



Facies Analysis and Thin-Section Petrography for Determining the Lithological Characteristics of Deep-Water Deposits: A Literature Review

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Abstract. Facies analysis and thin-section petrography are complementary and essential approaches for determining the lithological characteristics of deep-water deposits. Deep-water sediments are formed by diverse depositional processes such as turbidity currents, debris flows, slumps, and pelagic suspension settling, producing a wide range of lithofacies with distinctive textural, compositional, and sedimentary structural attributes. This literature review synthesizes studies that apply facies analysis and thin-section petrography to characterize deep-water deposits across various basins and geological ages worldwide. Field-based facies analysis emphasizes lithology, sedimentary structures, bed geometry, and vertical–lateral facies relationships to reconstruct depositional environments. In contrast, thin-section petrography provides microscopic insights into mineral composition, grain texture, cement types, porosity, and diagenetic features that are not observable in the field. The integration of these methods, often combined with advanced techniques such as XRD, SEM, and geochemical analyses, has proven effective in distinguishing lithofacies, understanding sedimentary processes, and evaluating reservoir quality. The review highlights that grain size, sorting, cement type, pore-throat size, and diagenetic processes are key controls on lithological characteristics and reservoir potential in deep-water systems. Therefore, the combined application of facies analysis and thin-section petrography provides a comprehensive framework for interpreting deep-water sedimentary systems.

Keywords: Deep-Water Deposits; Diagenesis; Facies Analysis; Lithofacies; Thin-Section Petrography.

1. INTRODUCTION

Deep-water depositional systems represent some of the most complex and economically significant sedimentary environments in the geological record. Understanding the lithological characteristics of deep-water deposits is fundamental to petroleum exploration, reservoir characterization, and the reconstruction of ancient sedimentary environments (Geçer et al., 2019; Peng, 2020). Deep-water settings encompass a broad spectrum of depositional processes, including turbidity currents, debris flows, suspension settling, and contourite deposition, each producing distinctive lithofacies with unique textural, compositional, and structural attributes (Nugraha et al., 2023; Peng, 2020). The prevalence of fine-grained sedimentary rocks in deep-water successions comprising approximately two-thirds of the stratigraphic record underscores the importance of detailed sedimentological investigation, yet the transportation and depositional processes of these rocks remain poorly understood compared with their shelf counterparts (Peng, 2020).

Facies analysis and thin-section petrography constitute two of the most powerful and complementary methodologies for characterizing the lithological properties of sedimentary rocks. Facies analysis involves the systematic description and interpretation of sedimentary rocks based on their lithology, texture, sedimentary structures, geometry, and fossil content, enabling the reconstruction of depositional environments and processes (Feng, 2019; Nugraha

et al., 2023). The term "lithofacies" itself has been widely debated in sedimentary petrology and sedimentology; however, it is generally understood as the facies of sedimentary rocks, encompassing both the physical characteristics and the inferred depositional environments (Feng, 2019). Thin-section petrography, on the other hand, provides microscopic-scale observations of mineral composition, grain texture, diagenetic features, porosity, and cement types, which are essential for understanding the provenance, diagenetic history, and reservoir quality of sedimentary rocks (Geçer et al., 2019; Lai et al., 2017; Radwan, 2020).

The integration of facies analysis with thin-section petrography has proven indispensable in deep-water sedimentological studies. For instance, the identification of submarine fan lithofacies in the Haymana Basin of Turkey relied on the combined analysis of lithology, texture, sedimentary structures, and petrographic characteristics to separate distinct lithofacies and evaluate their reservoir potential (Geçer et al., 2019). Similarly, studies of deep-water fine-grained sedimentary rocks in the Midland Basin employed a combination of sedimentological, petrographic, and bulk geochemical analyses to define lithofacies and elucidate transport and depositional processes (Peng, 2020). In deep-marine settings such as the Voiron Flysch in the Chablais Prealps, sedimentological methods including biostratigraphy, structural analysis, and petrographic analysis of detrital composition have been applied to reconstruct deep-sea fan depositional settings (Ragusa, Ospina-Ostios, Kindler, & Sartori, 2021).

The objective of this literature review is to synthesize the current state of knowledge regarding the application of facies analysis and thin-section petrography in determining the lithological characteristics of deep-water deposits. This review examines the methodological frameworks employed, the range of lithofacies identified in deep-water settings, the petrographic characteristics that distinguish these lithofacies, and the implications for depositional environment interpretation and reservoir quality assessment. By drawing upon a diverse body of literature spanning various geological ages and basins worldwide, this review aims to provide a comprehensive understanding of how these analytical approaches contribute to the characterization of deep-water sedimentary systems.

2. LITERATURE REVIEW

Facies Analysis as a Basis for Lithological Characterization in Deep-Water Systems

In the reviewed literature, facies are operationally defined from lithology, bed geometry, sedimentary structures, and fossil/trace-fossil content, and then grouped into genetically related facies associations to represent parts of a depositional system and

reconstruct palaeoenvironments/palaeobathymetry (Benyamin, Pratiwi, & Indah, 2022; Song et al., 2024). For example, deep-water basin studies explicitly link facies analysis with palaeobathymetric reconstruction using palaeontological and palaeoecological information (e.g., benthic foraminifera; ichnofossils) alongside sedimentological criteria (Song et al., 2024), while outer-ramp successions use facies associations (distal vs proximal outer ramp) to interpret relative deepening/shallowing and transgressive surfaces (Benyamin et al., 2022). These approaches frame “lithological characteristics” not only as rock type (e.g., mudstone, marl, sandstone, packstone) but also as process-related assemblages (e.g., turbidite sheets vs slump deposits) that predict lateral continuity, stacking patterns, and heterogeneity (Benyamin et al., 2022; Song et al., 2024).

Deep-water siliciclastic and mixed systems are commonly interpreted through gravity-flow process indicators such as graded bedding and cyclic alternations of sand- and mud-dominated intervals, which are used to support turbidite interpretations and to subdivide proximal–distal trends. In mixed siliciclastic–carbonate successions, facies analysis is paired with petrography to document co-occurrence of siliciclastic grains, carbonate skeletal components, volcanic-derived particles, and reworked shallow-water indicators (e.g., glauconite; neritic shell fragments), thereby refining lithological classification and sediment-routing interpretations beyond what outcrop appearance alone can provide (Muñoz-Cervera & Cañaveras, 2023). For deep-marine turbidites, hierarchical facies concepts are sometimes explicitly tied to lobe architectures (e.g., off-axis and lobe-fringe settings) based on observed scarcity of channel architectures and dominance of sheet-like sandstones interbedded with shales (Muñoz-Cervera & Cañaveras, 2023).

Thin-Section Petrography and Microfacies Concepts

Thin-section petrography under plane-polarized and cross-polarized light is used in the reviewed works to identify mineral constituents, allochems/fossils, matrix vs cement proportions, grain size and sorting, and diagenetic features that collectively define lithological classes and microfacies (Rahman et al., 2025; Wilson et al., 2013; K. Zhang et al., 2020). In carbonates, multiple studies formalize microfacies determination as grouping based on the type and abundance of components seen in thin section, explicitly linking microfacies to depositional environment interpretations (Moyano-Paz et al., 2022; Zou et al., 2022). Carbonate textural nomenclature frequently follows Dunham-style textural classes (and commonly uses modifications by Embry & Klovan), enabling standardized lithological descriptors (e.g., wackestone/packstone/grainstone/floatstone) grounded in thin-section fabrics (Salehi et al., 2023; Wilson et al., 2013).

In clastic and mixed systems, modal petrography and compositional ternary approaches (e.g., QFL-type logic) are used to classify sandstones, infer compositional maturity, and relate composition/lithofacies to reservoir quality and depositional energy (Nugrahanto et al., 2021; K. Zhang et al., 2020). Quantitative point counting is explicitly operationalized in several studies as counting hundreds of components per thin section (e.g., ~400 counts in Gazzi–Dickinson-type workflows; ≥ 300 grains in sandstone petrography) to obtain representative detrital modes and reduce grain-size bias (Benavente et al., 2025; Li et al., 2019). Such quantification supports lithological discrimination (e.g., calcilithite/litharenite dominance in deep-marine turbidites) and informs provenance and tectonic setting interpretations that can be essential to deep-water basin analysis (Li et al., 2019; Muñoz-Cervera & Cañaveras, 2023; K. Zhang et al., 2020).

Diagenesis and Non-Uniqueness: Why Petrography Matters in Deep-Water Deposits

A recurring theoretical issue is interpretational non-uniqueness: similar macroscopic or log-imaged textures may arise from distinct depositional or diagenetic processes (Wilson et al., 2013). The clearest demonstration is the combined FMI–petrography evaluation of carbonates, where petrography was required to resolve primary depositional textures and secondary alteration (including complex diagenetic overprinting and gas-smearing impacts on image quality), and where the same FMI “facies” could correspond to multiple petrographic origins (Wilson et al., 2013). In siliciclastic reservoirs, integrated petrography (thin section) with SEM/CL and well-log analysis is used to identify diagenetic minerals (e.g., quartz, carbonate, clays), reconstruct paragenetic sequences, and define diagenetic facies whose pore systems and cements directly control reservoir quality (Boulvain et al., 2020). Comparable diagenetic reasoning appears in classic reservoir studies where grain-coating clays and variable quartz cement abundances are interpreted as facies-controlled and reservoir-critical (Meller & Ledésert, 2017), reinforcing that lithological characterization in deep-water successions often requires separating depositional lithofacies from diagenetic “overprints” (Boulvain et al., 2020; Meller & Ledésert, 2017).

3. RESEARCH METHODS

This literature review was conducted through a systematic examination of published research articles that employ facies analysis and/or thin-section petrography to characterize deep-water or related sedimentary deposits. The methodological approaches documented in the literature can be broadly categorized into field-based sedimentological methods, laboratory-based petrographic and mineralogical analyses, and integrated multi-proxy approaches.

Field-Based Sedimentological Methods

Field-based facies analysis forms the foundation of most deep-water sedimentological studies. This typically involves the measurement of detailed stratigraphic sections, systematic description of lithology, sedimentary structures, bed geometry, and texture, and the documentation of vertical and lateral facies relationships (Nugraha et al., 2023; Orme et al., 2020; Ramli et al., 2021). Facies are defined by lithology, stratification, texture, and sedimentary structures, following established classification schemes (Muljana et al., 2021). In the study of the Seulimeum Formation in Indonesia, for example, lithofacies analysis consisted of describing sedimentary rocks in the field and classifying them into facies and facies associations based on established frameworks (Nugraha et al., 2023). Similarly, the investigation of the Pandua Formation shale in Southeast Sulawesi involved measured stratigraphic sections to determine shale lithofacies based on geometric, lithological, and sedimentary structure parameters, with a measured section thickness of 671 m (Ramli et al., 2021).

Outcrop analysis and section measurement are considered of prime importance in the study of architectural element analysis and facies characterization (Mehmood et al., 2023). In the study of the Pab Formation in Pakistan, outcrop analysis and section measurement were performed to identify lithofacies, which were then categorized based on their depositional characteristics and facies associations (Mehmood et al., 2023). The Gercus Formation study in NE-Iraq employed field photographic documentation for the whole stratigraphic section, covering lithologies, sedimentary structures, and different lithofacies types, with 50 rock samples collected from studied sections (Al-Mashaikie & Mohammed, 2017).

Thin-Section Petrography and Microscopic Analysis

Thin-section petrography is a cornerstone analytical technique in the characterization of deep-water deposits. Standard petrographic thin sections are prepared from representative rock samples and examined under polarizing microscopes to determine mineral composition, grain texture, cement types, porosity, and diagenetic features (Alam et al., 2024; Lai et al., 2017; Radwan, 2020). In the study of the Sidri Member in the Gulf of Suez Basin, 30 thin-

section samples representing the reservoir section of four wells were described in detail, and standard petrographic characteristics were determined (Radwan, 2020). The Barail sandstone study in Bangladesh involved the preparation of ten thin sections from eleven representative samples, which were investigated under a petrographic microscope to observe grain morphology, texture, grain types, and porosity (Alam et al., 2024).

Modal analysis through point counting is a widely employed quantitative petrographic technique. Various counting methods have been utilized, including the Gazzi-Dickinson method and the classic QFR method, as well as hybrid approaches combining both (Armas et al., 2014; Nugraha et al., 2023). In the study of the Seulimeum Formation, a total of 1000 points per thin section were counted using the hybrid-point counting method (Nugraha et al., 2023). The Anacleto Formation study employed 14 sandstone thin sections with the hybrid-point counting method combining the criteria of both the Gazzi-Dickinson and classic methods (Armas et al., 2014). For the Haymana Formation sandstones, sandstone petrography and mineral composition were determined through detailed thin-section analysis of 45 outcrop samples (Geçer et al., 2019).

Advanced Analytical Techniques

Beyond conventional optical microscopy, several advanced analytical techniques are commonly integrated with facies analysis and thin-section petrography. X-ray diffraction (XRD) analysis is frequently employed to determine bulk mineralogy and clay mineral composition (Khan et al., 2022; Lai et al., 2017; Zhang et al., 2023). Scanning electron microscopy (SEM) provides high-resolution imaging of grain surfaces, pore structures, clay mineral morphology, and diagenetic features (Qureshi et al., 2023; B. Zhang et al., 2023). In the study of the Tredian Formation in Pakistan, an integrated lithofacies, optical microscopy, and SEM analysis was used to investigate sedimentary processes, depositional architecture, and reservoir rock potential (Qureshi et al., 2023). Energy dispersive spectroscopy (EDS) and electron backscatter diffraction (EBSD) have also been employed for detailed mineral identification and characterization (B. Zhang et al., 2023).

QEMSCAN (Quantitative Evaluation of Minerals by Scanning Electron Microscopy) methodology, which uses both backscattered electron intensity and low-count energy dispersive X-ray analysis, has been applied in some studies for detailed mineralogical characterization (Counts & Amos, 2016). Geochemical analyses, including total organic carbon (TOC) measurements, stable isotope analyses, and X-ray fluorescence (XRF), are frequently combined with petrographic observations to provide comprehensive lithofacies characterization (Khan et al., 2022; Peng, 2020; B. Zhang et al., 2023).

Integrated Multi-Proxy Approaches

The most comprehensive studies of deep-water deposits employ integrated multi-proxy approaches that combine field sedimentology with multiple laboratory techniques. For instance, the study of the Cline Shale in the Midland Basin combined sedimentological, petrographic, and bulk geochemical analysis to define seven lithofacies (Peng, 2020). The investigation of the Patala Formation in Pakistan integrated sedimentological, petrographical, cathodoluminescence microscopy, XRD, TOC, total organic nitrogen, and stable isotope analyses to address the controls of lithofacies and diagenesis on shale-gas reservoir potential (Khan et al., 2022). The study of fine-grained sedimentary rocks in the Rio Muni Basin employed XRD, SEM, and thin-section analysis to determine mineralogical characteristics and establish lithofacies classifications (B. Zhang et al., 2023).

4. RESULTS AND DISCUSSION

Lithofacies Classification in Deep-Water Deposits

The literature reveals a diverse array of lithofacies types identified in deep-water depositional settings, reflecting the variety of sedimentary processes operative in these environments. Deep-water lithofacies are typically classified based on grain size, sedimentary structures, composition, bed geometry, and inferred depositional processes (Nugraha et al., 2023; Orme et al., 2020; Peng, 2020).

In the Upper Pennsylvanian Cline Shale of the Midland Basin, seven lithofacies were defined through combined sedimentological, petrographic, and geochemical analysis, stacking in repeated patterns to constitute composite cycle sets of approximately 8 to 20 m thickness (Peng, 2020). The lower units of each composite cycle set are characterized by basal siliciclastic-rich lithofacies interpreted to record dilute, low-density turbidity currents, potentially derived from hyperpycnal input, grading upward into carbonate-rich lithofacies interpreted as debris-flow deposits or pelagic suspension deposits (Peng, 2020). This study challenged the conventional model that deep-water fine-grained sedimentary rocks are dominantly background sedimentation, demonstrating the prevalence of sediment density flow deposits even in distal basin floor environments (Peng, 2020).

The Seulimeum Formation in Indonesia was characterized by eight lithofacies, including conglomerate, conglomeratic sandstone, thick-bedded sandstone, sandstone to mudstone heterolithics, slumped sandstone, siltstone, claystone, and sandy tuff, grouped into three facies associations representing inner fan, middle fan, and outer fan to basin plain deposits in a deep-water depositional setting (Nugraha et al., 2023). Similarly, the Gercus Formation in

NE-Iraq was composed of seven lithotypes shale/claystone, mudstone, sandstone, carbonate, conglomerate, breccias, and debris flow arranged in repeated cycles of mixed siliciclastic-carbonate turbidites in a range of gravity-flow regimes (Al-Mashaikie & Mohammed, 2017). These successions were grouped into four facies associations confirming marine depositional systems, including slump siliciclastic-calcliturbidites, proximal and distal siliciclastic-calcliturbidites, and slope siliciclastic turbidites (Al-Mashaikie & Mohammed, 2017).

In the Haymana Formation of Turkey, three distinct lithofacies (A, B, and C) were identified in submarine-fan sandstones based on analysis of lithology, texture, sedimentary structure, and petrography (Geçer et al., 2019). Lithofacies A sandstones exhibited medium-coarse grain sizes (0.4–0.6 mm), moderate-good sorting, and subrounded grains, while Lithofacies B sandstones exhibited fine grain sizes (0.2 mm), moderate sorting, and subrounded-subangular grains, and Lithofacies C sandstones exhibited very fine grain sizes (0.112 mm) representing non-reservoir facies (Geçer et al., 2019).

The Rongmawa Formation at Dênggar in southern Tibet, interpreted as a deep-marine trench basin setting, was characterized using a lithofacies scheme that documented massive sandstone interbedded with massive siltstone, red claystones containing radiolaria, and green siltstones, reflecting deposition by high-density turbidity currents and suspension settling (Orme et al., 2020). The Billy Springs Formation in South Australia, deposited in a deep-water slope or shelf setting, was characterized by convolute-laminated slump deposits, rhythmically-laminated silty mudstones, rare diamictites, and fining-upward turbidite lithofacies (Counts & Amos, 2016).

Petrographic Characteristics of Deep-Water Lithofacies

Thin-section petrography reveals critical information about the composition, texture, and diagenetic history of deep-water deposits that cannot be obtained from field observations alone. The petrographic analysis of deep-water sandstones typically focuses on framework grain composition (quartz, feldspar, lithic fragments), matrix content, cement types, and porosity characteristics (Geçer et al., 2019; Lai et al., 2017; Radwan, 2020).

In the Haymana Formation submarine-fan sandstones, petrographic analysis demonstrated that Lithofacies A had the best permeability (80–120 mD), related to large grain size, the presence of cross-bedding, small amounts of authigenic clays or cements in pore throats, and enlarged pore apertures (Geçer et al., 2019). In contrast, Lithofacies B sandstones contained variable yet small pore and pore-throat sizes affected by abundant pore-filling authigenic clays, small grain sizes, and no dissolution, with permeability ranging from 16 to 35 mD (Geçer et al., 2019). The Lithofacies A sandstones had large pore-throat sizes (mean =

2.06–3 μm) and high porosities (average 20–25%), while Lithofacies B sandstones had small median pore-throat sizes (mean = 1.52 μm) and low porosities (average 4–6%) (Geçer et al., 2019).

The petrographic analysis of the Sidri Member sandstones in the Gulf of Suez Basin indicated that the sandstone reservoir is fine- to medium-grained arkose with dominant siliceous cement, composed mainly of quartz, feldspars, and lithic fragments, with pores reflecting primary and secondary porosity as well as inter-granular pores (Radwan, 2020). This petrographic characterization, when coupled with gamma-ray log patterns, enabled the interpretation of depositional settings including tidal channel, mixed tidal flat, and low-relief offshore mudstone environments (Radwan, 2020).

In the Upper Triassic Xujiahe Formation of the Central Sichuan Basin, six lithofacies were identified on the basis of petrographic analyses: argillaceous sandstones, poorly sorted sandstones, quartz-cemented sandstones, carbonate-cemented sandstones, clay-mineral-cemented sandstones, and clean sandstones with abundant secondary porosity (Lai et al., 2017). The best reservoir-quality rocks had high percentages of detrital quartz but low percentages of matrix, quartz, and carbonate cement, demonstrating how differences in textural and compositional attributes of various lithofacies significantly affect porosity-depth trends (Lai et al., 2017).

The Tredian Formation study in Pakistan revealed that petrographic examination of sandstones indicated a lithology ranging from sub-feldspathic arenite to feldspathic arenite with moderate packing (Qureshi et al., 2023). The diagenetic investigation, supported by SEM studies, showed the presence of primary calcite cement, silica cement, and iron oxide/hydroxide cements, as well as secondary cements including ferroan-dolomite, chlorite, and illite linked with chemical alteration of unstable grains (Qureshi et al., 2023). The reservoir quality of certain lithofacies was destroyed by early-stage calcite cementation, while other lithofacies had strong reservoir potential owing to the scarcity of calcite cement, dissolution of unstable feldspar grains, and grain fracture (Qureshi et al., 2023).

Deep-Water Sedimentary Processes and Facies Associations

The integration of facies analysis and petrography has significantly advanced understanding of the diverse sedimentary processes operating in deep-water environments. Turbidity currents, debris flows, slumps, and pelagic/hemipelagic settling are the primary depositional mechanisms, each producing characteristic lithofacies signatures (Al-Mashaikie & Mohammed, 2017; Nugraha et al., 2023; Peng, 2020).

The Vischkuil Formation in the Karoo Basin of South Africa demonstrated that widespread zones of syn-sedimentary deformation in deep-water settings do not necessarily indicate a slope setting and should not be used as a single criterion to determine depositional setting (van Merwe, Hodgson, & Flint, 2009). The deformed intervals comprised a lower division of tight down-flow verging folds dissected by thrust planes interpreted as slides, overlain by an upper division of chaotic lithofacies with large contorted clasts of sandstone supported by a fine-grained matrix interpreted as debrites (van Merwe et al., 2009). This finding has important implications for the interpretation of deep-water facies, as it demonstrates that when associated with major debrites, such deformation features may develop on a flat basin floor (van Merwe et al., 2009).

The study of sandy debris-flow deposits in the Nanpu Sag of the Bohai Bay Basin provided indicators for identification of lacustrine sandstones of sandy debris-flow origin, including massive structures with upper and lower sharp contacts with interbedded mudrocks, lateral pinch-outs, locally imbricated to floating pebble-size grains, and elongated mudrock clasts (J. Zhang et al., 2022). These properties were attributed to deposition of non-Newtonian flows with sediment-support mechanisms of dispersive pressure, matrix strength, and buoyancy (J. Zhang et al., 2022).

The Punta Negra Formation in the Argentine Precordillera illustrated the challenges of distinguishing between deep-water turbidite deposits and storm-dominated prodelta inner-shelf systems, as their repetitive and monotonous interbedding of sandstone and mudstone and similar sedimentary structures can easily confuse sedimentological analysis (Basílici, Vieira Luca, & Poiré, 2012). Five lithofacies were distinguished according to grain size distribution, sedimentary structures, and geometry of beds, with 13 thin sections furnishing data on petrographical and textural characteristics (Basílici et al., 2012).

Role of Diagenesis in Modifying Deep-Water Lithofacies

Diagenetic processes play a crucial role in modifying the original depositional characteristics of deep-water sediments, and thin-section petrography is essential for documenting these modifications. The Patala Formation in Pakistan demonstrated that spatially variable eo-, meso-, and telo-diagenetic features such as compaction, cementation, stylolitization, dissolution, and re-precipitation are superimposed upon the depositional fabric, locally affecting reservoir quality (Khan et al., 2022). The organic-rich siliceous and carbonaceous mudstone lithofacies were considered the most prospective intervals, while calcareous and argillaceous mudstones were considered least promising in terms of reservoir quality (Khan et al., 2022).

In the Xujiahe Formation tight gas sandstones, loss of depositional porosity was greater due to compaction than to cementation (Lai et al., 2017). Eodiagenesis included mechanical compaction, precipitation of early calcite cements, kaolinite, and smectite, and leaching of feldspars by meteoric water, while mesodiagenesis consisted of compaction, framework grain dissolution, and subsequent precipitation of illite, quartz, and late carbonate cements (Lai et al., 2017). The diagenetic evolution pathways and reservoir-quality prediction models of various lithofacies were reconstructed by integrated petrographic data, providing insights into how detrital composition and texture influence diagenesis and reservoir quality evolution (Lai et al., 2017).

The Pandua Formation shale study in Southeast Sulawesi demonstrated the utility of combining megascopic and petrographic analysis for lithofacies determination, identifying 11 lithofacies based on clay content, sedimentary structure variations, and mineral composition (Ramli et al., 2021). The lithofacies with high concentrations of TOC were carbon-rich massive siltstone and carbon-rich laminated siltstone, both categorized as potentially excellent source rock with TOC values of 5.78% and 5.74%, respectively (Ramli et al., 2021).

Implications for Reservoir Characterization and Hydrocarbon Exploration

The combined application of facies analysis and thin-section petrography has direct implications for reservoir characterization and hydrocarbon exploration in deep-water settings. The Haymana Formation study concluded that the proximal sandstones of the submarine-fan complex may contain high-potential reservoirs, with Lithofacies A sandstones showing good reservoir characterization based on their large grain size, presence of cross-bedding, and minimal authigenic clay content (Geçer et al., 2019). In contrast, Lithofacies B sandstones were not suitable as diagenetic traps for hydrocarbon exploration due to their small pore-throat sizes and low porosities (Geçer et al., 2019).

The fine-grained sedimentary rocks of the Rio Muni Basin in West Africa were characterized through XRD, SEM, and thin-section analysis, allowing recognition of three distinct lithofacies: siliceous-clayey rock, terrigenous clastic mixed fine-grained rock, and lime-mixed fine-grained rock (B. Zhang et al., 2023). Based on the evolutionary history and lithofacies characteristics, depositional models for organic-rich fine-grained sedimentary rocks were reconstructed, with the Albian stage model being "continental margin–restricted sea–marine algae–source rocks" and the Cenomanian–Turonian stage model being "continental margin–semiopen sea–mixed-source rocks" (B. Zhang et al., 2023).

The Barail sandstone study demonstrated that the average porosity of sandstones was 16.9%, with pore spaces of both primary and secondary origin that were mostly interconnected (Alam et al., 2024). Both the depositional process and diagenesis influenced the porosity, with porosity distribution in fluvial multistory channel-fill deposits being less heterogeneous compared to tidal-influenced channel-fill deposits (Alam et al., 2024). The petrographic analysis showed that these sandstones were mostly litharenite in type, derived from quartzose recycled orogens (Alam et al., 2024).

The Kockatea Shale study in the Perth Basin demonstrated how lithofacies identification through thin-section petrography and XRD analysis could support shale-gas potential assessment (Dargahi & Rezaee, 2013). Seven lithofacies were identified in a continuous 35 m core, with the greatest amounts of TOC existing in the fossiliferous mudstone and pyritic mudstone lithofacies (Dargahi & Rezaee, 2013). The study undertook petrographical and mineralogical analysis of the lithofacies with respect to the general depositional environment, which was generally a quiet environment of deposition with reduced circulation (Dargahi & Rezaee, 2013).

Challenges and Limitations

Despite the demonstrated utility of facies analysis and thin-section petrography, several challenges persist in the characterization of deep-water deposits. The fine-grained nature of many deep-water sediments makes detailed petrographic analysis more challenging than for coarser-grained deposits (Peng, 2020; Ramli et al., 2021). The distinction between different types of gravity flow deposits (turbidites, debrites, slumps) can be ambiguous, particularly when sedimentary structures are similar (Basilici et al., 2012; van Merwe et al., 2009). Furthermore, diagenetic overprinting can obscure primary depositional textures and compositions, complicating the interpretation of original depositional processes (Khan et al., 2022; Lai et al., 2017).

The classification of shale lithofacies presents particular challenges due to rapid lithology change, complex mineral composition, and laminae development (Zhou et al., 2023). Previous research has proposed various lithofacies classification schemes for shale, but when the content of each mineral component or grain size is less than 50%, classification by commonly used schemes based on mineral composition or grain size becomes difficult (Zhou et al., 2023). Currently, shale lithofacies are classified using a combination of sedimentary structure and lithology, with sedimentary structures frequently determined through core observation and thin-section identification (Zhou et al., 2023).

The study of the Montney Formation in Canada demonstrated that the relationship between porosity and lamination can be used to estimate reservoir properties, but reservoir quality is not solely dependent on lamination because of the complex interaction between components (Woo, Lee, Ozyer, & Rhee, 2021). Thin-section images were used to verify grain and porosity shapes, with porosity identification enhanced by pink epoxy infilling of intergranular spaces (Woo et al., 2021).

5. CONCLUSIONS AND SUGGESTIONS

This literature review demonstrates that facies analysis and thin-section petrography are indispensable and complementary tools for determining the lithological characteristics of deep-water deposits. The integration of these approaches enables comprehensive characterization of deep-water sedimentary systems from the macroscopic to microscopic scale.

Facies analysis provides the framework for identifying and classifying the diverse lithofacies present in deep-water settings, including turbidites, debrites, slump deposits, hemipelagites, and pelagic sediments. The systematic documentation of lithology, sedimentary structures, bed geometry, and vertical/lateral facies relationships enables the reconstruction of depositional environments and the identification of sedimentary processes. Thin-section petrography complements field-based observations by revealing the mineral composition, grain texture, diagenetic features, and porosity characteristics that are critical for understanding provenance, diagenetic history, and reservoir quality.

The reviewed literature highlights several key findings. First, deep-water deposits exhibit a wide range of lithofacies types that reflect the diversity of sedimentary processes operating in these environments, from high-density turbidity currents to dilute low-density flows and pelagic suspension settling. Second, petrographic characteristics such as grain size, sorting, cement type, and pore-throat size exert fundamental controls on reservoir quality, with significant variations observed among different lithofacies within the same formation. Third, diagenetic processes can substantially modify the original depositional characteristics of deep-water sediments, and understanding these modifications requires detailed petrographic analysis. Fourth, the integration of facies analysis and petrography with advanced analytical techniques such as XRD, SEM, and geochemical analysis provides the most comprehensive characterization of deep-water lithofacies.

Future research should continue to refine lithofacies classification schemes for fine-grained deep-water deposits, develop more robust criteria for distinguishing between different gravity flow deposit types, and integrate emerging analytical techniques with traditional facies analysis and petrography. The continued advancement of these methodological approaches will enhance our ability to characterize deep-water depositional systems, predict reservoir quality, and support hydrocarbon exploration in increasingly challenging geological settings.

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