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Elemental Capture Spectrometry as a tool to understand depositional setup in mixed lithology environment: A case study from Andaman Deepwater

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Summary

Identification of exact mineralogy is one of the essential ingredients to understand the depositional setup of any field. This becomes all the more important if deposition happens in a complex geological setting like Deepwater Andaman Basin. Methodologies for mineral identification based on traditional logs do not have enough resolution to give solutions in all situations, particularly when the mineralogy is complex and different minerals have similar overlapping physical properties.

In this work we propose to demonstrate the application of some of the cross-plots based on the elemental concentrations from ECS tool to identify mineralogy in a complex volcanoclastic environment. This information, in conjunction with information from other logs, satisfactorily brings out the depositional setup of this otherwise complex basin.

Keywords: *ECS, Andaman Inner Forearc, Depositional setup*

Introduction

RHOB-NPHI & M-N Crossplots are oftenly used as mineralogy identification tools. The identification of mineralogy here is based on the physical properties (RHOB, NPHI & DT values) of the minerals in pure forms (endpoints). While endpoint determination in case of RHOB-NPHI crossplot is affected by the porosity of the formations, the M-N crossplot provides a dimensionless mapping of different mineralogy irrespective of the porosities. These crossplots however have poor resolution in mixed lithology environment (carbonates+siliciclstic, carbonates +volcanoclastics, siliciclastics + volcanoclastic) where combination of different minerals can show similar physical properties. ECS uses elemental composition for mineralogical identification and therefore offers a much robust option particularly in mixed lithology domain.

Applications of ECS in complex reservoirs are well documented. ECS tools measures dry weight percentages of Si, Ca, Fe, S, Ti and Gd and evaluate Al percentage from anti-correlation algorithm. Relative ratios of these elements can reveal a lot about the nature of the rocks. These can be visualized in Ca vs Si, Fe vs Si, Al vs Si crossplots.

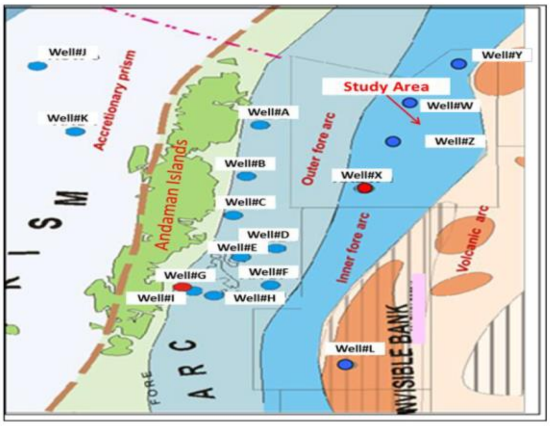

Fig-1 : Location of the Study Area.

The study pertains to wells drilled in one of the Andaman deep water blocks, situated in the inner forearc settings (Fig-1) of a standard subduction arc system. Four wells have been drilled in the study area. In the present study ECS crossplots have been extensively used in conjunction with textural information from Image Logs for understanding the depositional setup in the study area.

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Understanding the Middle Miocene Section in Well-X

In the first well drilled in the area, Well-X, a zone extending to almost 200m in Mid. Miocene section created a lot of interest initially. Higher resistivity, low GR and prominent gas like crossover in the RHOB-NPHI overlay were observed throughout this zone (Fig-3). The microphotographs and SEM studies of the cutting samples and side wall core of the section revealed the presence of **marl interspersed with volcanic tuffs** (Fig-2). Encountered for the first time, the zone was tested with TCP-DST, showing negligible influx and poor injectivity.

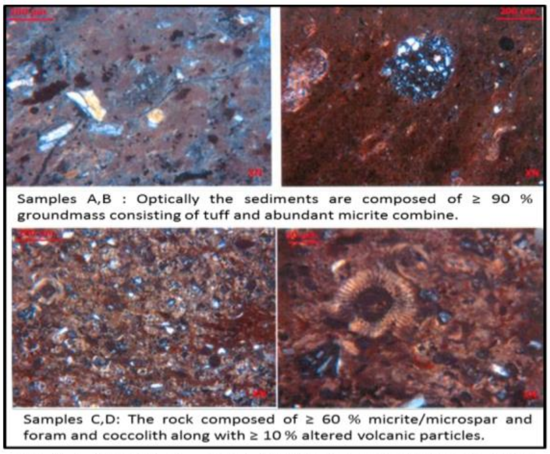

Fig-2 : Optical & SEM Attributes of Cuttings/ SWC samples from Mid. Miocene of Well- X.

Situated in the Inner Forearc setting, volcanic and pyroclastic inputs from the adjoining volcanic arc systems are expected. The gas like pull on RHOB-NPHI and M-N crossplots (Fig-4) indicate the presence of rhyolitic tuff in the formations. Due to high viscosity of rhyolites, when it erupts as part of pyroclastic process, volcanic gases (predominantly steam) get trapped in number of micropores, most of them not connected to each other, resulting in an overall decrease in bulk density of the resulting tuff. Together with low hydrogen index of the entrapped volcanic gases it gives rise to good gas like crossover. The rhyolitic nature of the tuff is also supported by the high Si, low Fe concentrations revealed by the ECS crossplots (Fig- 7) which will be discussed in detail later.

In Fig-5 conventional logs belonging to top of Middle Miocene have been displayed along with Image Logs, ECS tracks (WQFM, WCAR & WCLA) and CMR log. The ECS logs (track-7) show high percentage of silica (WQFM) together with low concentrations of carbonates (WCAR) and clays (WCLA). The carbonate and clay percentages in ECS represent the marly matrix, whereas the high QFM comes from the presence of rhyolitic tuff.

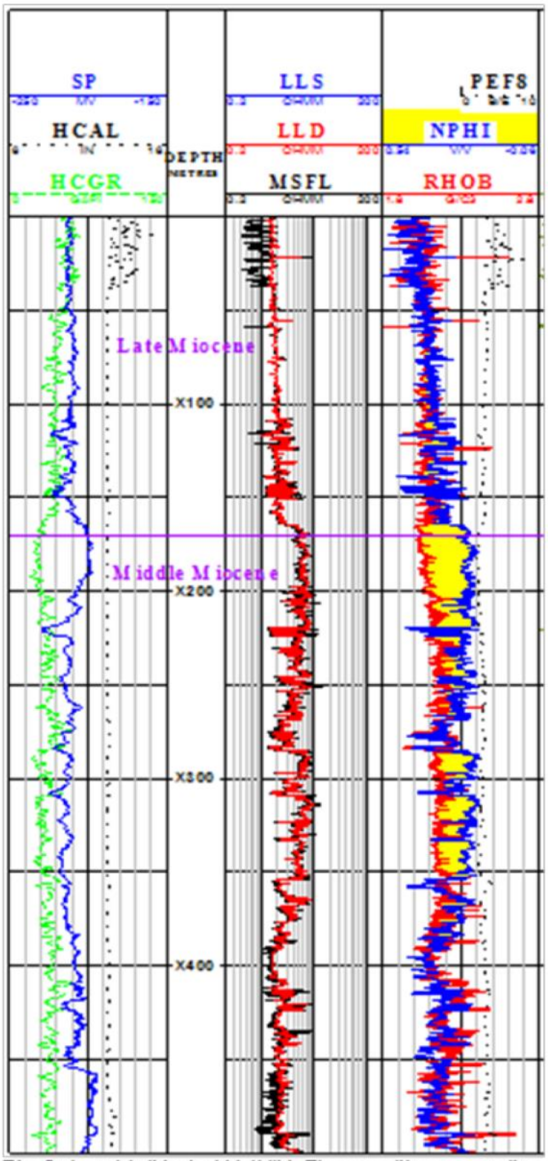

Fig-3: Log Motifs for Well#X. The gas like separation in RHOB-NPHI crossplot is attributed to high concentrations of rhyolitic tuff in the formations

The FMI log (track-5&6) against the zone shows the formation is deposited as alternation of thin contrasting laminations (~10-15 cm thick) dipping at ENE – E direction (low dips). Considering all aspects the sequence is interpreted to be marl-rhyolitic tuff intercalations. Both marl and tuff have high microporosities which is confirmed by CMR log response (tack-7 & 8) almost all of the porosity is capillary bound in nature.

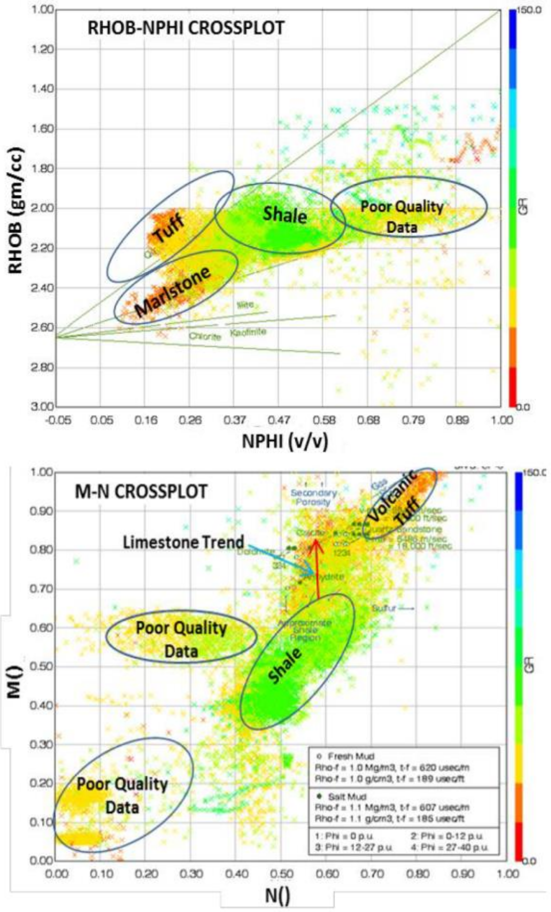

Fig-4 : RHOB-NPHI and M-N Crossplot of Well#X.

Such log characters were encountered in other wells drilled in the area with varying proportions. To properly understand the depositional setup of the area, an analysis across the drilled wells was carried out.

Analysis of the ECS crossplots

ECS tools measures dry weight percentages of Si, Ca, Fe, Ti and Gd and evaluates Al percentage from anticorrelation algorithm. Relative ratios of these elements can reveal a lot about the nature of the rocks. These can be visualized in Ca vs Si, Fe vs Si, Al vs Si crossplots. The overlays in these crossplots mark the clustering for standard minerals including clay minerals, calcite and quartz (Fig-6 & 7). Most salient point to observe is the distinctness of calcite, quartz and clay minerals in all the crossplots.

To demonstrate the capability of ECS tool in resolving different environments, ECS crossplot for the Early Miocene and Middle Miocene sections of Well-X are given in Figures 6 & 7 respectively. The Early Miocene plot presents a clear Calcite to Shale trend in all the crossplots. On the other hand crossplots for Middle Miocene section present completely different trend. The crossplots show high quartz content. The trend can be defined as Quartz to Calcite trend with very little effect of clays. As will be discussed in detail later, this is the result of rhyolitic tuff input from the volcanic activities during this period.

To understand the depositional setup of the study area, the Si vs Ca crossplots for all the wells (Wells#X, Y, Z & W) were compiled (Fig-8) for the intervals where ECS logs were recorded. The following observations can be made:

a) Similarity in trends can be observed across wells for sediments deposited in same age.
b) Three pulls can be distinctly seen defining the clusters in all the crossplots. The pulls correspond to Calcite, Silica (which comes from the rhyolitic nature of the pyroclasts) and Clays. The relative pull of calcite and shale in the calcite-shale trend indicate the different facies of marl.
c) The depositional setup changes from a calcite dominated carbonates (calcite to shale trend on crossplot) to clay dominated carbonates (shale to calcite trend) as we move up from late Miocene to early Miocene.
d) The crossplot for Middle Miocene section shows a distinct shift from calcite – clay trend to calcite-silica trend (NE movement of the clusters) indicating a marlrhyolitic tuff composition of the sediments. The maximum pyroclastic input (pull towards silica) is seen in Well#X followed by Well#Z. Well#Y receives least amount of pyroclastic input (significant pull towards calcite is seen).

From the analysis it can be concluded that the study area comprises of carbonate dominant environment in the Miocene age with gradual deepening of the water level leading to change in carbonate facies from calcite dominated in early miocene to clay dominated in late Miocene. The volcanic activity in adjoining volcanic arcs peaked at the top of Middle Miocene and kept adding pyroclasts and volcanoclastic inputs in the area in the form of rhyolitic tuffs (seen on ECS logs as gradual increase in Silica concentrations).

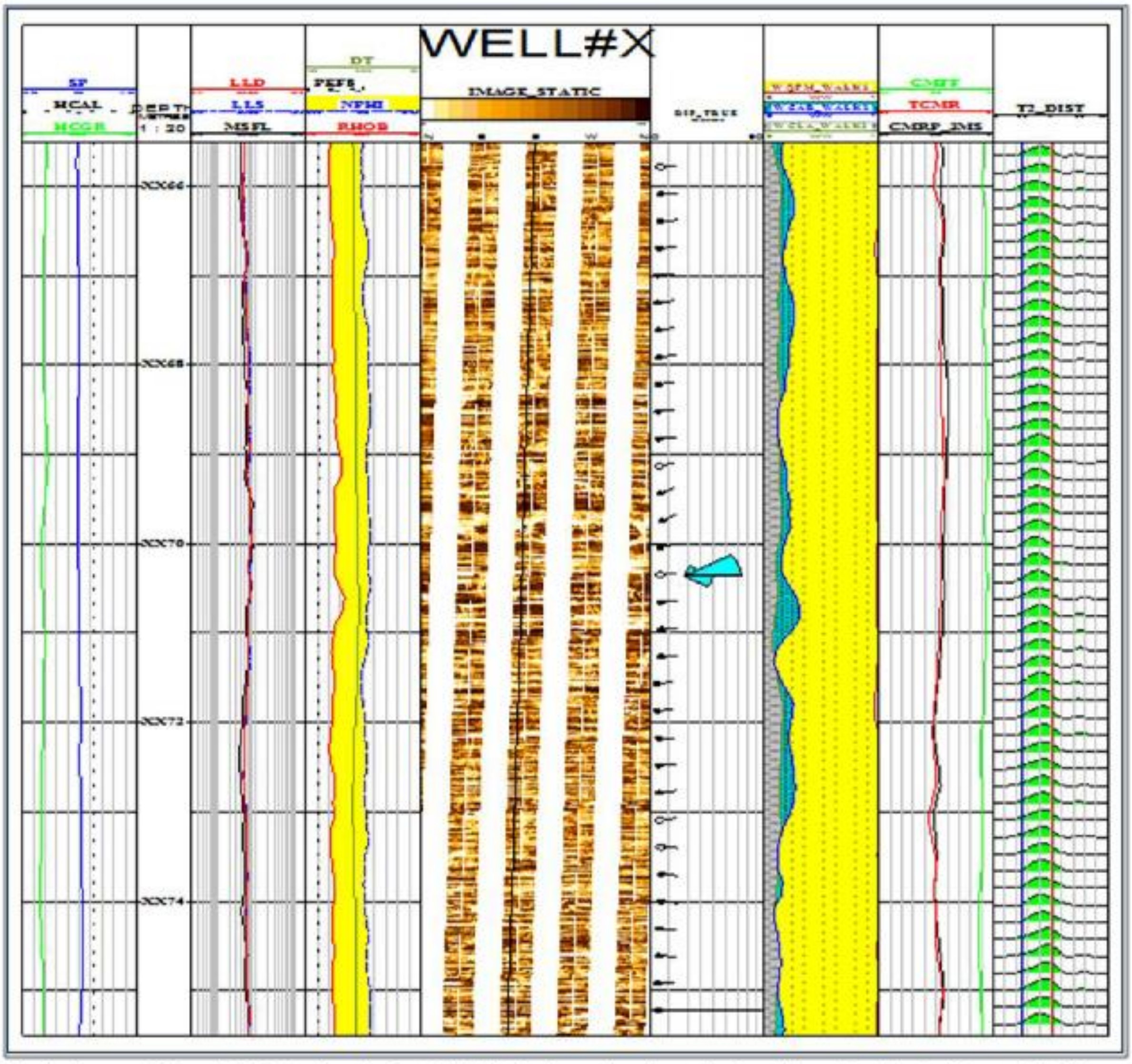

Fig-5 : Image, ECS and CMR log tracks for Well#X. On image log, low dipping alternating laminations ~ 10-15 cms are observed. ECS track shows high WQFM together with low WCAR and WCLAY. The sequence is interpreted to be comprised of Marl and Rhyolitic tuff interspersed and interlayered with each other. Both of these are characterized by high amount of microporosity which is evident in CMR showing high capillary bound water.

Tuffaceous input can come in the form of ash-fall deposits, ash flow deposits or ash turbidites. The texture revealed by the FMI, indicates that the deposition of the volcanic tuff didn't seem to hinder the overall carbonate depositional setup (deposition of marls) in the area. Hence the tuffaceous input is interpreted to be **ash fall deposits** as this is the only options that will not disturb the marly depositional environment.

To sum up the sedimentary column comprising thin lamination of rhyolite tuffs intermixed and intercalated with marl is a result of multi-episodic ash fall pyroclasts depositing in an otherwise marly depositional setup.

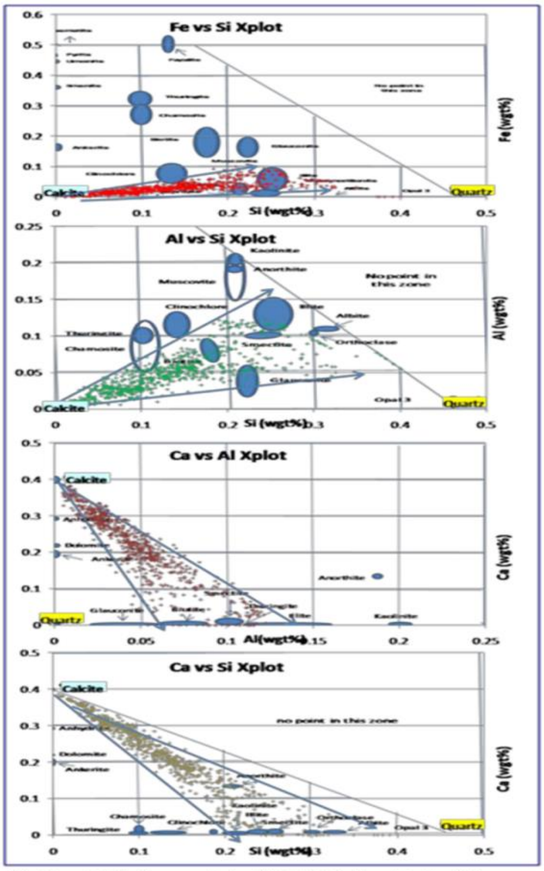

Fig-6 : ECS Crossplots (Well-X) for Early Miocene Section showing a clear Calcite to Shale Trend.

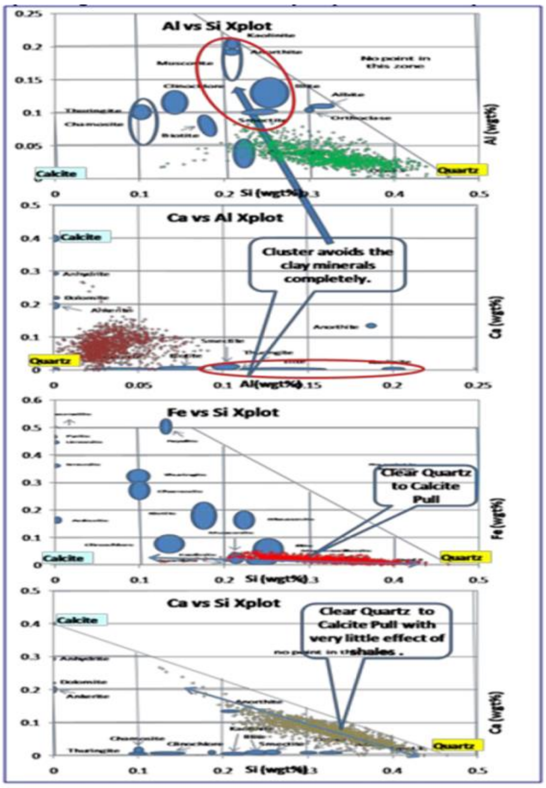

Fig-7 : ECS Crossplots (Well-X) for Mid. Miocene Section showing a distinct NE shift towards Quartz to Calcite trend with very little shale effect. The high silica concentrations comes from the pyroclastic input in the form of rhyolitic tuff.

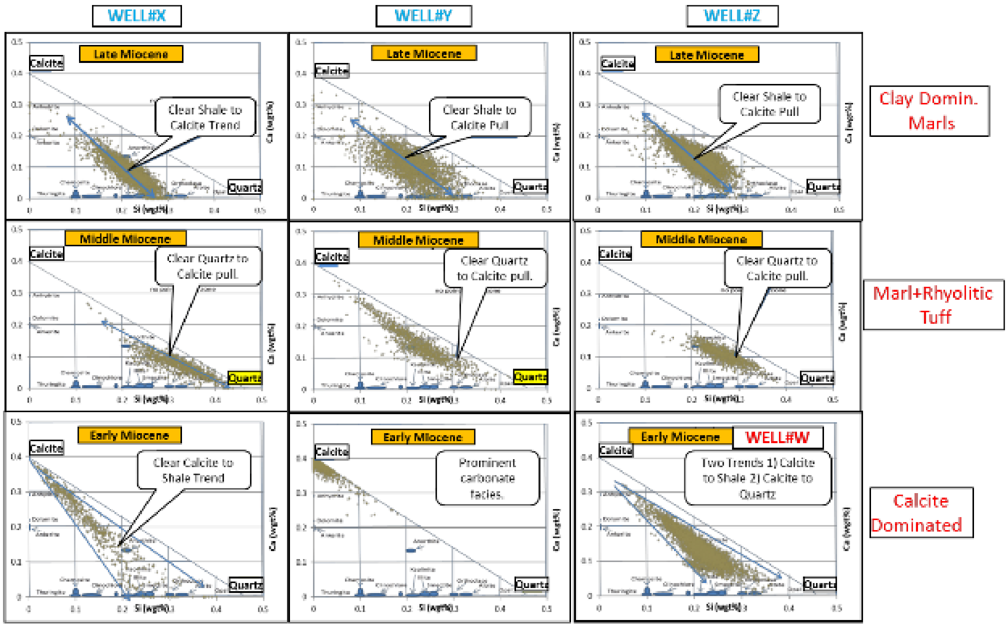

Fig-8: **Ca vs Si** crossplots compiled for all the wells. The plots show a gradual change from calcite dominated carbonates (early miocene) to shale dominated carbonates (late miocene) across the study area. The distinct NE shift in middle miocene is on behalf of the pyroclastic inputs (rhyolitic tuffs) deposited as ash fall deposit.

Conclusions

1. The depositional setup of a complex area like Andaman Inner Forearc region could be understood clearly with the help of hitech logs such as FMI and ECS logs. Elemental information from ECS, textural information from Image logs and Information about the porosity types from CMR add immense value to understand complex geological formations.

2. ECS log provide good resolution in identifying mineralogy particularly in mixed lithology environment.

3. The inner forearc region of the Andaman Deepwater, where the study area is located comprises of carbonate dominant environment in the Miocene age with gradual deepening of the water level. The shale content in the marl facies increases from early miocene to late Miocene.

4. The multi-episodic volcanic activities in the adjoining volcanic arc system kept adding ash fall pyroclasts into the otherwise marly depositional setup. These ash fall deposits appear as lamination of rhyolite tuffs intermixed and intercalated with marl, the ambient depositional

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