



Comprehensive Reservoir Rock Typing of the Ordovician-Silurian Chimneyhill Subgroup, Anadarko Basin, U.S.A.

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Declaration of authenticity

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Miskolc, 07.11.2024.

Mahmoud Mohamed



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Declaration of the supervisor

I, the undersigned **Professor Szabo Norbert Peter**, University of Miskolc, Institute of exploration geoscience, consider the TDK thesis suitable for submission.

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Abstract

Accurate reservoir characterization is essential for evaluating hydrocarbon potential and informing field development, particularly in carbonate reservoirs. This study focuses on the detailed reservoir characterization of the Ordovician-Silurian Chimneyhill Subgroup, part of the Hunton Group in the Anadarko Basin, U.S.A., aimed at assessing its hydrocarbon viability. Using a variety of well log data, including neutron porosity (NPHI), density porosity (DPHI), spontaneous potential (SP), natural gamma ray intensity (GR), and resistivity (R) logs, key lithological variations were interpreted, and petrophysical properties were estimated to evaluate production feasibility. The Chimneyhill Subgroup predominantly consists of dolomite, as confirmed by bit cuttings. Based on log responses, three principal reservoir zones were identified: Chimneyhill A, B and C. Chimneyhill A exhibited high resistivity and porosity values, indicating gas-bearing dolomite, while Chimneyhill B showed lower resistivity and approximately similar porosity, with neutron and density logs closely overlain. Chimneyhill C displayed mixed lithological characteristics, with an increase in porosity. The Pickett plot was employed to calculate the tortuosity (α), cementation exponent (m) and saturation exponent (n), which were applied in the Archie's equation to determine water saturation (S_w) for each zone. The results revealed that Chimneyhill A had a low water saturation, making it the most economically viable zone for gas production. Chimneyhill B, with higher water saturation, showed limited hydrocarbon potential, while Chimneyhill C presented mixed results with only marginal hydrocarbon potential. These findings provide a clear strategy for optimizing field development, with Zone A being the primary target for gas extraction.

Keywords

Well logging - Reservoir evaluation - Chimneyhill Subgroup - Anadarko Basin.

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1.0 Introduction

Significant geological activity occurred throughout the Ordovician-Silurian epoch, which resulted in the deposition of large carbonate sequences that are currently essential repositories for hydrocarbons. One such sequence is the Hunton Group, which is located in the fertile Anadarko Basin in the United States. Because of its potential as a reservoir for hydrocarbons, the Chimneyhill Subgroup is an important period of interest within this group. The goal of this research is to present a thorough investigation of the Chimneyhill Subgroup's reservoir rock type, with an emphasis on its hydrocarbon potential, petrophysical characteristics, and geological environment.

The Anadarko Basin, which mostly spans Oklahoma and Texas, is a notable geological feature in the southern United States and is well-known for its significant oil and gas deposits. The basin is a crucial region for the exploration and production of hydrocarbons due to its intricate stratigraphy, extensive sedimentation history, and tectonic activity. The Hunton Group is unique among the basin's geological units because of its substantial reservoir potential. This group, which is mostly composed of carbonate rocks, has undergone extensive diagenetic processes, leading to a variety of porosity and permeability properties (Amsden, 1980; Johnson, 1989).

This research explores the nuances of reservoir rock type, a crucial factor in assessing hydrocarbon reservoirs, with a focus on the Chimneyhill Subgroup. The process of classifying reservoir rocks according to their petrophysical characteristics, diagenetic changes, and depositional facies is known as reservoir rock typing. Understanding the reservoir's hydrocarbon storage and flow capacity requires this procedure (Scholle et al., 1983). Numerous geological investigations have focused on the Chimneyhill Subgroup, which is mainly made up of dolomites and limestones. However, a thorough examination of its reservoir rock types is required to completely understand its potential as a hydrocarbon reservoir.

The lithological features of the Chimneyhill Subgroup will be investigated in this study, with particular attention paid to depositional settings, diagenetic processes, and the consequent petrophysical properties (Ham, 1973). This study attempts to give a comprehensive understanding of the reservoir rock types within the Chimneyhill Subgroup by means of petrophysical measurements. By doing this, it hopes to advance our understanding of reservoir properties and support more efficient methods for exploring for and producing hydrocarbons in the Anadarko

Basin. This paper will give a thorough overview of the Anadarko Basin's geological environment, concentrating on the Hunton Group's Chimneyhill Subgroup. The methods and conclusions of the reservoir rock type study will next be described, emphasizing the importance of the findings for the exploration and production of hydrocarbons because information from previous studies shows that the reservoir zone of the Hunton occur at depth from 16,303 to 16,412ft (109ft thick) as obtained from the drilled well data, and the subsurface geologic map section (Fig. 2) indicated an updip fault and a structurally low well that produced gas and water. In this case, is the whole 109ft zone porous and permeable, and what should be done to enhance the production potential of this well? The petrophysical analysis below gives some proficient suggestions to solve this problem.

1.2 Motivation

As students with a strong interest in geology, geophysics, and energy resources, we are excited to contribute to cutting-edge research in petrophysical well-log interpretation. Our participation in the TDK project will allow us to apply theoretical knowledge to real-world problems, particularly in assessing hydrocarbon potential. Hungary's role in energy research, including oil and gas exploration, offers a unique opportunity to contribute to scientific advancements and to understand better the geological formations that could drive future energy strategies.

This project aims to develop a deeper understanding of petrophysical properties such as porosity, permeability, and fluid saturation, which are critical for identifying hydrocarbon reservoirs. By analyzing well-log data and applying advanced interpretation techniques, even though the data is not from Hungary, we hope this can help uncover new insights into Hungary's subsurface, potentially enhancing local energy exploration efforts.

This project aligns with our academic interests and gives us the opportunity to contribute meaningfully to scientific research. We will help advance Hungary's energy sector while gaining hands-on experience with industry-standard tools and methods.

2.0 Geology of the Area

2.1 Geological settings in the Anadarko Basin

The Anadarko Basin is a large, deep, Paleozoic sedimentary basin located in the southwestern United States, primarily in Oklahoma and extending into Texas, Kansas, and Colorado about 40,000 feet at the southern edge, next to the upfaulted Wichita-Amarillo uplift in Anadarko,

Oklahoma. The basin covers about 50,000 square miles in western Oklahoma and part of the Texas Panhandle region. The Anadarko Basin is important as it is the most productive natural gas production region of the United States. The basin is also a source of petroleum. Oil and natural gas production occurs both in the basin and along the surrounding flanking margins (Bobby D., 2014). The Anadarko Basin formed in Late Paleozoic time as part of the Southern Oklahoma Aulacogen – the structural basin sank and filled with sediments shed from surrounding rising uplifts in the region, primarily during Pennsylvanian time (concurrent with the Ouachita Orogeny). The deepest part of the basin is adjacent to the Wichita Mountains-Amarillo Uplift on its southern margin. The basin is bounded on northeast by the Nemaha Ridge (a buried uplift), and by the Amarillo Uplift and Cimarron Arch (also buried uplifts) to the west and northwest. (Feinstein, 1981; Wroblewski, 1967). Subsidence in the Anadarko basin was most rapid immediately after it was initiated during Pennsylvanian-Morrowan, with subsidence rates decreasing through the Permian. The basin was filled by the end of the Wolfcampian when the Anadarko basin was covered by shelf carbonates (Kluth and Coney, 1981; Rascoe and Adler, 1983; Kluth, 1986; Perry, 1989) (Fig. 1).

2.2 Structural features

In 1967, Wroblewski reported that the largest early Paleozoic structural features identified in the Anadarko basin are the northwest-southeast-trending Fort Cobb, Cordell, Sayre, and Mobeetie anticlinal trends. These features were in existence prior to the pre-Woodford unconformity, that is, Late Devonian time, because upper Hunton (Silurian-Devonian) was absent on their crests because of some combination of erosion or nondeposition. Wroblewski feels indirect evidence indicates these older structures may have been in existence since the Precambrian. Chenoweth (1984), attributes the ancient anticlinal trends and many other arches and domes of the Mid-continent region to epeirogenic activity in the early Paleozoic North American Plate interior related to orogenic activity along the eastern plate margin during the Devonian, Acadian orogeny. Thinning of the Silurian section and evidence of erosion and non-deposition are documented by Chenoweth on smaller pre-Late Devonian anticlines in the Texas panhandle portion of the Anadarko basin.

Producing structures in the Anadarko basin region are results of a range of combinations of tectonic activities with erosional and depositional structural development. The more complex combinations are represented by lower Paleozoic paleo-highs, owing some of their geometry to tectonic uplift and erosion during the middle Paleozoic, Acadian orogeny, that have been reactivated during the

upper Paleozoic Ouachita-Wichita orogeny and subjected to folding and thrusting with renewed erosion to obtain their present configuration. The simplest combinations are represented by upper Paleozoic blankets of porous quartz elastics or carbonates, subjected to homoclinal dip, that wedge out updip because of some blend of erosion and facies change, to form stratigraphic traps. In some instances, upper Paleozoic sediment body geometry, or depositional structure, including fluvial and deltaic distributary channels, delta fringe and shoreline sand bodies contribute to the development of structure and increase the level of complexity. The range of structural complexity in the Anadarko basin region is a continuum from the most complex to the simplest of hydrocarbon trapping configurations (Mahlon M. et al., 1991). In recent times, parts of the Anadarko Basin have been experiencing an abundance of low-to-moderate magnitude earthquakes. The earthquakes have been "attributed" (proving is difficult) to the increased intensity of drilling and fracking taking place in the Anadarko region. Current thought is that the drilling and fracking activity is releasing potential energy associated with old fault systems in the region, currently making Oklahoma the most seismically active region in the United States (Shah and Keller, 2016).

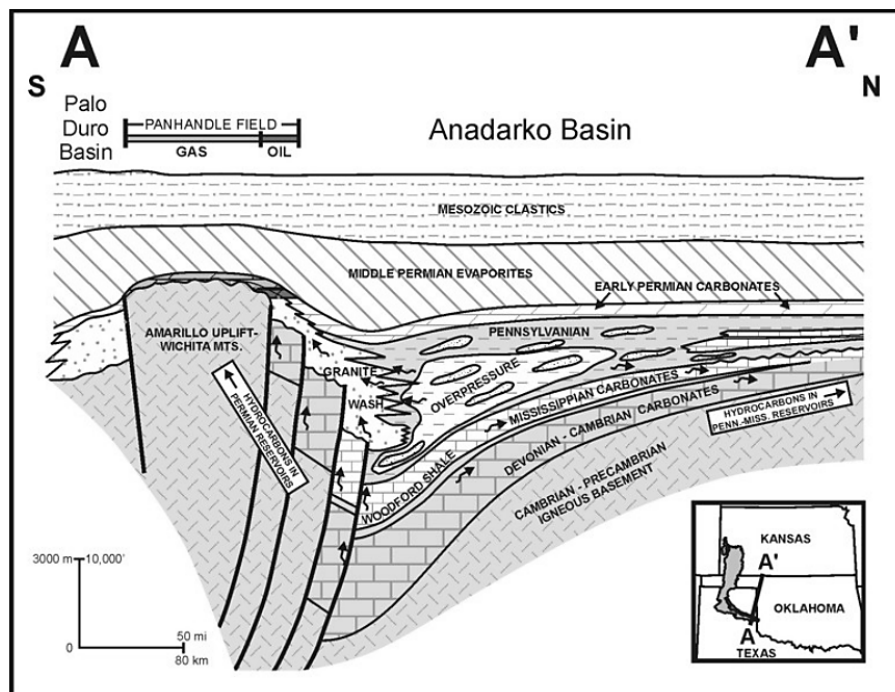


Fig. 1. South-north cross section AA' through Anadarko basin (after Pippin, 1970; Dutton and Garret, 1989; Johnson, 1989; and Sorenson, 2005). Arrows depict Sorenson's (2005) postulated hydrocarbon-migration pathways. The broad Kansas shelf extends to the right (north) on the flat side of the asymmetrical basin.

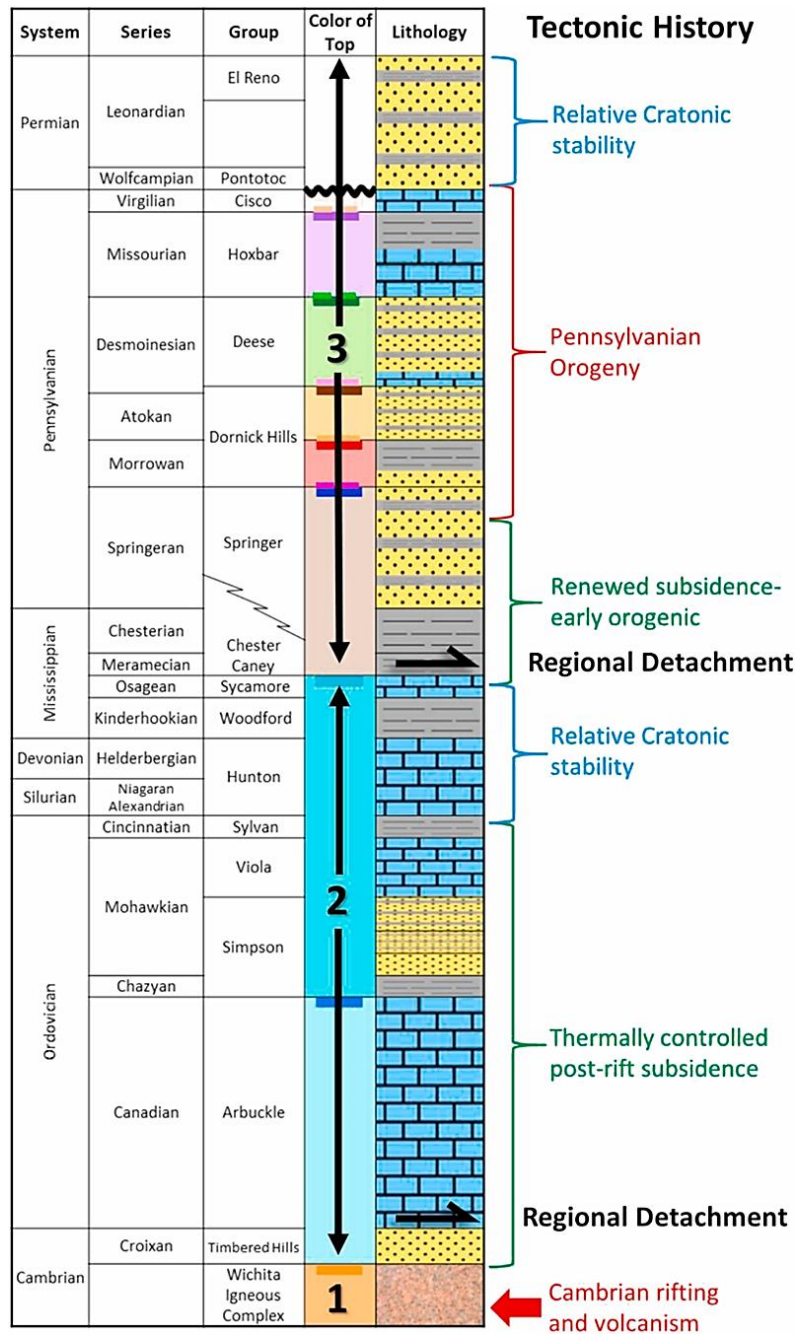


Fig. 2. Traditional subsurface lithostratigraphic nomenclature delineates stratigraphy. Modified from Granath (1989). Color of top refers to horizons interpreted in the cross sections, dashed where they represent an unconformable surface. Detachments levels shown by black arrows. Lithologies include an igneous basement, followed by clastic, carbonate, and shale units. Numbers 1–3 indicate the three mechanical packages. Modified from Turko and Mitra (2020b).

2.3 Stratigraphy of Anadarko Basin

Several studies show that the stratigraphic units in the Anadarko basin are classified into three mechanical packages: igneous/volcanic basement, post-rift mainly carbonate section, and shallower clastic section (Fig. 2). The basin is primarily underlain by **Cambrian-aged**, layered rhyolite that was formed during the stage of rifting. Above the basement layer, there is a thin transgressive sandstone that changes in thickness across the area (Donovan et al., 1989). Stratigraphy from the **Ordovician** to the **mid-Mississippian** period is mainly composed of a substantial carbonate sequence consisting of the Arbuckle, Viola, Hunton, and Sycamore Groups. Hunton group, including the Chimneyhill subgroup, is prominent during the **Silurian** period. The Devonian period also encompasses the Simpson, Woodford, and Sylvan clastic Groups (Richard and John, 2021). The Caney Shale and Springer Shale top the underlying carbonate layer in the Mississippian formation. A local detachment layer has been found in these shale formations, as well as another one at the bottom of the Arbuckle Group. The formations above the Springer detachment are mostly formed at the same time as the **Pennsylvanian** Orogeny and consist mainly of clastic sand/shale packages with occasional thin limestone layers. **Permian** period is the youngest rocks that consists of sandstone and shales that cap the stratigraphic column.

2.4 Hunton Group

Hunton - Silurian and Devonian age. Essentially a carbonate stratum, the Hunton is primarily made up of the Chimneyhill Limestone and the Henryhouse Shale. The geology of the Hunton Group is primarily dolomitized creating stratigraphic traps with unusually high production considering the geology. It was originally deposited as shallow shelf Carbonates but has undergone significant diagenesis due to deep burial (Sternbach and Friedman, 1986).

The Chimneyhill subgroup is an informal stratigraphic unit within the Hunton group in the south-central Oklahoma. It spans the Late Ordovician to Silurian periods, and consists of limestone and oolitic limestone, with three main members: the oolitic member, the glauconitic member, and the pink-crinoidal member. The fossils found in the Chimneyhill Subgroup indicate a marine nearshore environment with a varying thickness, averaging around 35 feet (10.7 m), and it unconformably overlies the Sylvan Shale and is overlain by the Henryhouse Formation. The Chimneyhill Subgroup, along with other units of the Hunton Group, has potential as a hydrocarbon reservoir

due to secondary dissolution and diagenetic processes that enhance porosity and permeability. (Reeds, 1911).

2.5 Hydrocarbon reservoirs

The type of reservoirs varies with typical marine sandstones in the Simpson Group, Dolomite in the Arbuckle Group, and even dolomitized limestone in the Hunton Group. Upper Ordovician – Lower Devonian, is a major hydrocarbon reservoir in the Anadarko basin. Previously unreported nodular anhydrite (replaced and unreplaced) occurs at the top of the sequence, suggesting that hypersaline conditions developed in supratidal environments. Four prominent production fields are highlighted as follows:

Arbuckle - Cambrian and early Ordovician age. Primary production has been in the bald-headed anticlines along Nemaha Ridge and structural traps on the Shelf in northern Oklahoma. The Group is primarily a carbonate structure with high porosity near the eroded surface of the strata due to fracturing. **Chesteran** - Mississippian age. Typically made of oolitic and fossiliferous limestone inter-bedded with shale. The formation is prominent for its gas production found in its erratically porous limestone. **Simpson** - Pennsylvanian age. The primary oil producing reservoir of the Anadarko consists of marine sandstones, shale and carbonate rocks with primary production from its sandstones with green shales offering good source rock (Adler, 1971)

Hunton - Silurian and Devonian age. Essentially a carbonate stratum, the Hunton is primarily made up of the Chimney Hill Limestone and the Henryhouse Shale. The geology of the Hunton Group is primarily dolomitized creating stratigraphic traps with unusually high production (Gaswirth et al., 2013) (Fig. 2)

3. Material and method

3.1 Materials

The dataset used in this study was sourced from the book named "Basic Well Log Analysis" by George Asquith and Daniel Krygowski. The data, provided in the form of a LAS (Log ASCII Standard) file, covers a depth interval from 16,250 to 16,480 ft within the Chimneyhill Subgroup, part of the Hunton Group in the Anadarko Basin, USA. The LAS file contains critical logs, including the caliper log (CALI), density porosity log (DPHI), Neutron porosity log (NPHI), natural gamma-ray intensity log (GR), deep and medium resistivity logs (ILD/ILM), and

spontaneous potential log (SP). The well log analysis was conducted using Schlumberger's Techlog 2018 software, provided by the University of Miskolc for educational purposes. All data and software tools utilized in this study within an educational framework, and the findings are meant solely to contribute to scientific knowledge without any commercial exploitation.

3.2 Methodology

The study employed a comprehensive methodology that combined both qualitative and quantitative interpretations of well-log data to assess the reservoir characteristics of the Ordovician-Silurian Chimneyhill Subgroup within the Anadarko Basin in the USA.

A systematic approach was considered for the study in the Ordovician-Silurian Chimneyhill Subgroup within the Anadarko Basin. First, for analysis, LAS file data was imported into Schlumberger's Techlog software. A detailed examination of well logs, including CALI, GR, NPHI, DPHI, ILD/ILM, and SP, was performed to ascertain the borehole conditions and lithology. Key zones, mainly Chimneyhill A, B, and C, can be identified from the qualitative interpretation based on log response variations. The quantitative analysis involved the estimation of shale volume (V_{sh}), total and effective porosity (PHIT), water saturation (S_w), and bulk volume water (BVW). Cross-plots showing porosity versus water saturation were developed in order to identify hydrocarbon zones. Result interpretation on hydrocarbon potentials and recommendations on further core sampling and petrographic studies were suggested for optimization in reservoir studies. Fig. 3 below shows the flowchart of how the whole work is carried out.

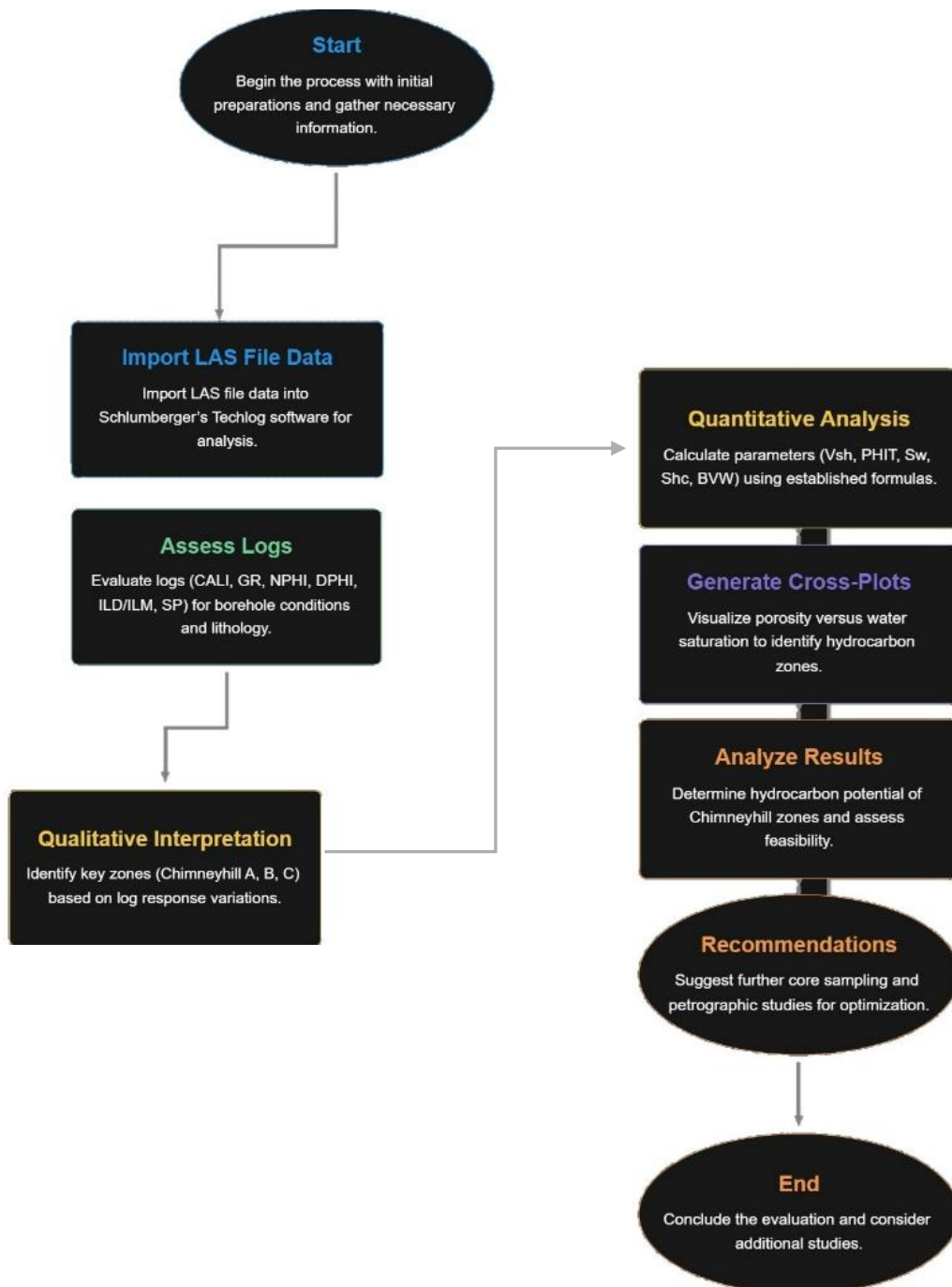


Fig. 3. Work flowchart

3.2.1 Qualitative interpretation

For the qualitative interpretation, a systematic analysis of well-log data was adopted. The process began importing the well log data from the LAS file into Schlumberger's Techlog software for a visual assessment of log curves. The CALI log was analyzed to detect borehole enlargements or irregularities, which could indicate drilling issues or invasion zones. The GR log was used to differentiate between clean and shaly formations. Lower GR readings indicated cleaner, reservoir-quality formations, while higher readings suggested shalier, non-reservoir intervals. This log provided a baseline for identifying lithological changes. A detailed comparison between the NPHI and DPHI logs was performed to identify hydrocarbon-bearing zones and lithology. The comparison focuses on detecting cross-over effects, where NPHI reads higher porosity than DPHI, indicating potential hydrocarbon presence due to the lower density of hydrocarbons compared to water. Gas zones exhibit a more pronounced cross-over due to the low hydrogen content of gas, while water-bearing zones show close alignment between the two logs. In clean sandstone formations, both logs often align closely because the rock matrix and pore content have similar effects on both tools. However, in shaly formations, the NPHI tends to read higher porosity than DPHI due to the higher hydrogen content in clay minerals, even if the actual porosity is low. Conversely, carbonates, depending on their composition (e.g., limestone vs. dolomite), may show discrepancies due to differences in matrix density. These variations between the logs provide insights into the rock type, helping to distinguish lithologies such as shales, clean sands, or carbonates based on how the readings deviate from each other. The ILD and ILM resistivity logs were analyzed to identify fluid content and invasion. If ILM is different from ILD (deep resistivity), it suggests an invaded zone where the shallow formation has been affected by drilling mud filtrate. If the ILD log shows high resistivity while ILM is lower, this points to a hydrocarbon-bearing zone with invasion, as hydrocarbons are poor conductors. Conversely, if ILD shows lower resistivity while ILM is higher, it indicates a water-saturated (aquifer) formation since water is conductive, resulting in low resistivity. Spontaneous Potential (SP) Log Analysis: Although less effective in carbonate formations, the SP log was assessed for deflections that could indicate permeable zones and formation boundaries. Negative deflections are usually noted as potential indicators of permeable formations. Identification of Zones: Based on the combined visual assessment and interpretation of the above logs, specific zones within the Chimneyhill Subgroup were delineated.

3.2.2 Quantitative interpretation

Further calculations were conducted for the anticipated invaded interval of the Chimneyhill Subgroup, between 16,250 ft to 16,480 ft. These calculations included an analysis of various petrophysical parameters such as: shale volume (V_{sh}), total porosity (PHIT), water saturation in the un-invaded zone (S_w), hydrocarbon saturation (S_{hc}), bulk volume of water (BVW).

Calculation of Shale Volume (V_{sh}): The shale volume was determined using the gamma ray index (I_{GR}) method. The gamma ray index was calculated using the formula:

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \dots \dots \dots (1)$$

where GR_{log} is the gamma ray reading at a given depth, GR_{min} is the minimum gamma ray reading for clean formations, and GR_{max} represents the maximum gamma ray reading for shale. It is known that the formula $V_{sh}=I_{GR}$ usually overestimates the shale volume. Depending on the formation's age, a non-linear Larionov equation for older rocks was applied to give a more reliable estimation

$$V_{sh} = 0.083 \times (23.7 \times I_{GR} - 1) \dots \dots \dots (2)$$

Porosity (PHIT) Calculation: The total porosity was calculated using a combination of density (DPHI) and neutron (NPHI) porosity logs:

$$PHIT = \frac{NPHI + DPHI}{2} \dots \dots \dots (3)$$

It is noted that the neutron log in the case study is already corrected for gas effects.

Water Saturation (S_w): Water saturation in the un-invaded (virgin) zone is a crucial parameter for any subsequent quantitative interpretation and reservoir assessment. Given that the reservoir consists of clean carbonates, the Archie's model (1942) is applied for this analysis as follows:

$$(S_w)^n = \frac{a R_w}{\Phi^m \times R_t} \dots \dots \dots (4)$$

The formation water resistivity (R_w), true resistivity of the virgin zone (R_t), and porosity (Φ) are essential parameters for determining reservoir water saturation (S_w). Although true resistivity (R_t) and porosity (Φ) can be directly obtained from log curves, formation water resistivity (R_w) cannot

be directly identified from the logs. The formation water resistivity (R_w) can be calculated using SP log data (Table 1) or direct determination from the Pickett plot which in turn allowed the determination of the cementation exponent (m), saturation exponent (n), by plotting log-log scales of true resistivity (R_t) against porosity (Φ).

Hydrocarbon Saturation (S_{hc}) and Bulk Volume of Water (BVW):

Hydrocarbon saturation was calculated as follow:

$$S_{hc} = 1 - S_w \dots \dots \dots (5)$$

The BVM was assessed to identify zones with potential movable water using:

$$BVW = PHIT \times S_w \dots \dots \dots (6)$$

Cross-Plot Analysis: Porosity versus water saturation cross-plots were generated to visualize the relationships between these parameters across the different zones. This analysis helped confirm the qualitative interpretation findings and further identified the potential hydrocarbon-bearing zones. These quantitative methods provided a numerical assessment that complemented the qualitative study, enabling a detailed understanding of reservoir potential within the Chimneyhill Subgroup in the Anadarko basin.

Table 1. Mathematical Calculation of R_w from SP, for temperatures in °F (after Western Atlas Logging Services, 1985).

Identify a zone on the logs that is clean, wet, and permeable. Pick the maximum value for SP in the zone.	
Calculate formation temperature at the depth of the SP value. $AMST$ = Annual Mean Surface Temperature BHT = Bottom Hole Temperature FD = Formation Depth T_f = formation temperature	$T_f = \left(\frac{BHT - AMST}{TD} \times FD \right) + AMST$
Convert R_{mf} from surface (measured) temperature to formation temperature. $R_{mf} = R_{mf}$ at formation temperature $R_{mfsurf} = R_{mf}$ at measured temperature T_{surf} = Measured temperature of R_{mf}	$R_{mf} = \frac{R_{mfsurf} (T_{surf} + 6.77)}{T_f + 6.77}$
Find the equivalent formation water resistivity, R_{we} , from the SP and R_{mf} . R_{we} = equivalent R_w	$R_{we} = R_{mf} \times 10^{SP / (61 + 0.133 \cdot BHT)}$
Convert R_{we} to R_w (this value is at formation temperature).	$R_w = \frac{R_{we} + 0.131 \times 10^{\left(\frac{1}{\log(BHT / 19.9)} \right)^{-2}}}{-0.5 \times R_{we} + 10^{\left(\frac{0.0426}{\log(BHT / 50.8)} \right)}}$

4.0 Results

4.1 Well-log interpretation (qualitative interpretation)

Analyzing the well log curve shapes and their relative positions is essential for evaluating potential reservoirs and differentiating between hydrocarbon-bearing and water-bearing productive zones. Figure 4 displays a comprehensive set of log data for the Ordovician-Silurian Chimneyhill Subgroup, part of the Hunton Group in the Anadarko Basin, U.S.A., presented in the log Compo format, a feature of Schlumberger's Techlog software. A visual review of the log data for the Chimneyhill Subgroup shows that the caliper curve (CALI) records a decrease in hole diameter from 16,303 to 16,384 ft, indicating invasion. Additionally, the bulk density correction (DRHO) is elevated over this interval due to a thick mud cake. Bit cuttings samples identified the formation as dolomite, although the overlapping neutron and density curves suggest a limestone response (Fig. 4). In dolomite, the neutron log typically shows higher porosity than the density log, but in a

gas zone, the neutron response often decreases, sometimes to a level lower than the density reading. The observed pattern likely represents gas-bearing dolomite, consistent with the mudlogger's report of gas detection from the formation. On the dual induction log (Fig. 4), the SP curve shows a negative deflection over the invaded interval, although the boundaries of this negative deflection are not well-defined, which is typical for carbonate rocks. The resistivity readings for the section from 16,303 ft to 16,324 ft (Fig 4) are about ten times higher than those of the underlying section between 16,324 ft and 16,362 ft, with an increase in resistivity observed from 16,362 ft to 16,384 ft. This pattern could be attributed to an increase in water saturation within the middle part of the analyzed section, distinct lithological variations, or a combination of both. To start the analysis, we decided to define three zones within the invaded interval and one additional zone immediately below (from 16,384 ft to 16,412 ft, as shown in **Fig. 4** to determine if these differences would have a significant impact on the interpretation. The zones were selected based on distinct variations in the log responses, and preliminary interpretations of these zones are outlined as follows:

Chimneyhill A: 16,303 ft to 16,324 ft: This interval shows high resistivity, with the neutron and density logs nearly overlapping. This response could indicate a dolomite formation masked by a gas effect. **Chimneyhill B: 16,324 ft to 16,362 ft:** This section exhibits comparatively lower resistivity, with the neutron and density logs almost overlain, displaying similar porosity. This suggests a zone with higher water saturation. **Chimneyhill C: 16,362 ft to 16,384 ft:** This zone has slightly higher porosity than Chimneyhill B and higher resistivity, which can be attributed more plausibly to lithological differences rather than a decrease in water saturation. **Lower Zone: 16,384 ft to 16,412 ft:** This interval shows higher resistivity than the zone directly above and presents a typical dolomite response in the porosity logs, characterized by low neutron porosity and negative density porosity. This behavior points to tight dolomite, likely with anhydrite, as indicated by the density log's negative porosity excursion. In summary, the preliminary qualitative analysis of the well log data for the Chimneyhill Subgroup in the Anadarko Basin highlights key variations in log responses, indicating potential gas-bearing dolomite, water-saturated zones, and lithological changes that impact reservoir characterization. These insights set the stage for further quantitative analysis to refine the interpretation and validate the presence of productive hydrocarbon zones through calculated parameters and cross-plot analysis.

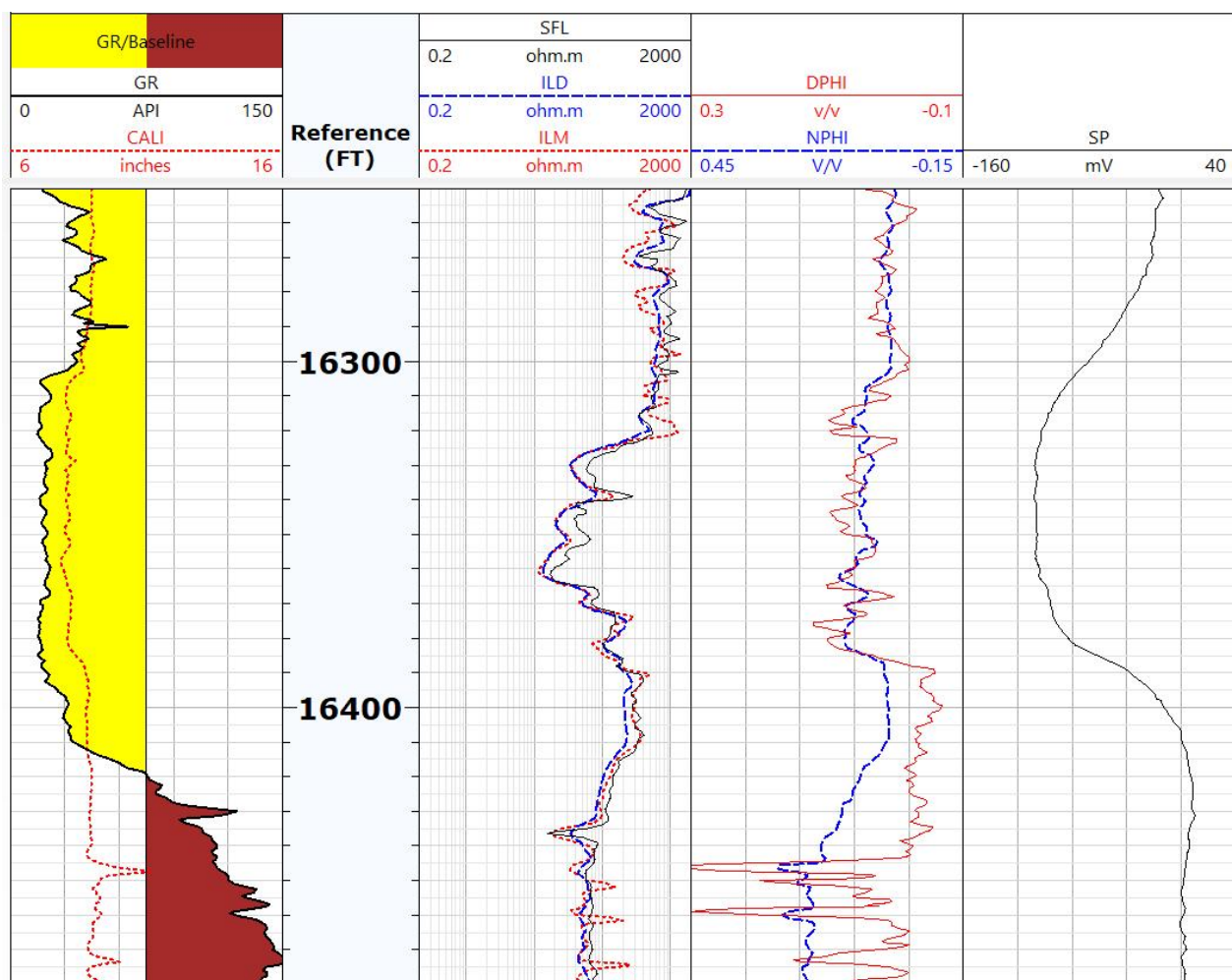


Fig 4. Well-logging data Compo as displayed on the Techlog Software for Chimneyhill Subgroup, Anadarko Basin, U.S.A.

4.2 Well log interpretation (Quantitative interpretation)

The invaded zone was quantitatively assessed using Archie's model (Archie, 1942). The obtained results are summarized as follows (Table 2) (Fig. 5).

Table 2. Observed well logging data and the petrophysical analysis of the Chimneyhill Subgroup

Depth (feet)	Φ (v/v decimal)	S_w (v/v decimal)	S_{hc} (v/v decimal)	(BVW) decimal
16305	0.033	0.25	0.75	0.00825
16308	0.034	0.24	0.76	0.00816
16310	0.064	0.13	0.87	0.00832

16315	0.042	0.16	0.84	0.00672
16321	0.077	0.13	0.87	0.01001
16325	0.083	0.51	0.49	0.04233
16345	0.081	0.61	0.39	0.04941
16357	0.049	0.75	0.25	0.03675
16361	0.08	0.60	0.4	0.048
16367	0.11	0.42	0.58	0.0462
16371	0.050	0.55	0.45	0.0275
16376	0.11	0.26	0.74	0.0286
16382	0.12	0.13	0.87	0.0156

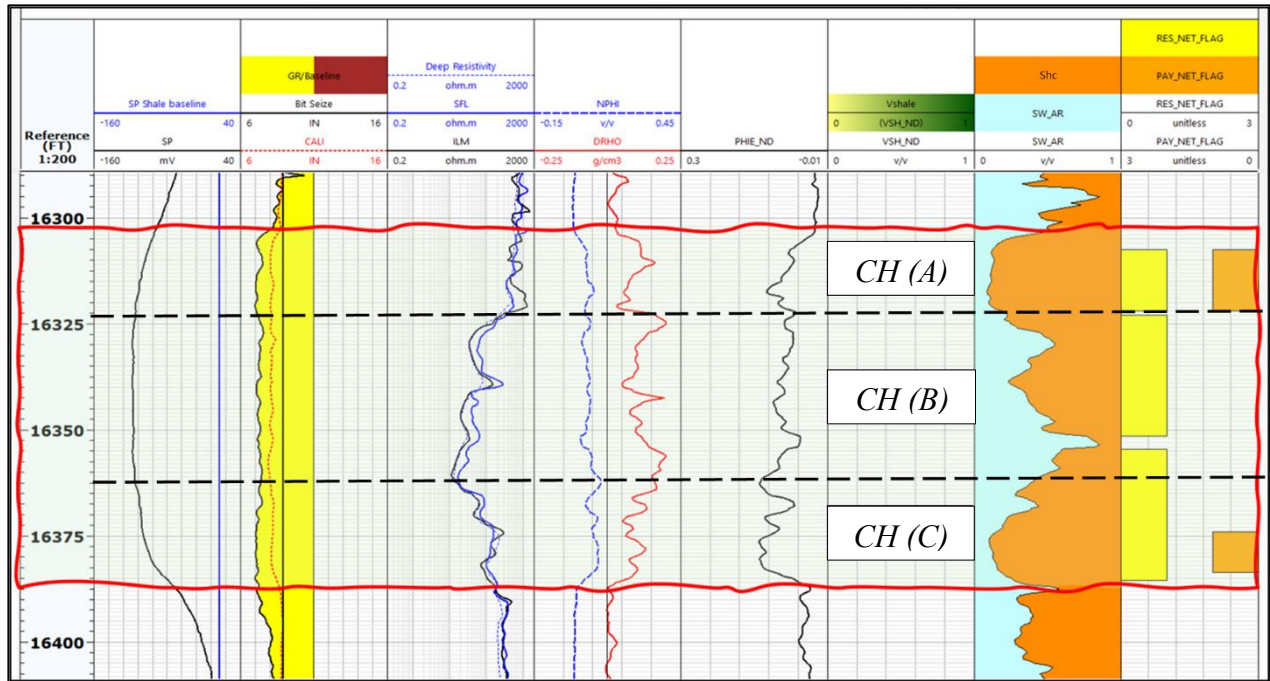


Fig 5. Comprehensive Well Log interpretation of the Chimneyhill Subgroup Showing Key Logs (Natural Gamma Ray, Resistivity, Shale Volume, Porosity, and Water Saturation) Across Evaluated Depths

The shale volume (V_{sh}) in the evaluated interval is generally very low, as indicated by the zero readings in most of the sections, confirming the dominance of clean carbonate formations. This observation aligns with the low gamma ray readings and clustering of point scatter around the dolomite litho-line in neutron density cross plot (Fig. 6).

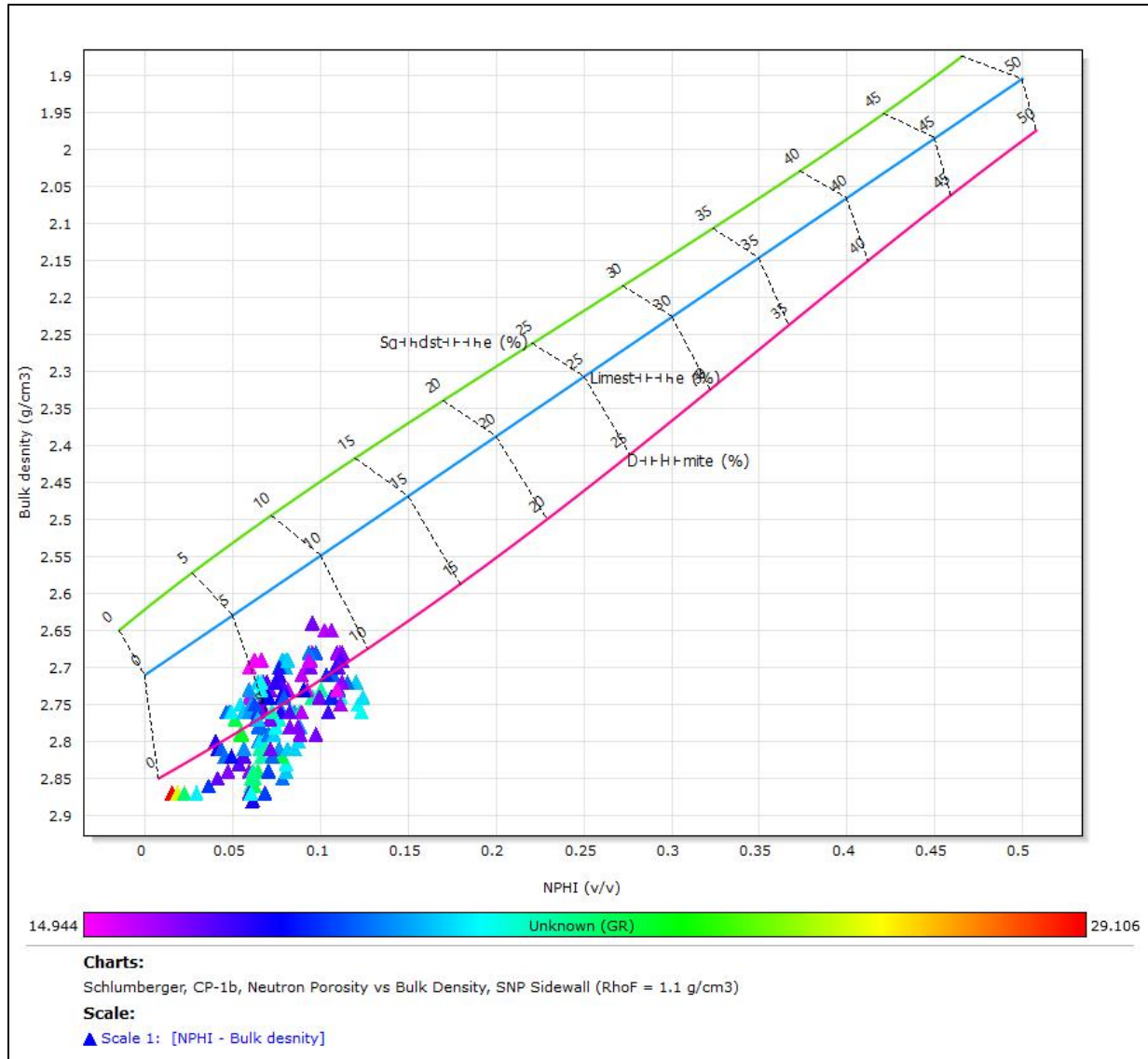


Fig 6. Neutron-density cross-plot (Schlumberger, 1972) of the Chimneyhill Subgroup, in the Anadarko Basin, USA.

The total porosity (PHIT) curve shows consistent values, especially in the upper and middle sections of the invaded zone, while slightly lower in the lower part indicates reasonable porosity within the carbonated rock. The porosity remains moderate to high in zones with lower V_{sh} , suggesting good reservoir quality. R_w , derived from the Pickett plot (Fig. 7), is 0.03 ohm-m at formation temperature, which contrasts with the 0.021 ohm-m value obtained from SP calculations. Due to the reliability of the Pickett plot and the known limitations of the SP method—particularly its susceptibility to inaccuracies in carbonate rock settings and potential hydrocarbon

effects—we opted for the higher R_w value of 0.03 ohm-m. This decision is to ensure a more conservative outcome.

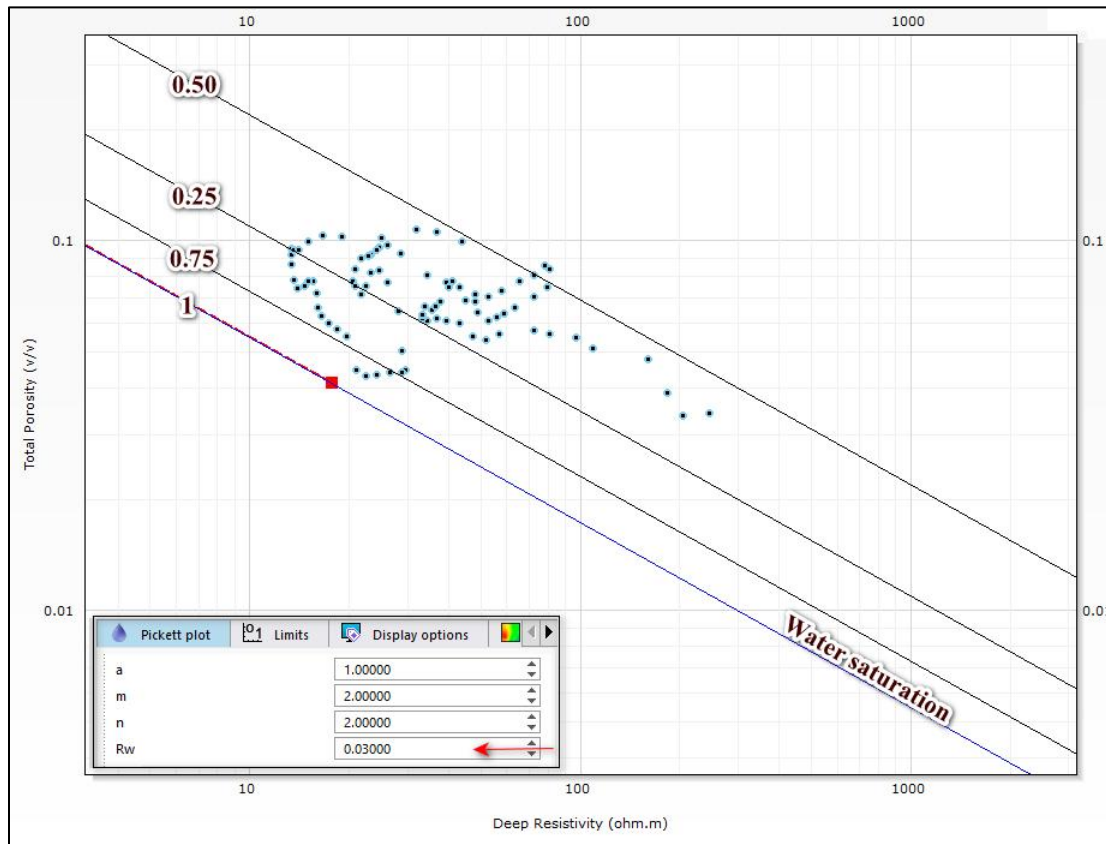


Fig 7. Pickett plot, Chimneyhill B zone, the Anadarko Basin, USA.

Using this R_w value along with porosity results, S_w was subsequently calculated using Archie's equation. The water saturation (S_w) in the invaded zone reveals key insights into the fluid content within the formation. S_w curve indicates lower values in the upper and lower portion of the invaded zone. In contrast, higher S_w values are seen in the middle parts of the interval suggesting higher water content. The hydrocarbon saturation (S_{hc}) is inversely related to water saturation and is notably higher in the upper and lower sections of the invaded zone where S_w is lower and V_{sh} is minimal. This implies that these sections are more favorable for hydrocarbon extraction. In the middle part of the interval, S_{hc} decreases as S_w increases, indicating a decline in hydrocarbon potential due to higher water saturation. The bulk volume of water (BVW) is an important parameter for assessing the presence of movable water. The BVW figures show lower values in the upper and lower part of the invaded zone, which aligns with lower S_w and higher S_{hc} ,

suggesting that hydrocarbons are more likely present in these sections (Table 1). In contrast, the BVW increases in the middle parts, aligning with higher S_w and lower hydrocarbon saturation, indicating poorer reservoir quality in this section. Porosity water saturation cross-plot (Fig. 8) illustrates the relationship between porosity and water saturation across different zones of the Chimneyhill Formation. **Chimneyhill A** displays a wide range of porosity values, with low water saturation decreasing progressively as porosity increases. This suggests that Chimneyhill A is promising with potential for hydrocarbon production. However, the presence of a wide range of porosities may require targeted strategies for maximizing recovery, especially if lower-porosity areas retain higher water saturation. **Chimneyhill B** shows similar porosity to Chimneyhill A but has more variability in water saturation, indicating a zone with higher water saturation and potentially less favorable reservoir properties. **Chimneyhill C** stands out with higher porosity values, and lower water saturation levels, which implies better reservoir characteristics. Overall, the plot highlights the heterogeneous nature of the Chimneyhill subgroup, where Chimneyhill A and C appears most promising for reservoir development.

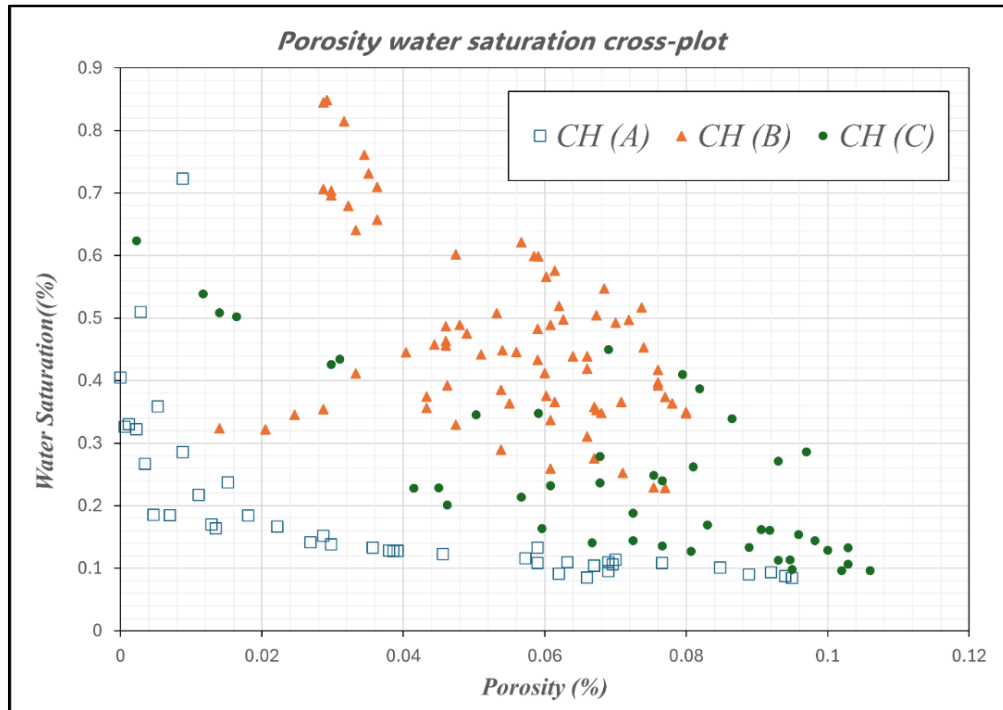


Fig 8. Porosity water saturation, Chimneyhill zone, Anadarko Basin, USA.

5. Discussion and Conclusions

Comprehensive analysis of the Ordovician-Silurian Chimneyhill Subgroup within the Anadarko Basin has provided valuable insights into its reservoir characteristics. The integrated qualitative and quantitative evaluation using well log data revealed significant lithological and petrophysical variations across different zones. Chimneyhill A stands out as the most promising zone for hydrocarbon production due to its low water saturation and high hydrocarbon potential, supported by consistent resistivity and porosity patterns indicative of gas-bearing dolomite. Chimneyhill C also shows potential with higher porosity and favorable hydrocarbon indicators, whereas Chimneyhill B is less favorable due to higher water saturation. Based on these findings, our recommendation is to employ a more comprehensive approach given the complexities of carbonate reservoirs, where conventional log-derived permeability estimates often fall short compared to clastic formations. We suggest further investigation through core sampling across these intervals to conduct detailed petrophysical analyses, including both Special and Routine Core Analyses (SCAL and RCA). This approach will allow for a more accurate assessment of permeability, pore system characteristics, and distribution. Additionally, we recommend petrographic studies to gain insights into pore structure, connectivity, and diagenetic processes affecting reservoir quality. Assessing diagenesis will provide valuable context for understanding porosity evolution, cementation, and dissolution patterns, which are critical for a refined evaluation of reservoir potential.

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