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Prediction of payzones in Cambay Basin: An application of geochemical techniques

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Abstract

Prediction of payzones for hydrocarbon accumulation based on rock eval pyrolysis is compared with perforation testing results in wells of Cambay Basin. Predictions have been made based on Rock Eval parameters i.e. S1 (the amount of hydrocarbon in mg HC/gm rock already generated and present in the rock, liberated at 300 °C without cracking the kerogen), PI (Production Index: the ratio S1/(S1+S2)) and OSI (Oil Saturation Index: (S1/TOC*100)).

To assess true source potential and presence/absence of accumulated hydrocarbons in a zone, selected samples of high S2 values were re-analysed after extraction with chloroform to detect the presence of free high molecular weight oil (C_{24} and above).The difference between $S2_{initial}$ (S2 for initial sample) and $S2_{extracted}$ (S2 for chloroform extracted sample) was added to $S1_{initial}$ (S1 for initial sample) to get $S1_{total}$ for total free oil content. PI_{total} ($S1_{total}/S1_{total}+S2_{extracted}$) and OSI_{total} ($S1_{total}$ X 100/TOC) were also calculated. Predictions were made using geochemical parameters both before and after chloroform extractions and compared with testing results. Predictability as well as Forecast Efficiency were determined.

A total no of 2882 side wall cores/conventional cores samples of different intervals from 113 exploratory/development wells of Cambay Basin were analysed and prediction of hydrocarbon accumulation in sediments based on geochemical analysis vis-à-vis perforation testing results in 385 intervals of 60 exploratory and development wells in Cambay Basin were evaluated for predictability and forecast efficiency assessment. It was observed that both predictability and forecast efficiency improved after chloroform extraction. 71% of predictability and 85% of forecast efficiency has been achieved using criteria $S1_{(total)}$ >0.5, $PI_{(total)}$>0.3 and $OSI_{(total)}$ >100.

Keywords

Rock Eval data, prediction of payzones, Predictability, Forecast efficiency.

Introduction

The present study involves Rock Eval data generated for 2882 side wall core/conventional core samples of different intervals from 113 exploratory/development wells of Cambay Basin. Geochemical predictions for hydrocarbon accumulation based on Rock Eval pyrolysis data are compared with actual perforation results for wells and percentage of oil bearing zones predicted based on geochemical data out of total number of oil bearing zones found after testing is determined for evaluation of effectiveness of geochemical predictions.

Rock-Eval pyrolysis is an established method for the bulk characterization of organic matter in sediments and provides information on hydrocarbon content, hydrocarbon generation potential, kerogen type and maturity (Espitalié et al., 1977, Peters, 1986). It provides rapid information for source rock screening during exploration drilling using basic or bulk-rock method. Further, it is being utilized in reservoir geochemistry to identify heavy oils, tar mats, estimate API gravity (Trabelsi et al., 1994) and to characterize reservoir quality (Jones et al., 2004, Jones and Tobey, 1999) using reservoir method.

Rock Eval (RE) analysis, comprising heating of small amount of rock in inert environment, initially at 300°C for 3 minutes, followed by programmed pyrolysis to 650°C and further under oxic environment, up to 850°C, provides data on free hydrocarbon content (S1), petroleum generative potential (S2), thermal maturity (Tmax) and organic richness (TOC) of the sample (figure-1).

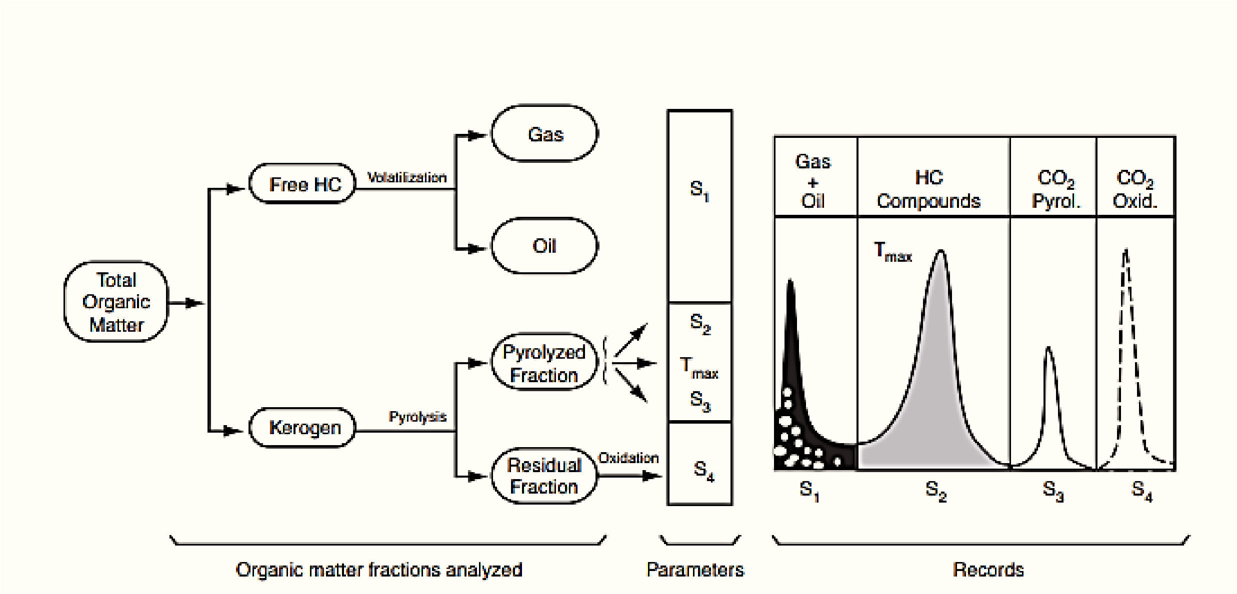


Figure-1: General diagram showing the different fractions of total organic matter of rocks analysed and corresponding parameters (Lafargue et al, 1998)

S1: the amount of free hydrocarbons (gas and oil) in the sample (in milligrams of hydrocarbon per gram of rock). Contamination of samples by drilling fluids and mud can give an abnormally high value for S1.

S2: the amount of hydrocarbons generated through thermal cracking of non-volatile organic matter. S2 is an indication of the quantity of hydrocarbons that the rock has the potential to produce.

S3: the amount of CO_2 (in milligrams CO_2 per gram of rock) produced during pyrolysis of kerogen. S3 is an indication of the amount of oxygen in the kerogen and is used to calculate the oxygen index. Contamination of the samples should be suspected if abnormally high S3 values are obtained.

T_{max}: the temperature at which the maximum release of hydrocarbons from cracking of kerogen occurs during pyrolysis (top of S_2 peak). T_{max} is an indication of the stage of maturation of the organic matter.

RE is also be used to determine TOC of the sample by oxidizing (in an oxidation oven kept at 850°C) the organic matter remaining in the sample after pyrolysis (residual organic carbon). The TOC is then determined by adding the residual organic carbon detected to the pyrolyzed organic carbon.

The type and maturity of organic matter in petroleum source rocks can be characterized from Rock Eval pyrolysis data (Emeis and Kvenvolden, 1986) using the following calculated parameters:

HI: hydrogen index (HI = [100 x S2]/TOC). HI is a parameter used to characterize the origin of organic matter. HI correlates with H to C ratio, which is higher in marine organisms and algae than in land plants. HI typically ranges from ~100 to 600 in geological samples.

OI: oxygen index (OI = [100 x S3]/TOC). OI is a parameter that correlates with the ratio of O to C, which is high for polysacharride-rich remains of land plants and inert organic material (residual organic matter) encountered as background in marine sediments. OI values range from near 0 to ~150.

In the present study, to predict possible hydrocarbon accumulations in studied zones, Production Index (PI=S1/S1+S2) and Oil Saturation Index (OSI=S1/TOC*100) were calculated. When OSI exceeds 100, it indicates free oil (Jarvie, 2012).

Using geochemical criteria i.e. $S1_{initial}$>0.5, $PI_{initial}$>0.4 and $OSI_{initial}$ >100 probable hydrocarbon accumulation zones were predicted. As hydrocarbons above C_{24} do not distil out in S1 peak, but are cracked in S2 peak (Tarafa et al., 1983), to assess true source potential and presence/absence of accumulated hydrocarbons in a horizon, selected samples of high S_2 values were re-analysed after extraction with chloroform to detect the presence of free high molecular weight oil (C_{24} and above). The difference between $S2_{initial}$ (S2 for initial sample) and $S2_{extracted}$ (S2 for chloroform extracted sample) was added to $S1_{initial}$ to get $S1_{total}$ for total free oil content. Subsequently, PI_{total} ($S1_{total}/S1_{total}+S2_{extracted}$) and OSI_{total} ($S1_{total}$ X 100/TOC) were also calculated. Further, probable hydrocarbon accumulation zones were predicted using the optimum criteria $S1_{total}$ >0.5, PI_{total}>0.3 and OSI_{total} >100.

Experimental

Visible contamination in samples (side wall cores/conventional cores) were removed by hand picking. Surface contamination were removed by warm water washing. Air dried sediment samples were pulverized to BSS 60 mesh size. Polyol used in mud system during drilling was removed by extracting with water until observation of clear extracted water before analysis. It is observed that Cores/SWCs require 8 hours or more for complete polyol removal. Programmed pyrolysis with Total Organic Carbon (TOC) determination were carried out using Rock Eval-6 Equipment (Standard and Turbo Model). Selected samples were extracted in soxhlet extractor with chloroform for determination of higher hydrocarbons, eluted with S2 peak.

Results and Discussions

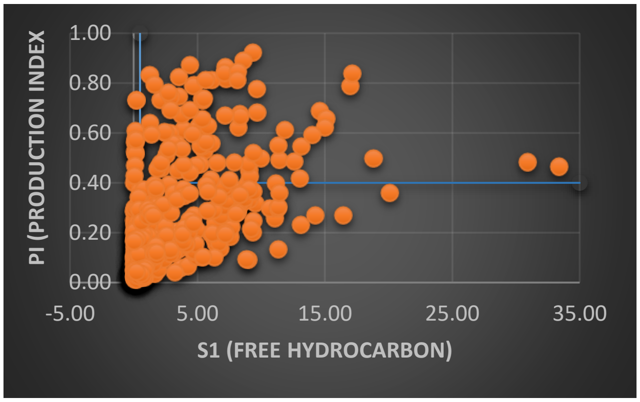
Initial screening for prediction of possible accumulation zones was done based on geochemical data S1, PI and OSI. As described above, samples of high S2 values were re-analysed after extraction with chloroform and predictions were made based on $S1_{total}$, PI_{total} and OSI_{total} (table-1).

Geochemical Criteria	**Water Extracted Samples (Initial data)**			**After Chloroform extraction**		
	$S1_{initial}$ (mg HC/gm rock)	**$PI_{initial}$**	**$OSI_{initial}$ (mg HC/gm TOC)**	**$S1_{total}$ (mg HC/gm TOC)**	**PI_{total}**	**OSI_{total} (mgHC/gm TOC)**
Before chloroform extraction	>0.5	>0.4	>100	-	-	-
After chloroform extraction	-	-	-	>0.5	>0.3	>100

Table-1: Geochemical criteria for prediction of hydrocarbon accumulation zones

***$S1_{total}$= $S1_{initial}$+ ($S2_{initial}$ - $S2_{chloroform\ extracted}$)
*$PI_{initial}$ = ($S1_{initial}$)/ ($S1_{initial}$+ $S2_{initial}$) and PI_{total} = ($S1_{total}$) / ($S1_{total}$ + $S2_{extracted}$)
*$OSI_{initial}$ = ($S1_{initial}$*100/TOC) and OSI_{total} = ($S1_{total}$*100/TOC)

By applying both the criteria (before chloroform extraction and after chloroform extraction), S1-PI plots (Figure-2 & 3) and S1-PI-OSI plots were created (Figure-4 & 5).



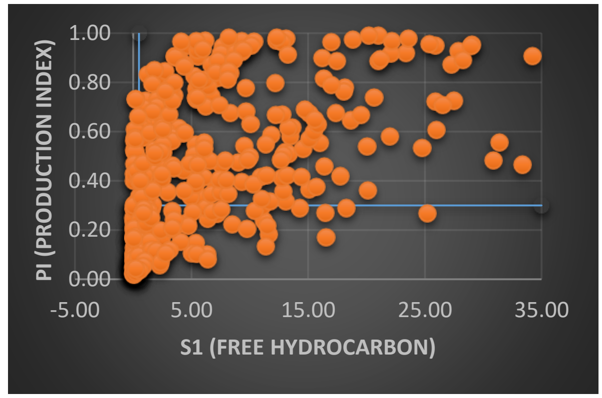
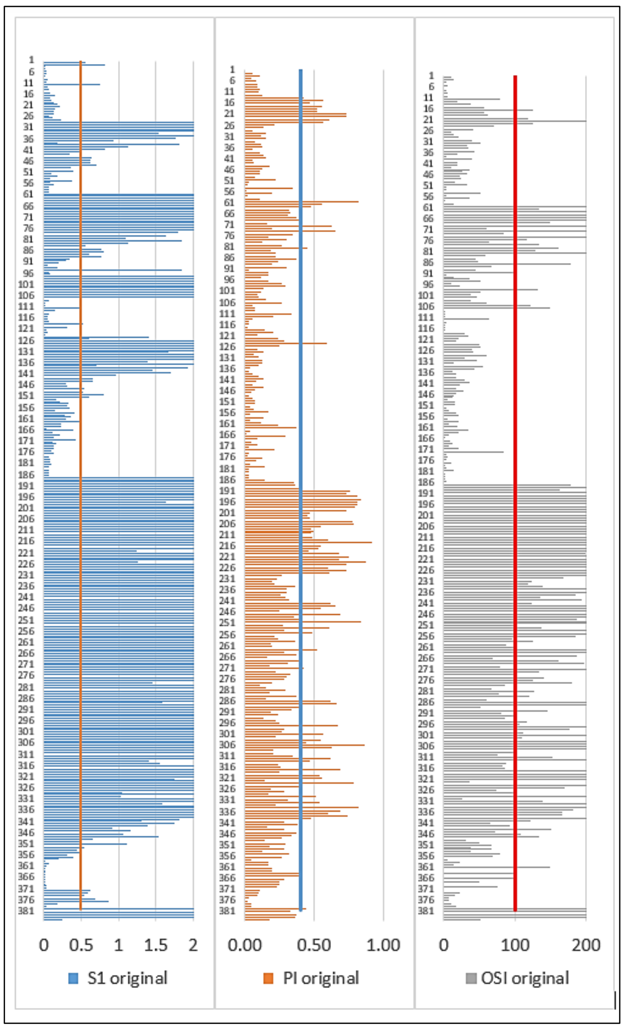


Figure-2: $S1_{initial}$-$PI_{initial}$ Plot (Before chloroform extraction)

Figure-3: $S1_{total}$-PI_{total} Plot (After chloroform extraction)



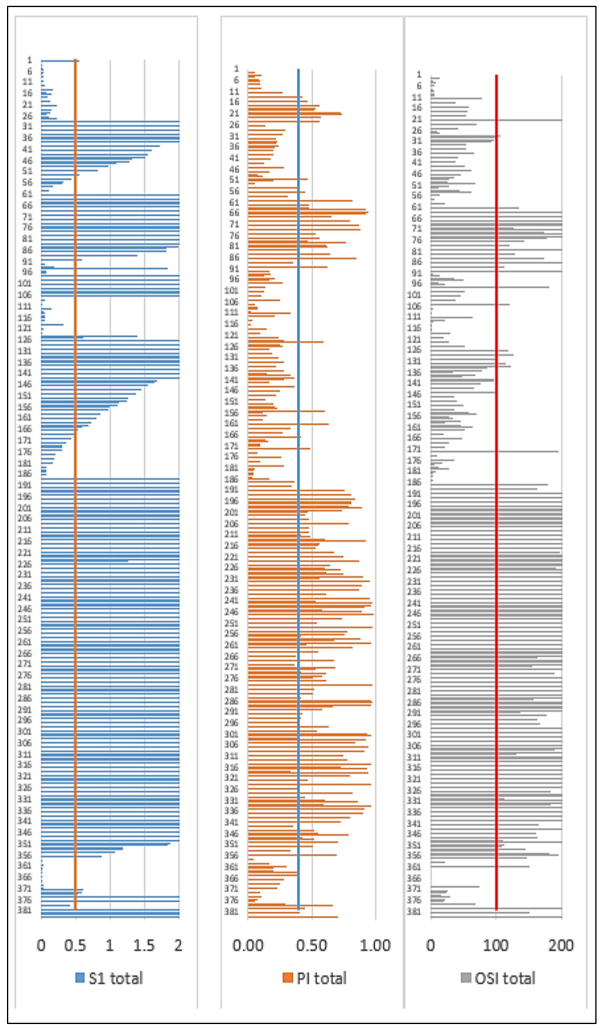


Figure-4: S1-PI-OSI (original) plot (Before chloroform extraction)

Figure-5: S1-PI-OSI (total) plot (After chloroform extraction)

Perforation testing results have been compared with the geochemical predictions for possible accumulations, Out of 2882 studied zones 385 zones have been tested in wells. 295 zones are oil bearing/oil indications and 90 are dry/non accumulation/water bearing zones out of 385 conventionally tested intervals.

Well name	Depth (m)	Formation	Type of samples	TOC (%)	S1 original	PI original	OSI original	S1 total	PI total	OSI total	S2-original	S2-after extraction	Status
W-AA	1450.40	Tarapur	SWC	1.22	**5.13**	**0.63**	**420**	7.69	0.95	630	3	0.44	Oil bearing
W-AA	1458.00	Tarapur	SWC	0.60	0.40	0.26	66.67	**0.88**	**0.58**	**147**	**1.12**	**0.64**	Oil bearing
W-BB	1870.00	Mandhali	SWC	0.99	**3.40**	**0.56**	**343**	5.54	0.91	560	2.72	0.58	Oil bearing
W-CC	1588.50	Cambay Shale	SWC	4.12	1.77	0.12	43	3.49	0.24	85	12.72	11	Dry
W-DD	1681.50	Cambay Shale	SWC	3.02	0.71	0.11	24	1.1	0.17	36	5.75	5.36	Dry

Table-2: Well data showing validation of the predictions

Rock Eval data of four wells is shown in table-2. For well AA and BB samples of depth 1450m & 1870m respectively were analysed which complied to criteria $S1_{(original)} > 0.5$, $PI_{(original)} > 0.4$ and $OSI_{(original)} > 100$, after perforation testing found oil bearing zones. Sample of depth 1457m of well AA after chloroform extraction complied with criteria $S1_{(total)} > 0.5$, $PI_{(total)} > 0.3$ and $OSI_{(total)} > 100$ and found oil bearing. For well CC & DD rock eval data doesn't complied with both the criteria and after perforation testing found dry.

Using the geochemical criteria (before chloroform extraction and after chloroform extraction), predictability is shown below (table-3 and figure-6) for oil bearing zones:

Geochemical Criteria	Total no. of oil bearing horizons found after testing	Prediction based on geochemical data	Predictability
Before chloroform extraction	295	85	29%
After chloroform extraction	295	208	71%

Table-3: Predictability for oil bearing intervals

***Predictability is percentage of oil bearing zones, predicted based on geochemical data out of total number of oil bearing horizons found after testing**

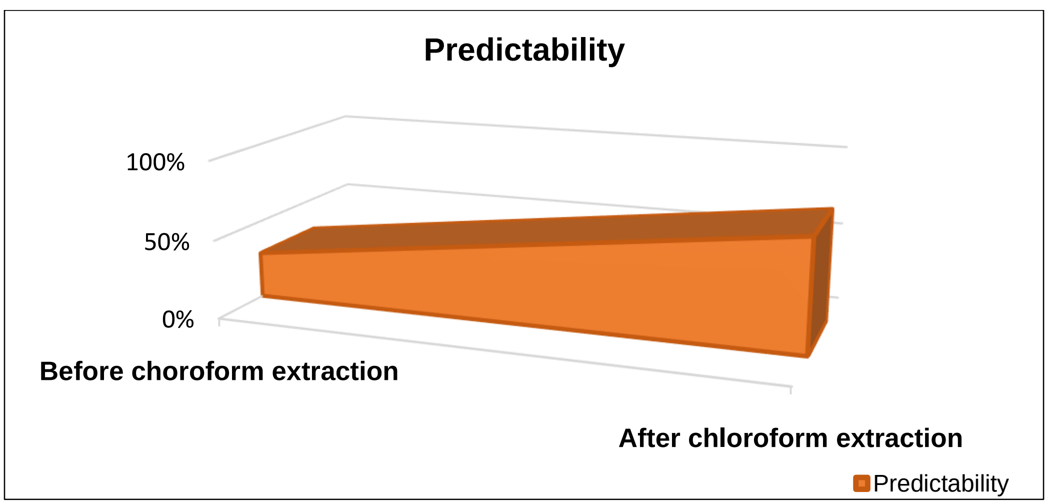


Figure-6: Predictability for oil bearing intervals

Using the geochemical criteria (before chloroform extraction and after chloroform extraction), forecast efficiency is also derived as shown below (Table-4 and Figure-7) for oil bearing zones:

Geochemical Criteria	Total number of geochemical predictions for hydrocarbon accumulation	Actual oil bearing horizons	Forecast Efficiency
Before chloroform extraction	85	77	91%
After chloroform extraction	208	177	85%

Table-4: Forecast Efficiency for oil bearing intervals

***Forecast efficiency is percentage of oil bearing/dry zones out of total number of predictions of oil bearing/dry horizons based on geochemical data.**

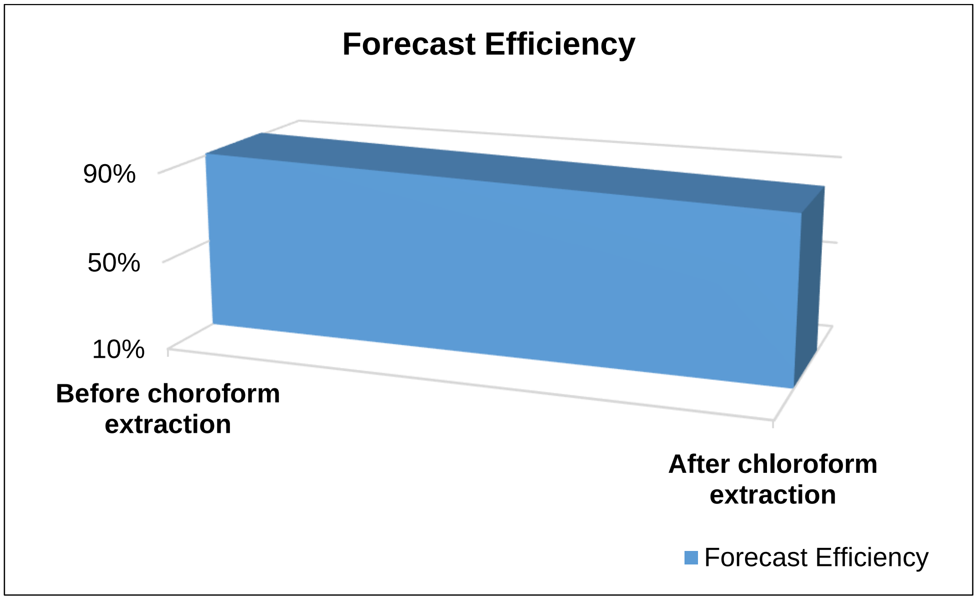


Figure-7: Forecast Efficiency for oil bearing interval

RE data based geochemical predictions are comparable with the testing results in terms of predictability as well as forecast efficiency. 71% and 85% of predictability and forecast efficiency respectively with the results of chloroform extracted sediments is indicative of better efficacy of the predictions.

Conclusions

As described above, Rock Eval data driven Predictability and Forecast efficiency for pay zones is 71% and 85% respectively which show that the applications of geochemical data based on RE includes predictions of pay zones in addition to source rock characterization and reservoir geochemistry. Interpretation based on Rock Eval data in conjunction with other G&G data could be utilized to make real-time drilling decisions w.r.t. intervals identified for testing and this can drastically reduce the cost of exploration by reducing the risk for finding the hydrocarbons.

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