Road, Vadodara-9, India

***Presenting author's e-mail:*** *ray_shilpi@ongc.co.in*

***Abstract***

Synrift clastic reservoirs of Triassic to lower Cretaceous ages are of prime interest for exploration targets in the recent past in KG-PG Basin. These reservoirs occurring within Manadapeta & Gollaplli Formations at deeper depth are of relatively low porosity and permeability and are at high pressure and at relatively high temperature. The petrophysical characters depict feldsphathic compact sandstone layers having porosity in the range of 10-18% with varied permeabilities within these Formations. Gollapalli Formation being relatively young depicts better reservoir characters in Endamuru, Mandapeta and Mandapeta west areas. The same Formation developed at deeper depths in the other fields of the basin has poor reservoir characters.

Porosity & permeability has got more bearing on productivity of well in these low porosity permeability reservoirs. Facies analysis, which is used to group the facie having similar flow potential, is essential in such reservoirs to assess their flow potential. Determining Flow zones and rock types on cores, its integration with testing data vis-à-vis interpreted petrophysical parameters and propagating them in other wells is essential for planning effective stimulation jobs.

In this study, a special focus was given to integrate core results for defining the interpretation model as well as rock typing and calibrating the results. Porosity, permeability, capillary pressure data and Swirr values from core data are corroborated with the petrophysical results. Four distinct rock types within these reservoirs are identified from flow zone indicator computed on cores and named as Rock type I to IV in order of increasing FZI values which can be referred as Shaly sand, fine grained/ silty sand, medium grained & coarse grained sandstone.

Due to low transmissibility of the reservoir, HF jobs are frequently being carried out. Brittleness index is the property of rock used to infer the susceptibility of fracturing the rocks which can be computed using Poisson ratio. Integration of facies derived from cores with the interpreted petrophysical parameters, testing results and their propagation in other wells where cores are not available are also focused in this study. Methodology to select the zones for hydro-fracturing jobs with computed brittleness index using processed log data to predict reservoir producibility is also highlighted.

## 1.0 Introduction:

Synrift clastic reservoirs of Triassic to lower Cretaceous ages are of prime interest for exploration targets in the recent past in the Fields of KG-PG Basin (fig. 1). These reservoirs occurring within Manadapeta & Gollaplli Formations at deeper depth are of relatively low porosity and permeability and are at high pressure and at relatively high temperature. The petrophysical characters depict feldsphathic compact sandstone layers having porosity in the range of 10-18% with varied permeabilities within these Formations. Gollapalli Formation being relatively young depicts better reservoir characters in Endamuru, Mandapeta and Mandapeta west areas. The same Formation developed at deeper depths in the other fields of the basin has poor reservoir characters.

Reservoir rocks are deposited in different geological condition & undergone different diagenetic conditions. Various changes occurred in the pore system due to diagenesis which controls the productivity of the formation. Rock typing is a process in classifying and similar flow zones of a reservoir rock having deposited in similar geological conditions & has undergone similar diagenetic conditions.

## 2.0 Methodology

The synrift reservoirs developed across various Fields have been systematically evaluated qualitatively and quantitatively using all the petrophysical data and available geological informations.

## 2.1 Mineralogical Model

Petrophysical model for processing of log data is developed for Nandigama/ Gollapalli & Mandapeta Formation by integrating core data and inferences from cross-plots. The mineralogical model consists of Quartz, Feldspar, Illite, Kaolinite and one heavy mineral in ELAN module is used for processing of log data. Mineral volumes computed from ELAN are used to compute permeability after changing permeability factor of different volumes to match with core measured permeability.

## 2.2 Rock Typing:

An attempt is made to determine rock typing within the sands developed in Gollapalli formation based on flow zone indicator (FZI). Two different approaches are used for determining rock types. One approach is used to compute Flow zone indicator from Irreducible water saturation ($S_{wirr}$) computed from ELAN processed output. As this method does not provide FZI and rock types in water bearing zone and hence could not be used to determine rock types in the entire Formation.

Another approach is used to compute FZI from permeability and porosity computed from ELAN processed output. FZI is computed dividing RQI with NPI. Reservoir Quality Index (RQI) is computed using KINT (intrinsic permeability computed from ELAN volumes & porosity) & PIGN (effective porosity computed from ELAN) with 0.0314sqrt(KINT/PIGN) equation and Normalized Porosity Index (NPI) is computed using PIGN/(1-PIGN) equation. This approach has some limitations as the permeability computed from ELAN is based on computed mineral volumes and porosity and not from pore geometry. It can be used for rock typing after properly calibrating the permeability from processed data with core permeability. Permeability factor of minerals were changed to match with core measured permeability and were used in others wells for permeability computation from mineral volumes & porosity. However, permeability computed on core samples in well Well-A (Fig-2A & 2B)) has good match with permeability computed from processed output. Moreover in Well-B (Fig-3), permeability computed from pressure build-up data (Reservoir study) is also fairly matching with permeability computed from processed output.

Four distinct rock types within the reservoir are identified from flow zone indicator calculated from core data are named as Rock type I to IV in order of increasing FZI values and are assigned as Shaly sand, fine grained/ silty sand, medium grained & coarse grained in Gollapalli Formation (Fig. 4) which is matching with broad lithological descriptions. Capillary pressure studies on core samples are also used to identify rock facies/ types. Capillary pressure and irreducible water saturation have been plotted and it is observed that four rock types can be distinguished from the plots (Fig. 5). These four rock types can be correlated with the rock types from FZI values computed from core data. FZI values computed from Porosity & permeability obtained from processed output are also grouped into same ranges and different rock types are generated for the entire formations.

The FZI values obtained in individual wells in the study area from ELAN are binned in the ranges corresponding to these four rock types already identified from integrated core data studies. Accordingly the reservoir facies log has been prepared and presented along with interpretation results. This log helps in identifying better reservoir facies corresponding to the lithofacies for planning hydro-fracturing jobs along with brittleness index. Based on crossplot between RQI & NPI on cores, rock types are determined as given in table-1. The rock type derived are associated with the dominant lithological components and propagated for the entire stratigraphic column vertically and laterally.

## 2.3 Brittleness Index:

Porosity & permeability has lot of bearing for productivity of well. Low porosity and poor permeability is observed in sands developed within Gollapalli & Mandapeta Formations in all the wells except wells pertaining to Endamuru structure. Due to low transmissibility, HF jobs are frequently being carried out.

Brittleness index is the property of rock which can be used to plan for successful fracturing jobs, and can be computed using Poisson ratio obtained from DSI log.

Mineralogical composition plays a vital role in determining brittleness of rock. Quartz is considered as more brittle composite as compared to shale which is more plastic in nature. Various mineral volumes present in the reservoir can also be used to compute brittleness index of a reservoir. Ratio of quartz volume to total volume of solid rock gives the brittleness index of the rock.

Zones, having low Poisson ratio are easy to fracture and high Young modulus helps in inferring the sustainability of the fracture. The zones with low Poisson's ratio/ high brittleness index and high Young's modulus are to be preferred for successful HF jobs. Following methodology is used to compute BI in wells where DSI log is not recorded.

- Brittleness index (BI_Poisson) can be computed from Poisson ratio & Young's modulus using Rickman et al (2008) equation as given below.

  *Brittleness Index = 100*(Young's modulus -1)/(8 - 1)*

  *Brittleness Index = 100*(Poisson's ratio - 0.4)/(0.15 - 0.4)*

  *Brittleness Index* = ([(E -1)/7) + [(v - o.4)/(-0.25)])/2
- Brittleness Index (BI_Volume) is also computed from ELAN volumes as given below in the same well (BTSAB) as quartz is also regarded as a brittle composite

  $$\text{Brittleness Index} = \frac{\text{Volume of Quartz}}{\text{Total minerals volume}}$$

- Crossplot between two computed BI from Poisson ratio & ELAN volume is prepared (Fig. 7).
- A transform between BI_Poisson & BI_volume is made and generated an equation given below, which is used to compute brittleness index in other wells where DSI log is not available (Fig. 7).

$$y = 0.038 * e^{3.351x}$$

Where

$$x = \frac{\text{Volume of Quartz}}{\text{Total matrix volume}}$$

## 3.0 Discussions

The interpreted petrophysical parameters brought out these sandstone layers having porosity in the range of 10-18% with varied permeabilities within these Formations. Permeability computed on core samples in well Well-A (Fig-2A & 2B) has good match with permeability computed from processed output. Moreover in Well-B (Fig-3), permeability computed from pressure build-up data (Reservoir study) is also fairly matching with permeability computed from processed output

Well-C is used as key well for computing brittleness index as DSI log is recorded in this well. Brittleness index (BI_Poisson) computed from Poisson ratio using Rickman et al (2008) equation (Track-9, fig. 6) and Brittleness Index (BI_Volume) computed from ELAN volumes (Track-10, fig. 6) has good match & validating the methodology. Generated transform between BI_Poisson & BI_volume is used to compute brittleness index in other wells where DSI log is not available.

Importance of combining of brittleness index with rock type for hydro-fracturing job is demonstrated in Well-D (Fig. 8), where production from zone has increased after HF job. Zone in the interval 4165-4170m has porosity in the range of 10-15% & the reservoir is having mainly fine grained sand as inferred from rock typing but brittleness index is favorable for HF (Fig. 8, Track-9). Production from this zone has increased by hydro-fracturing.

## 4.0 Conclusions

1. Porosity, permeability and grain density obtained from processed output are matched with the core porosity, permeability & grain density in well-A to see efficacy of petrophysical model used.
2. The computed porosity and permeability from petrophysical evaluation are correlatable with core-derived values and can be used for rock typing.
3. Computed porosity and permeability from petrophysical evaluation can be used to determine flow zone indicator (FZI) which can be further used for rock typing. Based on FZI values, four rock types are inferred within the reservoir.
4. Computation of brittleness index after calibrating with available rock mechanical properties make the selection of intervals for hydro-fracturing more assertive.
5. Making comprehensive Geomechanical models along with formation evaluation before taking up hydro-fracturing jobs help to increase the success of jobs with more productivity.

## 5.0 References


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**Table 1: Association of rock types to lithology**

| Criteria | Rock Type | Rock Type(grain) |
|---|---|---|
| FZI<=0.01 | Shale | Shale |
| FZI between 0.01-0.05 | Rock type-I | Shaly Sand |
| FZI between 0.051-1.5 | Rock type-II | Silty Sand/Fine grained sandstone |
| FZI between 1.51-2.5 | Rock type-III | Medium grained sandstone |
| FZI > 2.5 | Rock type-IV | Coarse grained sandstone |

Fig: 1

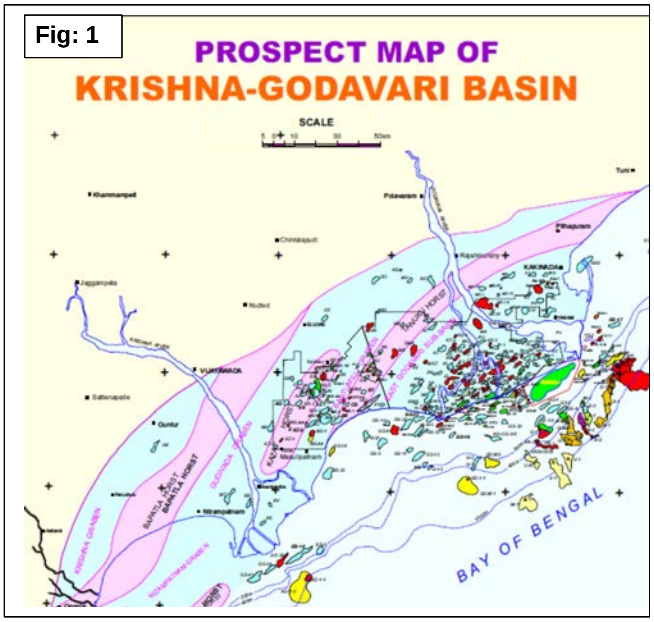
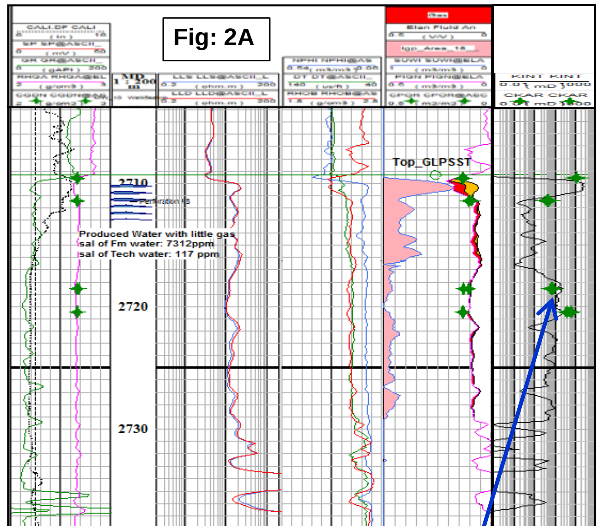



Fig: 2A




Comparison of permeability computed using ELAN vol & PIGN as well as core measured permeability

Fig: 3

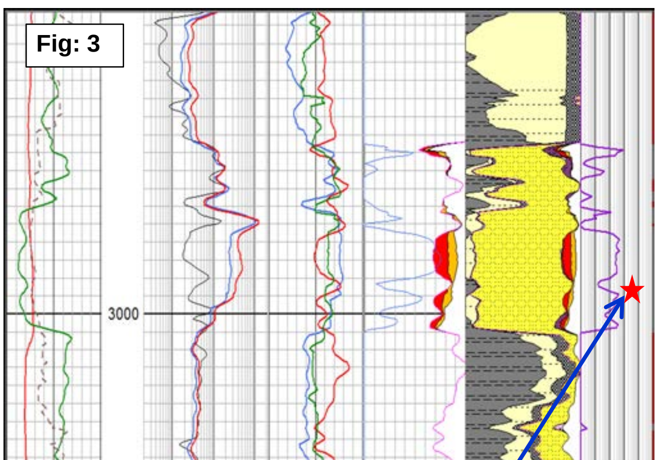



Fig. 3: Comparison of permeability computed using ELAN vol & PIGN as well as computed from pressure build up data

Fig: 2B

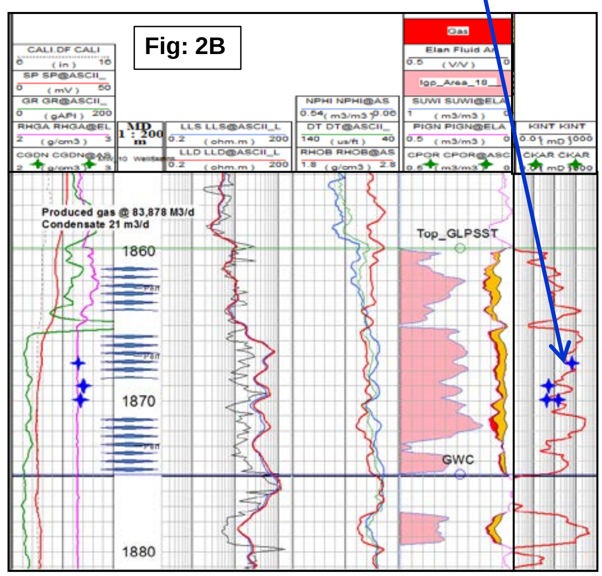



Fig: 4

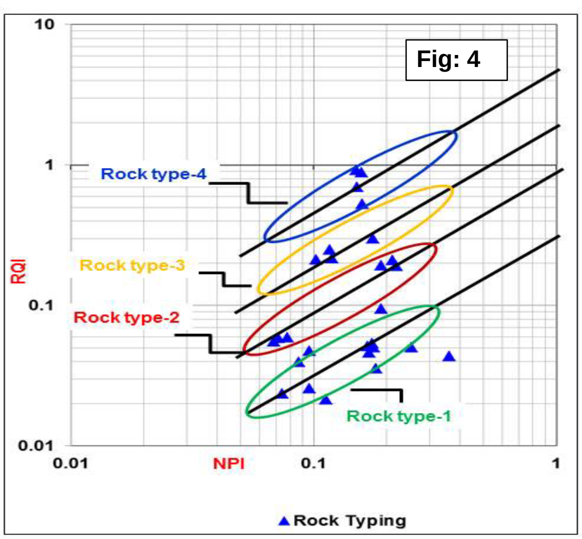
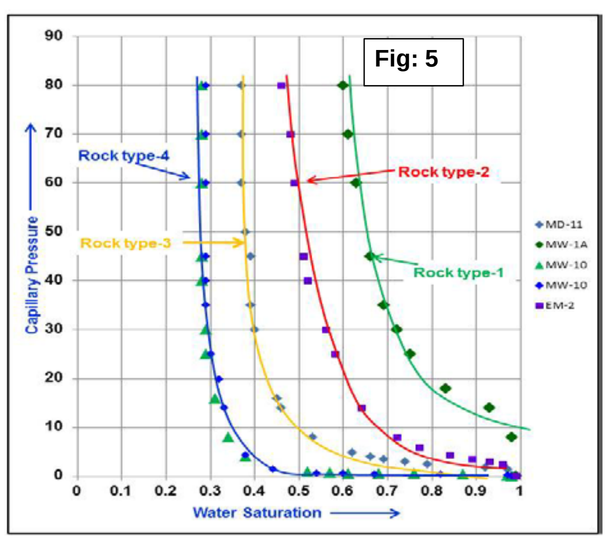



Fig: 5



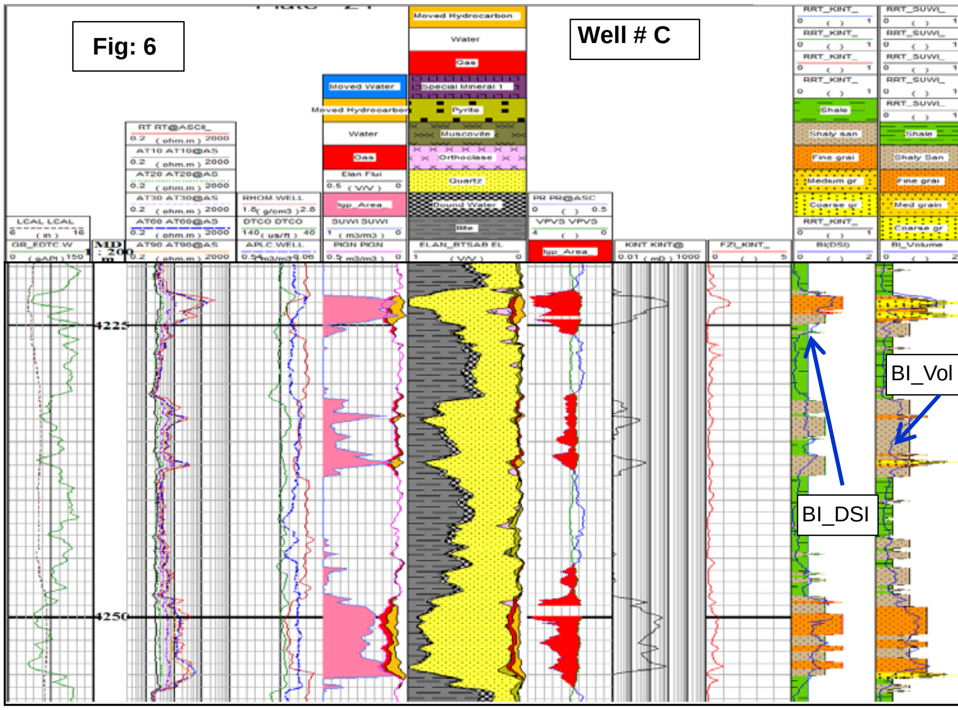



Fig. 6: Comparison of Brittleness index (BI_Poisson) computed from Poisson ratio using Rickman et. al. (2008) equation and Brittleness Index (BI_Volume) computed from ELAN volumes using regression

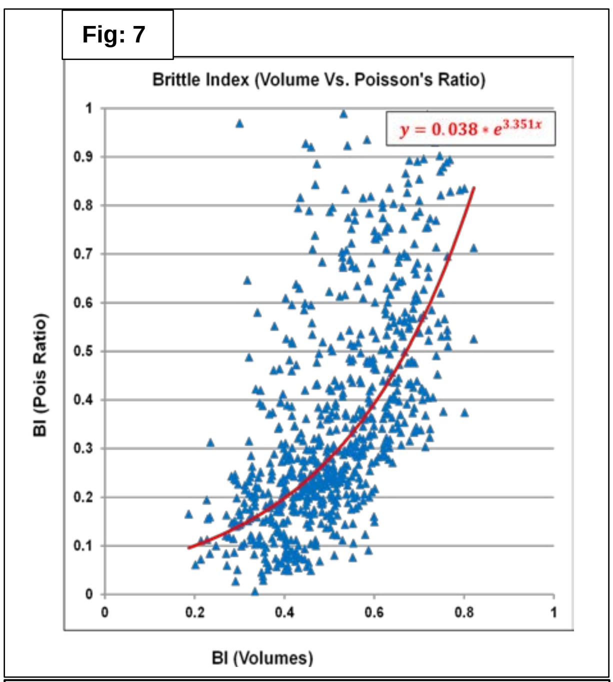



Fig. 7: Brittle Index computed from Poisson Ratio & ELAN Volumes. Regression of transform is used to compute BI from ELAN volumes where Poisson Ratio is not available: may be helpful in deciding HF job

$$y = 0.038 * e^{3.351x}$$

Where,

$$x = \frac{\textit{Volume of Quartz}}{\textit{Total matrix volume}}$$

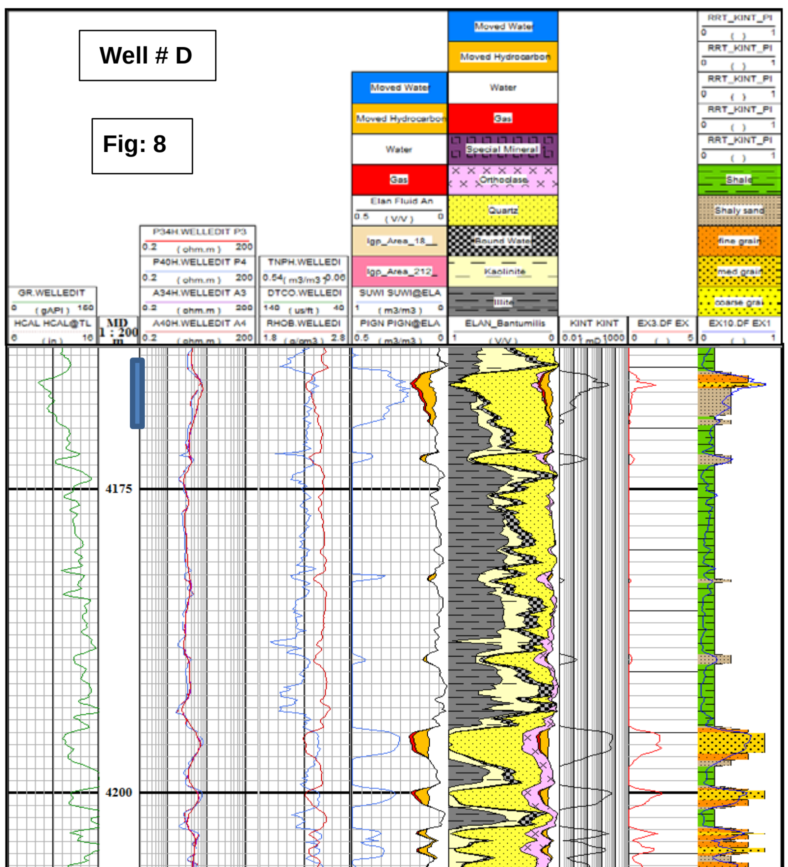



Fig. 8: Production of the zone 4165-4170m increased after HF job