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Reservoir Characterization Review in Sedimentary Basins

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Evaluating the subsurface characteristics of reservoirs is an important part of gas storage, hydrocarbon exploration, and production in sedimentary basins. This process combines geological, geophysical, and engineering data to understand the subsurface geology, and fluid distribution, determine reserves and predict the fluid movement in the reservoir. And in the case of empty reservoir, the storage capacity, sealing strength is analysed. The primary goal of reservoir characterization is to create a precise and dependable reservoir model to maximize the production procedure and reduce the associated risks of hydrocarbon exploration and production. This review examines different approaches used for reservoir characterization in sedimentary basins, including geological, geophysical, and engineering methods. Each method's advantages and disadvantages are discussed, alongside their uses in different reservoir contexts. The importance of combining multiple lines of evidence to enhance the accuracy of the reservoir models is also examined.

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1. INTRODUCTION

Energy research comprises renewable energy, energy efficiency, and energy storage. Both the creation of new energy technology and our comprehension of the intricate mechanisms underlying energy generation and consumption have made tremendous strides in recent years. Energy storage requires the presence or the availability of reservoirs which is the subject of this review.

Renewable energy such as geothermal, solar and other sources have grown significantly in recent years. By 2025, the International Energy Agency (IEA) projects that over 30% of the world's electricity will come from renewable sources [1]. Technology advancements in renewable energy have lowered costs, increased efficiency, and increased reliability, making it a more appealing alternative for nations trying to lower their carbon impact. To effectively reduce gas emissions and address climate change, energy efficiency must be improved. This is why studying reservoir characterization to better understand reservoir capability and storage strength is important for effectively storing ozone layer-depleting gases. Current studies have concentrated on creating more energy-efficient technology, including smart thermostats and LED lighting, and on comprehending the social and economic variables that affect how much energy is utilized. The IEA estimates that increasing energy efficiency may cut the world's energy demand by 40% by 2040 [2].

On the other hand, energy storage is a crucial part of the switch to renewable energy. Current energy storage technology advancements have concentrated on creating more effective and affordable batteries and investigating alternate storage technologies like hydrogen fuel cells [1].

While efforts are made to introduce the effective and wide use of renewable energy, the search for oil and gas for economic sustainance remains intact. Thus, it is critical for successful hydrocarbon exploration and production in sedimentary basins to understand reservoir characteristics [3-6]. This includes information on porosity, permeability, fluid saturation, rock types, and the environmental conditions of deposition. This is required to realize the potential of hydrocarbon reservoirs [7] and devise effective strategies for drilling, completion, and production. Not only is it necessary to detect reservoirs, but their characterization is important for managing the associated risks and uncertainties [8,9]. By combining seismic, well log, and core data, engineers can construct more accurate geological models and make intelligent choices regarding reservoir development, such as well spacing, artificial lift, and water injection.

2. TYPES OF RESERVOIR ROCKS

The origin, composition, and depositional environment all affect the features and attributes of the many reservoir rocks [10,11]. The following are a few of the most typical kinds of reservoir rocks: sandstone and carbonate.

Sandstone is a sedimentary rock comprising grains of sand-sized rocks, minerals, or organic substances. It is one of the most prevalent varieties of reservoir rocks, and due to its high porosity and permeability, it may store significant amounts of hydrocarbons [12]. Sandstone reservoirs are typically found in fluvial and shallow marine environments, and the features of these reservoirs can change based on the grain size, sorting, and cementation.

Carbonates: Sedimentary rocks mostly made of calcium carbonate (CaCO3) or magnesium carbonate are called carbonates (MgCO3). They can develop in various situations, including evaporite, shallow marine, and reef conditions. Because of their intricate pore networks and significant variability, carbonate reservoirs are notorious for being challenging to explore and produce. They can, however, also have high porosity and permeability, which attracts oil and gas exploration as a target [13].

3. IMPORTANCE OF RESERVOIR CHARACTERIZATION

It is critical for successful hydrocarbon exploration and production in sedimentary basins to understand reservoir characteristics [3-6]. This includes information on porosity, permeability, fluid saturation, rock types, and the environmental conditions of deposition. This is required to realize the potential of hydrocarbon reservoirs [14] and devise effective strategies for drilling, completion, and production. Not only is it necessary to detect reservoirs, but their characterization is important for managing the associated risks and uncertainties (Ibekwe et al., 2023); Oguadinma et al. [15]. Combining seismic, well-log, and core data makes it possible to construct more accurate geological models and make intelligent choices regarding reservoir development, such as well spacing, artificial lift, and water injection.

4. METHODS OF RESERVOIR CHARACTERIZATION

Analyzing reservoirs is an intricate task that necessitates the combination of numerous kinds of information and practices (Fig. 2). Some of the most widely-used approaches for characterization include geological methods, which involve interpreting data that is located on the surface and underneath it to recognize the stratigraphic and structural arrangement of the sedimentary basin [17-21,15]. One such technique is mapping the surface, which entails identifying and plotting geological components such as outcrops, faults, and folds to grasp the structural makeup of the sedimentary basin [22]. The information collected from surface mapping can be used to modify subsurface models and advance the accuracy of the reservoir assessment. The methods for reservoir characterization are the ones listed below.

4.1 Geological Methods

4.1.1 Well logging

Using geological methodologies, it is possible to comprehend the sedimentary basin's structural and stratigraphic framework by interpreting surface and subsurface data [23]. These techniques consist of the following:

4.1.2 Surface mapping

It entails locating and mapping geological features, including outcrops, faults, and folds, to understand the sedimentary basin's structural architecture [23,24]. Surface mapping data can be used to limit subsurface models and increase the precision of reservoir characterization.

4.1.3 Core analysis

This step is focused on extracting rock samples from the subsurface during the drilling procedure. It is essential for validating the well-log data and constructing precise geological and reservoir models [25]. This stage also provides knowledge about the properties of the reservoir rocks, such as porosity, permeability, grain size, and mineralogy [26].

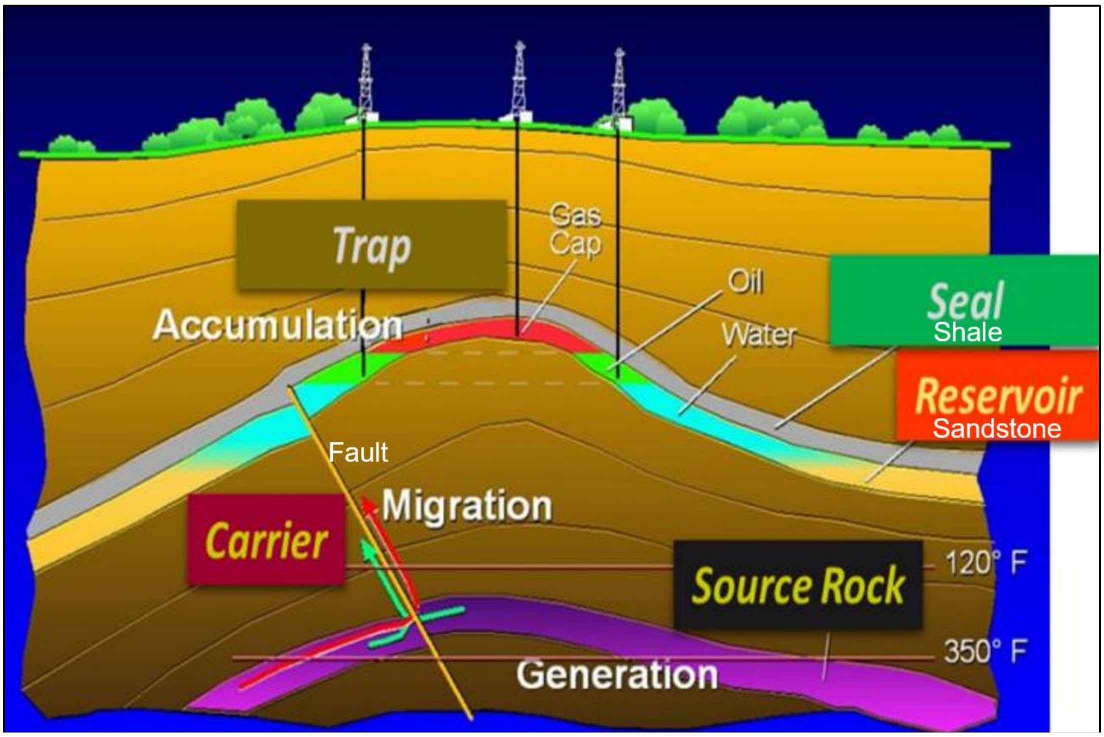

Fig. 1. A sedimentary basin showing the five elements of a petroleum system, which includes a reservoir [16]

4.1.4 Fluid samples analysis

Samples of fluids can be acquired from wells and cores, which gives insight into the nature, composition, and characteristics of the hydrocarbons (oil or gas) and other liquids (water) held within the reservoir.

4.1.5 Numeric modelling

Numerical models simulate the flow pattern of hydrocarbons and other fluids in the reservoir. These models use geological and petrophysical information to anticipate the reservoir output under various circumstances (such as primary production, secondary recovery, enhanced oil recovery and reservoir management).

4.2 Geophysical Methods

The physical properties of subsurface layers are evaluated and interpreted using remote sensing techniques known as geophysical methods [23]. These methods include.

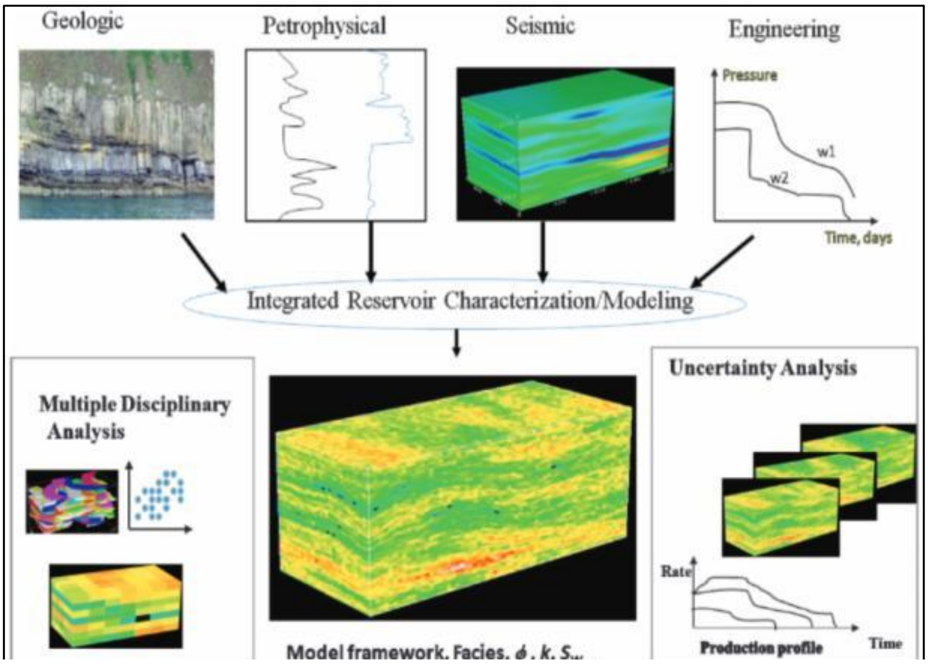

Fig. 2. Integrated multidisciplinary Illustration of reservoir characterization approach [23]

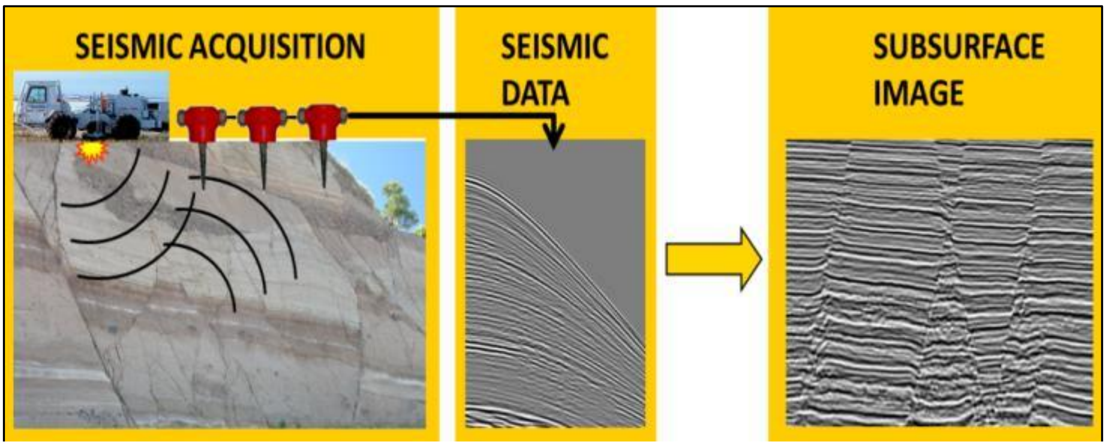

Fig. 3. Process of subsurface data collection from seismic acquisition to subsurface image [16].
The seismic image is an example of 2-Dimensional seismic data used for reservoir analysis and interpretation

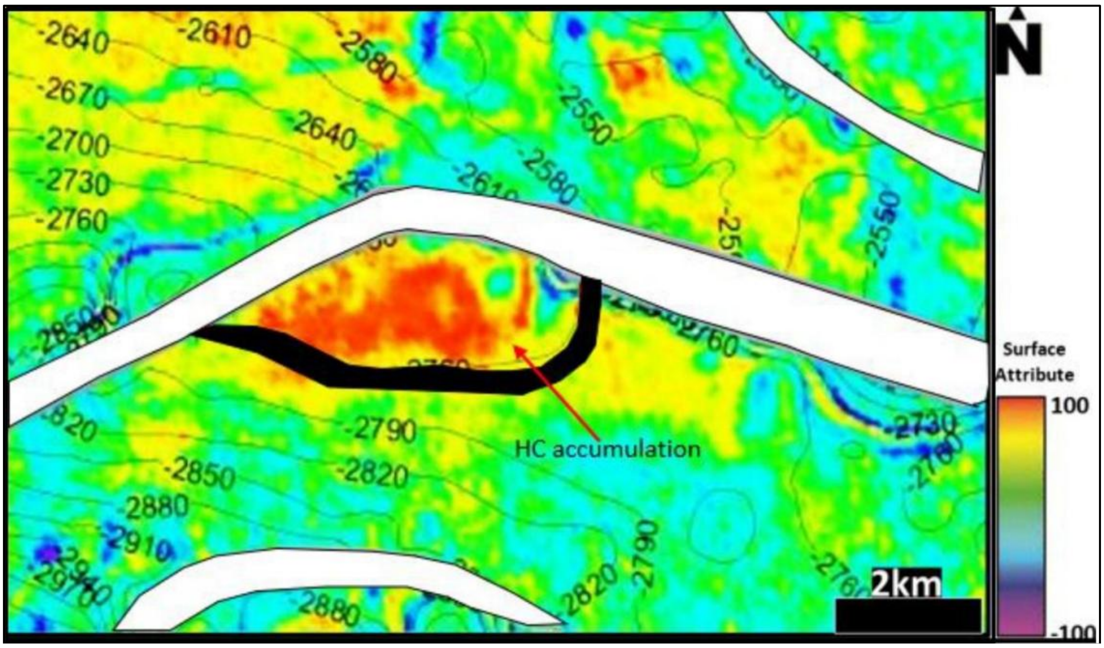

Fig. 4. Time map interpreted from subsurface seismic data. It shows hydrocarbon (HC) and some structural configuration [8]

4.2.1 Seismic survey

To picture the subsurface geology, seismic surveys generate and detect sound waves [16]. Seismic data can be used to evaluate reserves, forecast fluid flow behaviour in the reservoir, and offer precise information about the structural and stratigraphic framework of the sedimentary basin.

The essential instrument for subsurface imaging is seismic data analysis, which offers details about the lithology, fluid distribution, and subsurface structures [27,8], Fig. 4. To determine the position and shape of hydrocarbon reservoirs, it is utilized to create 3D models of the subsurface.

4.2.2 Gravity and magnetic surveys

Gravity and magnetic surveys measure changes in the Earth's gravitational and magnetic fields to map the subsurface geology. These techniques can be used to locate structures and lithologies that are not evident in seismic data as well as to learn about the thickness, density, and magnetic susceptibility of the rocks [28,29].

4.3 Engineering Methods

To calculate reserves and forecast fluid flow behaviour, engineering methods measure and evaluate production data from the reservoir [30]. These techniques consist of…you have to list all these techniques here before explaining each above primarily.

4.3.1 Production data analysis

To assess reserves and forecast fluid flow behaviour, production data analysis entails the interpretation of production rates and pressure data from the reservoir [31], Fig. 5. This technique can be used to optimize the production strategy and can provide information about the reservoir performance, including well productivity, drainage area, and fluid characteristics [30].

4.3.2 Well testing

To calculate the capacity of the reserves and forecast fluid flow behaviour, well testing measures pressure and flow rate data from the reservoir. It can be used to optimize the completion and stimulation approach by providing extensive information about the reservoir's attributes, such as permeability, skin factor, and wellbore storage [25].

5. RESERVOIR CHARACTERIZATION CHALLENGES

Because sedimentary basins are complicated and diverse (structure, form, dimension, depth,

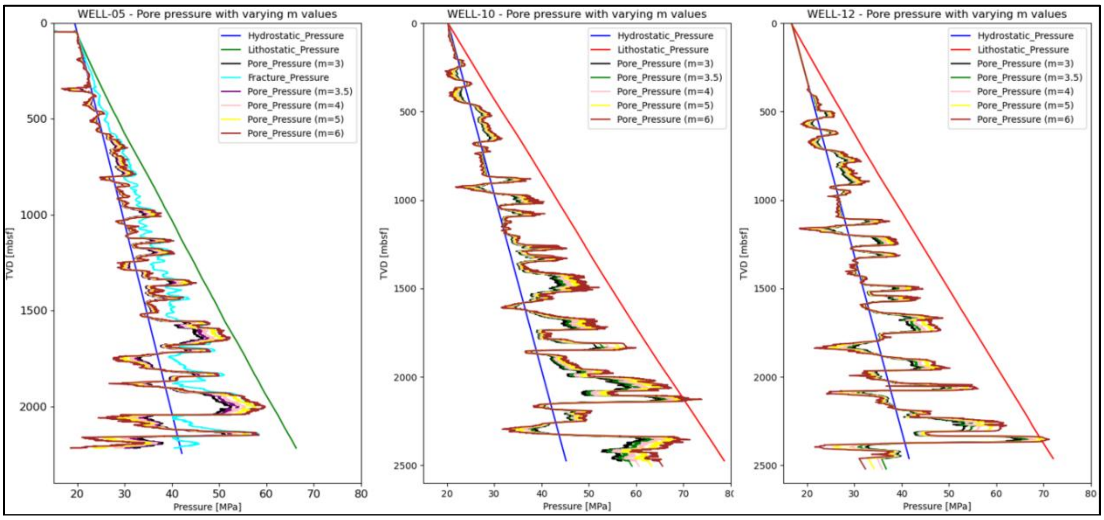

Fig. 5. Pore pressure prediction from Eaton modelling based on ∆t sonic method [31]

etc.), the characterization of reservoirs is difficult [17,18,21]. Even with the enormous advancements achieved in this area, engineers still have a lot of difficulties adequately describing reservoirs [18,21]. Some difficulties include data quality, heterogeneity, non-uniqueness, and sedimentary basin reservoir characterization uncertainty.

5.1 Data Quality

The location, accessibility, and depth of the reservoir all impact the type and amount of data that can be used to characterize the reservoir. The data is frequently lacking or imperfect, which can cause uncertainty and mistakes in the geological models. It's also possible that the data is of poor quality, which makes it challenging to comprehend or combine with other data types. For instance, low signal-to-noise ratios or resolution in seismic data may make it challenging to detect underlying features or distinguish between various rock types. The rocks' petrophysical characteristics may be unknown due to artifacts or well-log gaps. Additionally, it can be challenging to create reliable geological models since data from many sources may be inaccurate or conflicting [32-37].

5.2 Heterogeneity

Sedimentary basins are incredibly heterogeneous, with various fluid distributions, complicated geological formations, and distinct rock characteristics. It may be challenging to create precise geological models and forecast fluid flow behaviour in the reservoir due to this heterogeneity. The reservoir rocks' porosities, permeabilities, and lithologies may vary significantly depending on depth, location, margins, platforms, and basins. Fluid characteristics, saturation, and motility changes can also complicate fluid distribution. It can be challenging to create representative models for the entire reservoir and to extrapolate data from one location to another due to heterogeneity.

5.3 Non-uniqueness

Reservoir characterization is frequently impacted by non-uniqueness, which refers to the ability of different geological models to fit the same data. This might happen due to the sedimentary basin's complexity and heterogeneity, as well as the scarcity of data. Non-uniqueness can cause predictions of reservoir behaviour to be imprecise since different models may yield inconsistent results. To validate their projections, reservoir engineers must carefully assess the model's underlying assumptions and unknowns [38-42].

5.4 Uncertainty

An obstacle to reservoir characterization is uncertainty, which can compromise the models' dependability and accuracy. Several factors, such as data quality, facies heterogeneity, non-uniqueness, and modelling assumptions, can cause uncertainty. For instance, the uncertainty in the petrophysical characteristics of the rocks may affect the fluid distribution and flow behaviour predictions. The boundary conditions, well performance, and production history are only a few examples of the parameters and assumptions employed in numerical models that can introduce uncertainty. Reservoir engineers must carefully consider the sources of uncertainty, and their effects on forecasts of reservoir behaviour must be quantified.

6. CONCLUSION

Characterizing reservoirs is crucial in discovering and extracting hydrocarbons in sedimentary basins. Techniques from geology, geophysics, and engineering are utilized to characterize reservoirs. These techniques offer supplementary data on the underlying geology and fluid distribution dynamics, and they can be used to calculate reserves and forecast how fluids will flow in a reservoir. It can be challenging to create precise geological models and predict the flow behaviour of fluids in the reservoir due to issues with data quality, heterogeneity, non-uniqueness, and uncertainty. To develop accurate models, reservoir engineers must carefully assess the data and incorporate various supporting evidence. They must quantify the uncertainties and conduct sensitivity studies to evaluate the effects of different assumptions and parameters.

By combining various data sources and employing cutting-edge technology and methodology, such as high-resolution seismic imaging, advanced well logging techniques, and machine learning algorithms, increasing the accuracy of reservoir models, characterize reservoirs more accurately, and mitigate challenges in future hydrocarbons prospecting.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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