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Accurate Petrophysical Interpretation of Carbonate using the Elemental Capture Spectroscopy (ECS)

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Abstract

Elemental capture spectroscopy (ECS) is an important tool in the petroleum industry for determining the composition and properties of rock formations in a reservoir. Knowledge of the types and abundance of different minerals in the reservoir is crucial for accurate petrophysical interpretation, reservoir engineering practices, and stratigraphic correlation. ECS measures the elemental content of the rock, which directly impacts several physical properties that are essential for reservoir characterization, such as porosity, fluid saturation, permeability, and matrix density. The ability to accurately determine these properties leads to better reservoir mapping, improved production, and more effective resource management. Accurately determining the mineralogy and porosity of carbonate rocks and other materials is the aim of this paper. Calcite, dolomite, quartz, clay (illite), anhydrite, and pyrite, in addition to water as a fluid, are taken into account in the computation. The formation's lithology and porosity can be ascertained from this data. When compared to the core descriptions in the geological report, the results demonstrated a distinct zone of unique lithology with good prediction accuracy.

Keywords: Elemental capture spectroscopy, geochemical logging, carbonate rocks, and mineralogy determination.

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1- Introduction

By measuring natural activation and triggering neutron-capture gamma rays, geochemical logging tools, like elemental capture spectroscopy (ECS), can produce logs of the concentrations of the majority and a few trace inorganic elements in a rock sample. Elemental capture spectroscopy (ECS) is a part of the latest generation of geochemical logging tools and has been developed since the mid-1980s to meet the growing demand for more accurate and precise information about subsurface reservoirs [1–3].

The relative elemental yields of the formation are calculated using the Elemental Capture Spectroscopy (ECS) tool. Calcium (Ca), silicon (Si), magnesium (Mg), iron (Fe), sulfur (S), titanium (Ti), and gadolinium (Gd) are among the elemental yields determined from ECS spectra, with hydrogen providing a measure of the pore space and borehole fluids but otherwise being ignored in the mineralogy determination [4].

Generally, mud weight, fluid type (gas, oil, or water), borehole size, and rugosity have little to no effect on the ECS response. Consequently, these parameters have little effect on elemental content measurements, making them a robust and reliable tool for determining rock composition underground [5]. Not all sources of error and variability will affect ECS readings, so it's crucial to take into account the potential influence of outside factors like borehole fluid invasion [6].

The recent advancements in geochemical logging and spectrum analysis have improved the measurement of Mg yields due to the development of more sensitive and precise instrumentation and data analysis methods. The improved measurement of Mg yields allows for the evaluation of dolomite in barite mud systems, where traditional photo-electric absorption measurements are not useful because Mg is a key component of dolomite and can be used to identify its presence. This results in a more accurate mineralogical description of the formation and better determination of properties such as porosity, cation exchange capacity, grain-size distribution, and permeability [7]. Following is a summary of earlier research on the lithology and petrophysical computation in Iraqi oil fields:

Hassan et. al [8] concluded that the formations are composed of limestone, dolomite, and shale, according to data from the neutron porosity log and bulk density. Compared to the M-N profile, the MID profile produces better and more accurate findings [9]. Calcite is the main mineral found in the Shiranish Formation formations. According to Al-Khafji [10], in order to determine the type of pore-fluid in carbonate formations using the proper solid matrix characteristics, the lithology type must be known.

Al-Baldawi et. al [11] utilize the IPSOM approach, which combines seismic data with petrophysical log data

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*Corresponding Author: Name: Usama Alameedy, Email: usama.sahib@coeng.uobaghdad.edu.iq (density, neutron, and gamma-ray logs) to estimate the lithology (rock type) of a formation.

The cross-plot of the logs is used by Abdulkareem et. al [12] to further clarify the lithology interpretation because various rock types exhibit distinctive cross-plot reactions. In this instance, the cross plot shows that the Zubair Formation's lithology is sandstone, which is frequently a reliable host for hydrocarbons.

The analysis aims to emphasize geochemical tools' significance in formation evaluation; accurately determine dolomite and other mineralogy; and calculate porosity in clastic and carbonate reservoirs.

2- Procedure of the Measurement

The Elemental Capture Spectroscopy (ECS) sonde (Fig. 1) measures relative elemental yields based on neutron-induced capture gamma ray spectroscopy using a standard 16-Ci americium beryllium (AmBe) neutron source and a large bismuth germanate (BGO) detector. The rock's elements are excited by the AmBe neutron source, resulting in gamma rays that are picked up by the BGO detector. The elemental makeup and mineralogy of the rock can then be determined from the gamma-ray spectra by comparing the relative abundance of various elements.

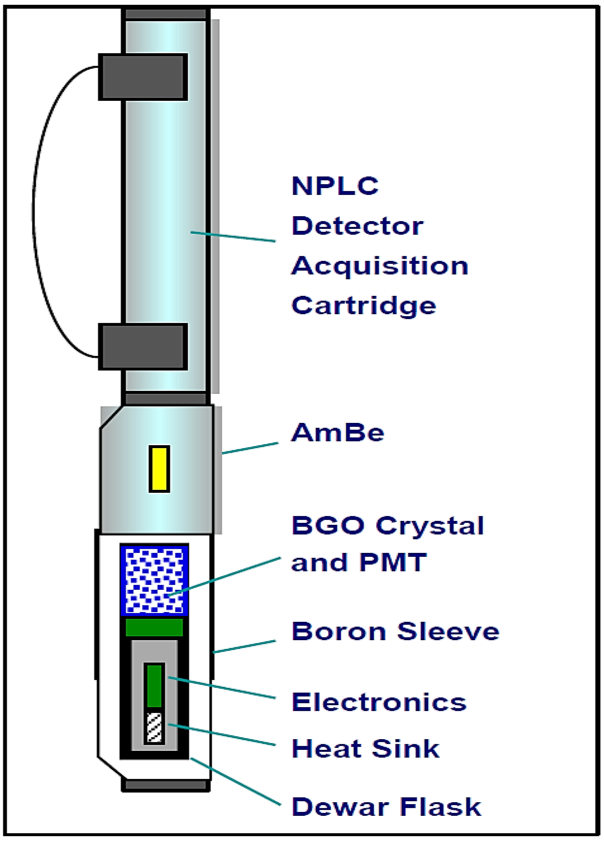

Fig. 1. Schematic of ECS Sonde [6]

The primary elements measured in both open and cased holes using ECS are silicon (Si), iron (Fe), calcium (Ca), sulfur (S), titanium (Ti), gadolinium (Gd), chlorine (Cl), barium (Ba), and hydrogen (H). These elements are typically abundant in most rocks and provide valuable information about the mineralogy and composition of the rock. The additional element, magnesium (Mg), can also be measured using ECS when logged at proper logging speeds and processed using the MgWALK methodology. Measuring magnesium provides additional information about the rock and can improve the accuracy of the interpretation of the other elements. A typical gamma-ray spectrum from the ECS sonde would show (Fig. 2) the thermal neutron capture gamma rays divided into the contributions of the different elements present in a siliciclastic environment without calcium or sulfur. Although small signals from aluminum and sodium may be present in the capture yields of iron (Fe) and calcium (Ca), this contamination can be taken into account during subsequent processing. Although they are present in the spectrum, the gamma rays produced by inelastic neutron reactions are not quantitatively used. The process of wellsite processing with the ECS tool involves spectral deconvolution of the gamma-ray energy spectrum to produce relative elemental yields, which are then converted to dry-weight elemental concentration logs. The elements mainly contributing to the measured gamma-ray spectrum are hydrogen (H), chlorine (Cl), silicon (Si), calcium (Ca), iron (Fe), sulfur (S), titanium (Ti), gadolinium (Gd), and potassium (K). These dry-weight elemental concentrations are used to calculate matrix properties and quantitative dry-weight lithologies using SpectroLith empirical relationships derived (explain in [13]) from a core chemistry and mineralogy database. The relative yields are then converted to dry-weight elemental concentration logs for the elements Si, Fe, Ca, S, Ti, and Gd using an oxides closure method.

The accuracy of the Elemental Capture Spectroscopy (ECS) measurement is relatively unaffected by mud weight, most fluid types, and borehole size and rugosity. However, its statistical precision can be affected by environmental conditions, particularly high salinity and large borehole sizes. The statistical uncertainties on the calculated dry weight elemental concentrations are typically around 2% (one standard deviation) for a typical borehole environment.

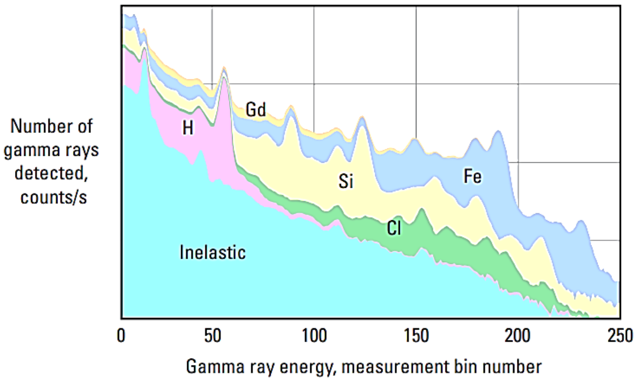

Fig. 2. Contributions to the Gamma-Ray Spectrum from Capture and Inelastic Interactions [6]

The dry-weight lithology fractions are calculated based on the concentration logs for elements such as Si, Fe, Ca, S, Ti, and Gd. Salt, siderite, QFM, gypsum plus anhydrite, total clay, pyrite, and total carbonate are just some of the lithologies that can be inferred from the elements measured by the ECS [14]. The matrix properties are also derived from these elemental concentration logs and include:

- Matrix grain density
- Matrix thermal and epithermal neutron
- Matrix sigma.

3- Results and Discussion

Traditionally, well logs, core analysis, and geological observations have been used to calculate lithologies. These techniques rely on measuring either chemical or physical qualities, such as elemental composition, or physical parameters like density and porosity. However, the accuracy and precision of these conventional techniques may be constrained, particularly in mud-filled wells where the presence of barite may impede photo-electric absorption measurements. In contrast, a geochemical instrument like ECS offers a more sophisticated approach to computing lithologies. Spectrometry, which is used to measure the formation's elemental makeup, is unaffected by the presence of barite. Additionally, employing mineral transformations derived from a top-notch database of mineralogy and chemistry, the geochemical tool may provide more exact and accurate measurements of elemental yields, which are then utilized to compute the lithologies.

Checking the accuracy of the logged measurement is the first step in processing any well in formation evaluation. For well Hf-1, log quality control (LQC) flags, as shown in Fig. 3, indicate how well the tool and its processing perform. We can define each track's meaning as follows:

Track 1: ECST (ECS Temperature, dark brown), FY2W_MGWALK (Relative yield Normalization factor, blue), ESUF_WALK2 (Elemental statistical uncertainty factor, green), ESSR_20 (Spectral count rate, black), resolution degradation factor (ERDF_20, Red), ECS correction factor (EOCF, red).

Track 2: Depth Index.

Track 3: Capture silicon relative yield (CSI, black).

Track 4: Capture carbonate relative yield (CCA, black).

Track 5: Capture Iron relative yield (CFEU, black).

Track 6: Capture Sulfur relative yield (CSUU, black).

Track 7: Capture Titanium relative yield (CTI, black).

Track 8: Capture Gadolinium relative yield (CGD, black).

Track 9: Capture Chlorine relative yield (CCHL, black).

Track 10: Capture Hydrogen relative yield (CHY, black), in elastic Carbone relative yield (IC, black).

When both the photomultiplier and crystal temperature are green, the measurement is successful. The dry-weight elemental concentrations have good statistical precision, as shown by the ESUF value of 1.0. The ESUF value needs to be lower than 0.5 for magnesium dry-weight extraction. Due to the high logging speed in the current well HF1, the elemental statistical uncertainty factor (ESUF) is >0.5 for some of the intervals. Resolution degradation factor, offset, gain, and 20 elemental yields can all be calculated from the processed ECS spectrum using the Spectral Processing program. Three steps are involved: first, the shift factor is used to modify the 20 elemental standards; second, a non-linear fitting algorithm is used to calculate the resolution degradation factor and offset; and third, a level-by-level fitting is used to calculate the level-by-level spectral gain and the 20 elemental yields. The ECS spectrum, the time required to acquire the spectrum, and the shift factor are all inputted into the program.

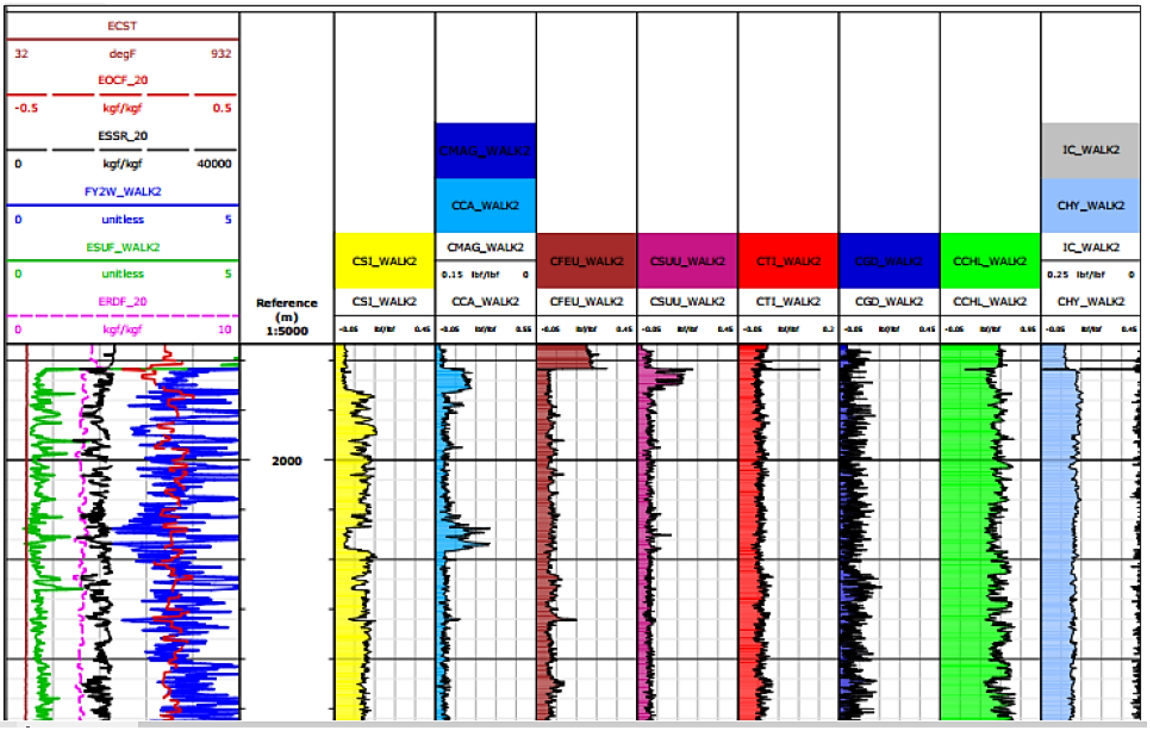

Fig. 3. ECS Yield LQC Plot

The MgWALK methodology is a geochemical method that utilizes magnesium (Mg) yield as a tool to differentiate between carbonate and non-carbonate minerals. The 20 relative yields are used by the ECS SpectroLith program to figure out how many different minerals are in a formation. The ECS SpectroLith program also performs depth normalization of the hydrogen yield, which corrects for absorption differences due to borehole fluid, mudcake, and formation effects to provide reliable coal and clay analysis. The final output of this program is filtered and corrected elemental yields and dry-weight mineral fractions of the formation, which can be used for various reservoir analyses. Dry-weight elementals are calculated based on a proprietary oxides closure model which converts relative elemental yields to dry weights. Dry-weight mineral fractions are calculated based on element-to-mineral transforms derived from a high-quality database of mineralogy and chemistry from over 400 core samples. The processed data is interpreted by combining density, neutron porosity, and PEF data to estimate mineral volumes and porosity. A variety of minerals are considered in the calculation, including calcite, dolomite, quartz, clay (illite), anhydrite, and pyrite, as well as water as a fluid. This information is used to determine the lithology and porosity of the formation.

The Interpretation result log's header is depicted in Fig. 4.

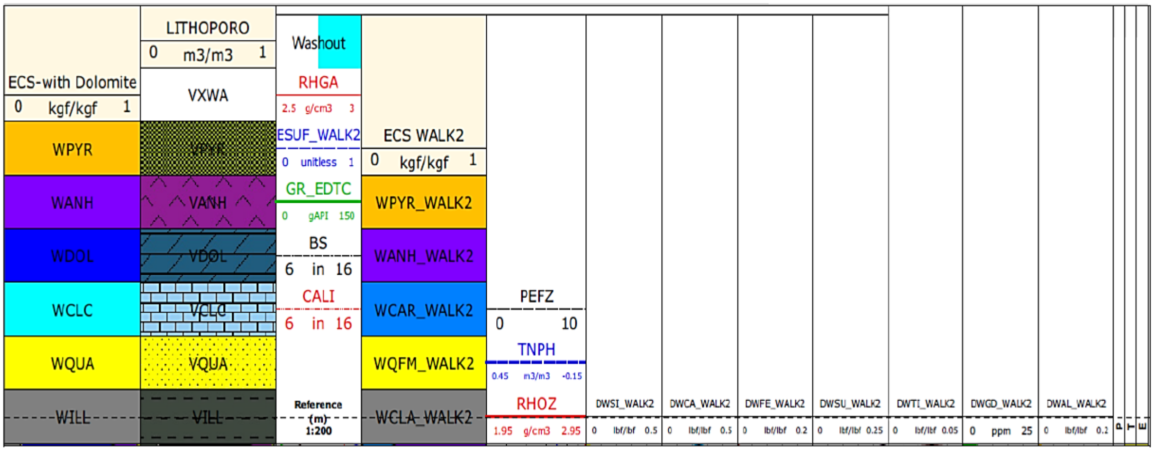

Fig. 4. ECS Interpretation Result Header

Track 1: Weight fractions of Illite (WILL), Quartz (WQUA), Calcite (WCLC), Dolomite (WDOL), Anhydrite (WANH), and Pyrite (WPYR) from ELAN

Track 2: Volume fractions of Illite (WILL), Quartz (WQUA), Calcite (WCLC), Dolomite (WDOL), Anhydrite (WANH), Pyrite (WPYR), Water (VXWA)

Track 3: Depth, Gamma ray (GR_EDTC), ESUF_WALK2, Caliper (HCAL), Bit Size (BS), grain density (RHGA)

Track 4: Weight fractions of Illite (WILL), Quartz (WQUA), Calcite (WCLC), Dolomite (WDOL), Anhydrite (WANH), and Pyrite (WPYR) from ECS WALK2 processing

Track 5: Bulk density (RHOZ), Neutron porosity (TNPH), Photo electric effect (PEFZ)

Track 6: Silicon dry weight. Track 7: Calcium dry weight. Track 8: Iron dry weight. Track 9: Sulfur dry weight. Track 10: Titanium dry weight. Track 11: Gadolinium dry weight. Track 12: Aluminum dry weight. Track 13: Quality control flags.

Various lithology types and zones' interpretation results are shown in Fig. 5 to Fig. 7.

Referring to Fig. 5, the interval depth of 1910–1930 m, with high levels of S and Ca, suggests that anhydrite is the dominant rock type in that interval. This is further supported by the low or zero porosity values are seen in this interval, as anhydrite typically has a low porosity due to its dense, compact crystal structure. The presence of minor amounts of calcite and dolomite in the same interval could indicate that these minerals are also present but in smaller quantities compared to anhydrite.

Fig. 6 shows the presence of sandstone as the dominant rock type in the interval depth of 2010–2045 m is usually indicative of higher porosity values, particularly in clean zones. The presence of minor calcite can also contribute to the porosity, but the exact porosity value will depend on the amount and distribution of calcite within the sandstone. If the sandstone is in a shaly sand zone, it may have lower porosity values.

The zone above 2380 meters and below 2400 meters in Fig. 7 is depicted as a limestone-dolomite interval based on data from the ECS SpectroLith program, which determines the dry-weight mineral fractions of various subsurface lithologies. Limestone and dolomite, both carbonate minerals, are found in great concentrations on the graph that depicts the distribution of various minerals in the subsurface. The high concentrations of the metals calcium and magnesium demonstrate this. Given that carbonate rocks often have larger porosities than other rock types, the porosity in this zone is most likely to be moderate to high. Understanding the region's subsurface geology and hydrocarbon potential can be aided by this information.

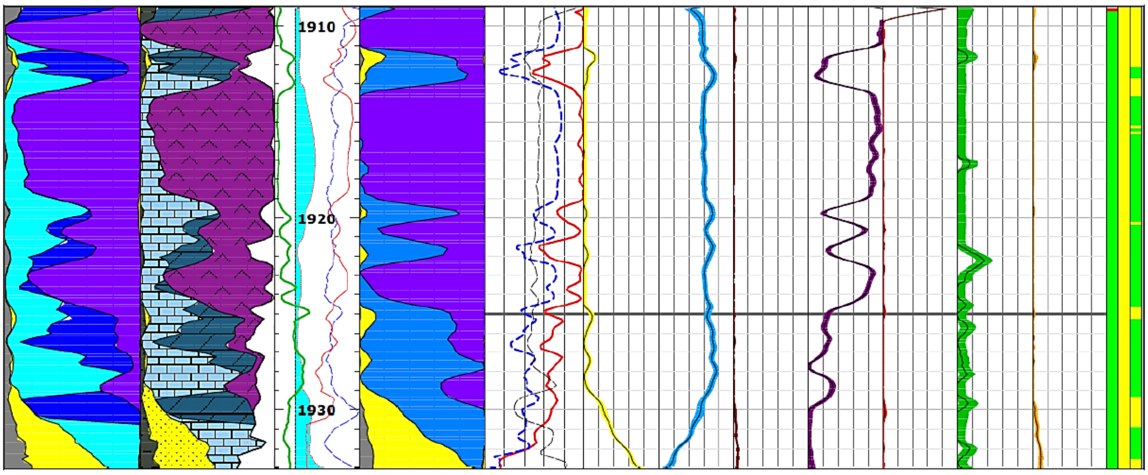

Fig. 5. Interpretation Results Across the Anhydrite-Dolomite Interval

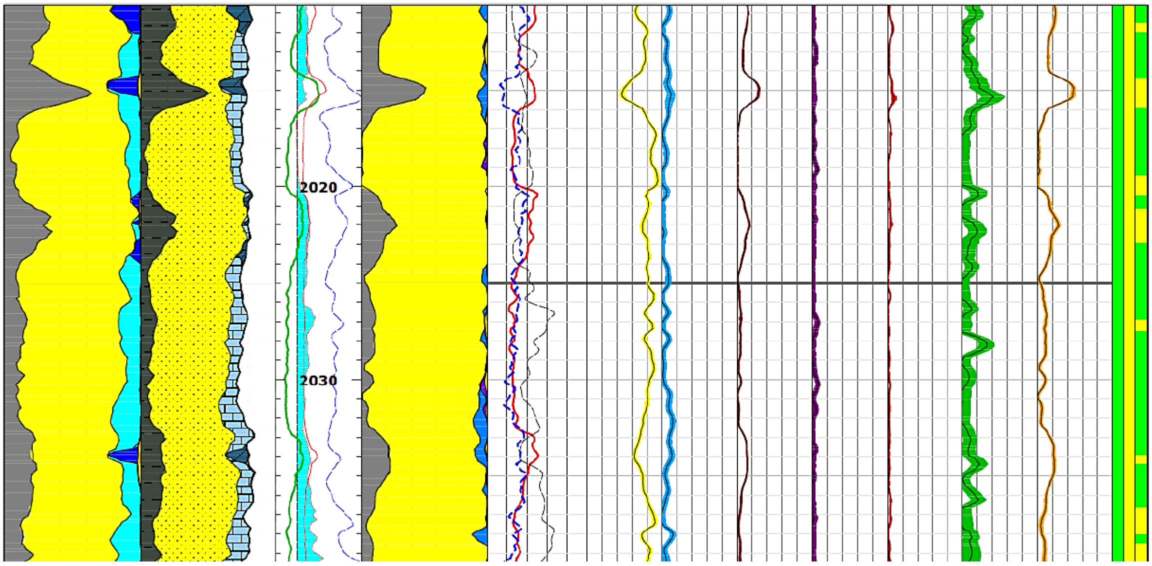

Fig. 6. Interpretation Results Across Clastic Interval

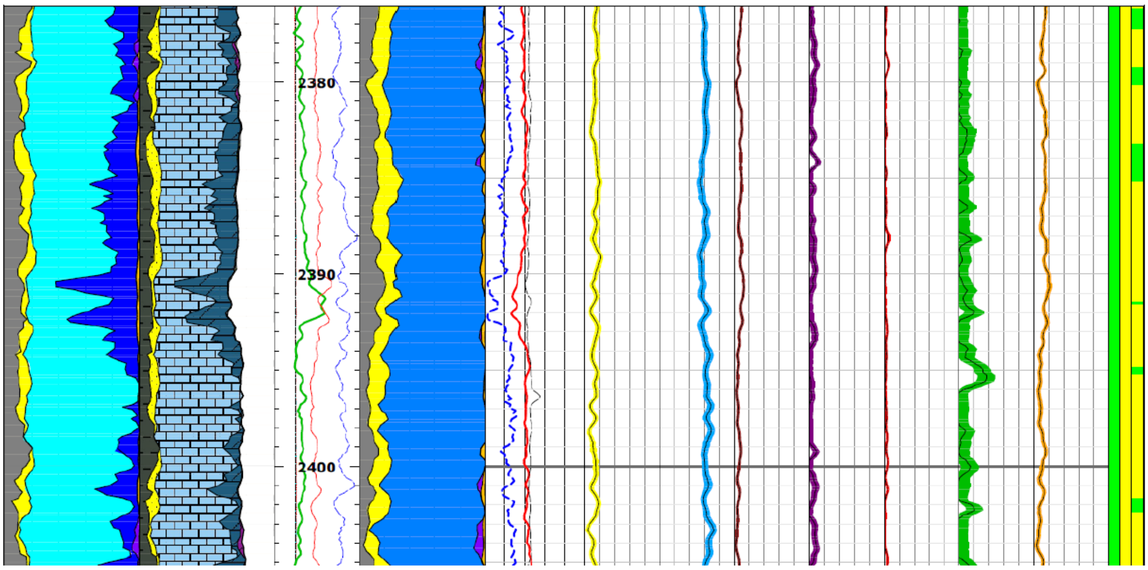

Fig. 7. Interpretation Result Across Limestone-Dolomite Interval

4- Conclusions

1. Accurately figuring out where minerals and rocks are: ECS makes it possible to measure elemental yields and turn them into dry-weight mineral fractions. This gives a clear picture of the composition of the subsurface.
2. Integration with other technologies: When ECS is combined with technologies like borehole imaging and formation testing, the subsurface can be seen more completely.
3. Measurement of Mg yields has become more accurate thanks to recent improvements in geochemical logging and spectrum analysis. This makes it possible to figure out how much Mg is in dolomite in barite mud systems.
4. Correction of traditional limitations: ECS addresses the limitations and challenges of traditional methods, such as the effects of barite on photoelectric absorption measurements.
5. Lithology-porosity calculation: The ECS SpectroLith program uses processed data from density, neutron porosity, and PEF to estimate mineral volumes and porosity. This gives a more complete picture of subsurface geology.
6. The petroleum industry employs elemental capture spectroscopy (ECS) to estimate the lithology (rock composition) of an oil or gas well. The mineral content of a rock sample is determined by using spectroscopic techniques to measure the abundance of different elements. Hydrocarbon exploration and production rely heavily on inferring the rock's permeability, porosity, and other properties from these measurements .
7. Environmental conditions, such as large borehole sizes and high salinity, can influence the statistical precision of ECS measurements. Accuracy and precision are also technical limitations of ECS that are influenced by variables like mud weight, fluid type, and borehole rugosity. The robustness of the ECS method is being worked on to address these issues by increasing measurement accuracy and improving data interpretation.
8. Combining ECS with other methods can enhance the precision and specificity of subsurface characterization. This allows for more informed choices to be made about exploration, development, and production.

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تفسير دقيق للخصائص البتروفيزيائية في الصخور الكربوناتية باستخدام مجسات جيوميكانيكية

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الخلاصة

يعتبر التحليل الطيفي لالتقاط العناصر (ECS) أداة مهمة في صناعة البترول لتحديد تكوين وخصائص التكوينات الصخرية في المكمن. تعد معرفة أنواع ووفرة المعادن المختلفة في المكمن أمرًا بالغ الأهمية للتفسير البتروفيزيائي الدقيق، وممارسات هندسة المكامن، والارتباط الطبقي. تقيس ECS المحتوى الأولي للصخر، والذي يؤثر بشكل مباشر على العديد من الخصائص الفيزيائية الضرورية لتوصيف الخزان، مثل المسامية، وتشبع السوائل، والنفاذية، وكثافة مادة الأساس. تؤدي القدرة على تحديد هذه الخصائص بدقة إلى رسم خرائط مكامن أفضل، وإنتاج محسّن، وإدارة أكثر فاعلية للموارد. الهدف من هذا البحث هو التحديد الدقيق لعلم المعادن ومسامية الدولوميت والمواد الأخرى.

الكلمات الدالة: التحليل الطيفي للعناصر، التسجيل الجيوكيميائي، الصخور الكربونية، وتحديد المعادن.