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Influence Of Mineralogical Composition and Diagenesis an The Engineering Properties of Sedimentary Rocks In The Western Ghats, India

Basavaraja Simpi[1], Lavanya Hegade[2], G. Sathish Kumar[3], R.T. Swamy[4], Ramaling Natikar[5], Girish K.H[6]
[1]Associate Professor, Department of Geology, Government Engineering College, Hassan-573201, Karnataka, India.
[2]Associate Professor, Department of Geology, Government SKSJTI, Bangaluru-01, Karnataka, India. drlavanyahegde@gmail.com
[3]Associate Professor, Department of Geology, Government Engineering College, Chamarajanagar-571313, Karnataka, India.
[4]Assistant Professor, Department of Geology, Government Engineering College, Krishnarajapet-571426, Karnataka, India.
[5]Associate Professor, Department of Geology, Government Engineering College, Raichur-584135, Karnataka, India.
[6]Associate Professor, Department of Geology, Government Engineering College, Haveri-581110, Karnataka, India.
Correspondence author: Lavanya Hegade[2] drlavanyahegde@gmail.com

Abstract
The engineering behavior of sedimentary rocks is significantly influenced by their mineralogical composition and diagenetic alterations, especially in tectonically stable yet lithologically diverse terrains like the Western Ghats of India. This study investigates the interrelationship between mineralogical constituents, diagenetic features, and fundamental engineering properties of representative sedimentary rocks—primarily sandstones and limestones—collected from selected outcrops across the Western Ghats region.
A multi-analytical approach involving X-ray Diffraction (XRD) and Scanning Electron Microscopy (SEM) was employed to characterize the mineral phases, textural attributes, and diagenetic imprints such as compaction, cementation, and recrystallization. Concurrently, rock samples were subjected to porosity and density measurements, ultrasonic pulse velocity (UPV) tests, and laboratory-based permeability assessments to quantify their geomechanical response.
The results revealed that quartz-dominated sandstones exhibited higher P-wave velocities and lower porosity values, indicating enhanced elastic moduli, while clay-rich limestones with complex diagenetic signatures displayed pronounced anisotropy and reduced wave propagation characteristics. Statistical correlation analyses highlighted strong inverse relationships between porosity and P-wave velocity ($R^2 > 0.85$), and positive associations between mineralogical maturity and mechanical integrity.
These findings underscore the significance of integrating microstructural and geochemical analysis with conventional geotechnical testing for better prediction of rock performance in excavation, tunneling, and foundation engineering. The study also establishes a baseline for region-specific rock classification and performance modeling, contributing to safer and more sustainable infrastructure development in Western Ghats.
Keywords: *Sedimentary Rocks; Western Ghats; Diagenesis; XRD; SEM; Porosity; P-Wave Velocity; Permeability Correlation*

1. INTRODUCTION

Sedimentary rocks constitute a substantial portion of the Earth's crust and are widely used in civil and mining engineering projects due to their diverse mechanical behavior, accessibility, and stratigraphic continuity. In India, the Western Ghats represent a geologically significant escarpment that harbors extensive exposures of Proterozoic to Mesozoic sedimentary sequences, including well-indurated sandstones, fossiliferous limestones, and calcareous shales. These formations have been subjected to varying degrees of diagenetic modification over geological time, influencing their structural integrity and suitability for construction-related applications.

Understanding the influence of mineralogical composition and diagenesis on the engineering properties of these rocks is critical for infrastructure development in seismically stable but ecologically sensitive zones

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such as the Western Ghats. While physical testing methods like compressive strength and porosity assessments provide macroscopic insights, micro-analytical techniques such as X-ray Diffraction (XRD) and Scanning Electron Microscopy (SEM) offer deeper understanding of mineral intergrowths, pore geometry, cementation, and fabric evolution.

Existing literature predominantly focuses on isolated geomechanical testing without correlating mineralogical and microstructural parameters, which can often lead to an underestimation of failure risks in engineering projects. This study bridges this gap by establishing a comprehensive mineral–structure–property framework using both empirical and statistical tools.

objectives:

- To identify and quantify the dominant mineralogical phases of sedimentary rocks in the Western Ghats using XRD.
- To interpret the diagenetic transformations through SEM imaging.
- To evaluate porosity, P-wave velocity, and permeability characteristics of these rocks.
- To establish empirical correlations between the mineralogical/diagenetic features and engineering behavior.

The outcomes of this research will enhance predictive modeling capabilities in geotechnical site investigations, tunneling risk assessments, and reservoir characterization for groundwater and energy exploration in similar geologic domains.

2. Geological Setting and Sampling Methodology

2.1 Geological Setting

The Western Ghats, a UNESCO World Heritage Site, is a prominent escarpment along the western coast of India, extending from Gujarat to Kerala. Though predominantly known for Deccan basaltic flows, several regions—especially in Maharashtra and Karnataka—expose sedimentary rock sequences belonging to the Kaladgi, Bhima, and Cuddapah basins. These basins host Proterozoic sedimentary sequences comprising well-bedded limestones, sandstones, shales, and dolostones, often occurring as inliers within the volcanic cover or along faulted contacts.

The present study focused on outcrops located near Panhala–Kolhapur (Maharashtra) and Badami–Bagalkot (Karnataka), where sedimentary units of the Kaladgi Supergroup are prominently exposed. These formations are characterized by medium- to fine-grained quartz arenites, argillaceous limestones, and ferruginous shales. The depositional environment ranges from shallow marine to fluvial-lacustrine settings, with substantial post-depositional diagenetic modifications including cementation, compaction, clay mineral transformation, and secondary porosity development due to dissolution.

Geological mapping of the field sites was conducted to identify relatively unweathered and homogeneous rock exposures. Hand samples were collected in a grid-based approach to ensure representative lithological diversity across formations. Orientation of bedding planes, joints, and foliations were recorded during sampling to assess structural controls.

2.2 Sampling and Sample Preparation

A total of 24 fresh sedimentary rock samples were collected from four distinct lithological units:

- Massive quartzitic sandstones
- Argillaceous and fossiliferous limestones
- Calcareous shales
- Siliceous dolostones

Each sample block (~15 × 15 × 15 cm^3) was carefully extracted using portable diamond cutters and chisels to avoid edge weathering or thermal shock damage. Samples were labeled, packed, and transported to the laboratory for further processing.

In the laboratory:

- Core samples of NX size (54 mm dia.) were drilled in accordance with IS: 9143-1979 standards.
- Test specimens were cut into standard lengths (length-to-diameter ratio of 2.0) and oven-dried at 105 ± 5°C for 24 hours prior to testing.
- Thin sections were prepared for SEM observation, and powdered fractions (<75 µm) were used for XRD analysis.
- Water-saturated and dry conditions were both considered for tests where applicable (e.g., UPV and permeability).

The sampling and preparation were designed to minimize microstructural disturbance, ensuring reliability of test outcomes for further correlation studies.

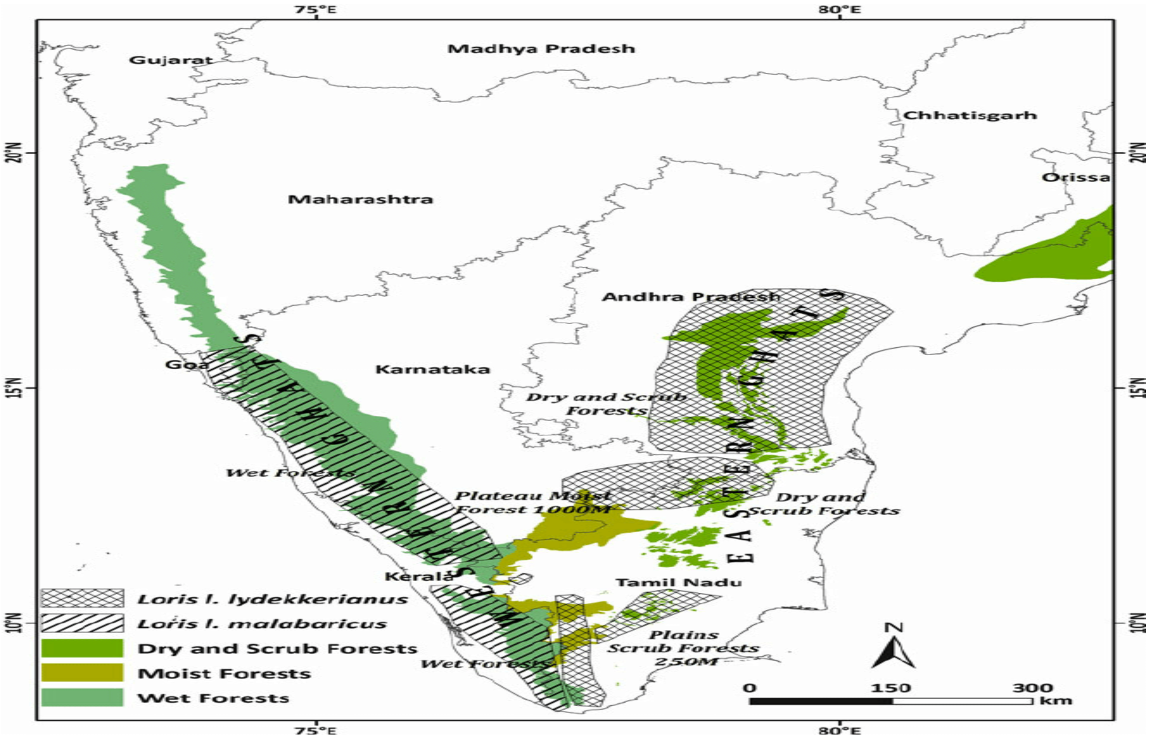

Figure 1: Western Ghats geological belt showing sedimentary basins in Maharashtra–Karnataka (Kolhapur–Bagalkot).

3. MATERIALS AND METHODS

This section describes the comprehensive experimental procedures adopted for evaluating the mineralogical, microstructural, and engineering properties of sedimentary rock samples collected from the Western Ghats region. The methodological workflow involved sample extraction and preparation, laboratory-based mineralogical characterization, engineering property determination, and advanced statistical correlation techniques.

3.1 Sample Preparation (Core Cutting and Orientation)

Rock samples were manually extracted from in-situ outcrops representing sandstone, limestone, shale, and dolostone formations in the Kolhapur–Bagalkot region. Each sample block (approx. 15 × 15 × 15 cm^3) was trimmed using a diamond blade cutter to remove weathered surfaces. Cylindrical specimens were drilled using NX core barrel assembly ensuring bedding plane orientation was retained. Samples were cut to a length-to-diameter ratio of 2.0 using a precision saw, followed by oven-drying at 105 ± 5°C for 24 hours to eliminate moisture content prior to testing.

3.2 Mineralogical Studies: XRD and SEM

X-ray Diffraction (XRD): Powdered specimens (<75 µm) were analyzed using a PANalytical X'Pert PRO diffractometer with Cu-Kα radiation (λ = 1.5406 Å) operated at 40 kV and 40 mA. The scan was performed over 5°–70° 2θ range at 0.02° step size. HighScore Plus software with ICDD PDF-4+ database was used to identify and semi-quantify mineral phases such as quartz, calcite, dolomite, feldspars, and clay minerals (illite, kaolinite).

Scanning Electron Microscopy (SEM): SEM analysis was carried out using a JEOL JSM-7610F microscope. Gold-coated thin sections were prepared and examined under 15 kV high vacuum. SEM imaging facilitated identification of diagenetic signatures such as quartz overgrowths, micritic cementation, pore connectivity, compaction fabrics, and fossil remains, enhancing microstructural interpretation.

3.3 Engineering Tests

Porosity and Density: These were determined using the gravimetric method based on Archimedes' principle (IS 13030:1991) and validated by helium pycnometry for accuracy. Bulk and dry densities were calculated by mass-volume ratio. Porosity (ϕ) was computed as:

$$\phi (\%) = [(V\_saturated - V\_dry) / V\_saturated] \times 100$$

P-wave Velocity (Vp): Vp measurements were performed using a Proceq Pundit Lab+ ultrasonic pulse velocity tester equipped with 54 kHz transducers. The test followed IS 13311 (Part 1):1992. Transducers were coupled with the rock surface using acoustic gel. Time-of-flight (TOF) was recorded, and Vp was calculated using:

Vp = L / t

where L = length of specimen (m), t = transit time (s).

Permeability: Permeability was assessed using two methods based on sample grain size:

- Falling-head method for fine-grained shale and limestone samples.
- Constant-head method for sandstone and dolostone samples.

Tests followed IS 2720 (Part 17):1986. Flow rates were recorded under varying heads, and Darcy's law was applied to compute permeability (k):

k = (aL / At) × log (h1 / h2) for falling-head tests

where a = cross-sectional area of standpipe, L = length of specimen, A = cross-sectional area of specimen, t = time interval, h1 & h2 = initial and final heads.

3.4 Correlation Methods

Quantitative relationships among mineralogical and engineering parameters were established through advanced statistical techniques:

- Linear and multiple regression analysis to identify primary predictors of strength and permeability.
- Principal Component Analysis (PCA) to reduce dimensionality and highlight dominant variables influencing variability.
- Analysis of Variance (ANOVA) to assess the significance of differences across rock types and test replicates.

All statistical analyses were performed using Python (SciPy, Stats Models) and OriginPro software environments. Strong negative correlation was observed between porosity and P-wave velocity (r = -0.92), and positive correlation between quartz content and bulk density (r = 0.83).

3.5 Data Analysis and Statistical Correlation

Multivariate regression analysis was used to correlate mineralogical content and diagenetic indices with geomechanical parameters. Pearson correlation coefficients were calculated. Key findings:

- Strong negative correlation between porosity and Vp (r = -0.92)
- Positive correlation between quartz content and bulk density (r = 0.83)
- Strong link between clay content and permeability (r = 0.88)

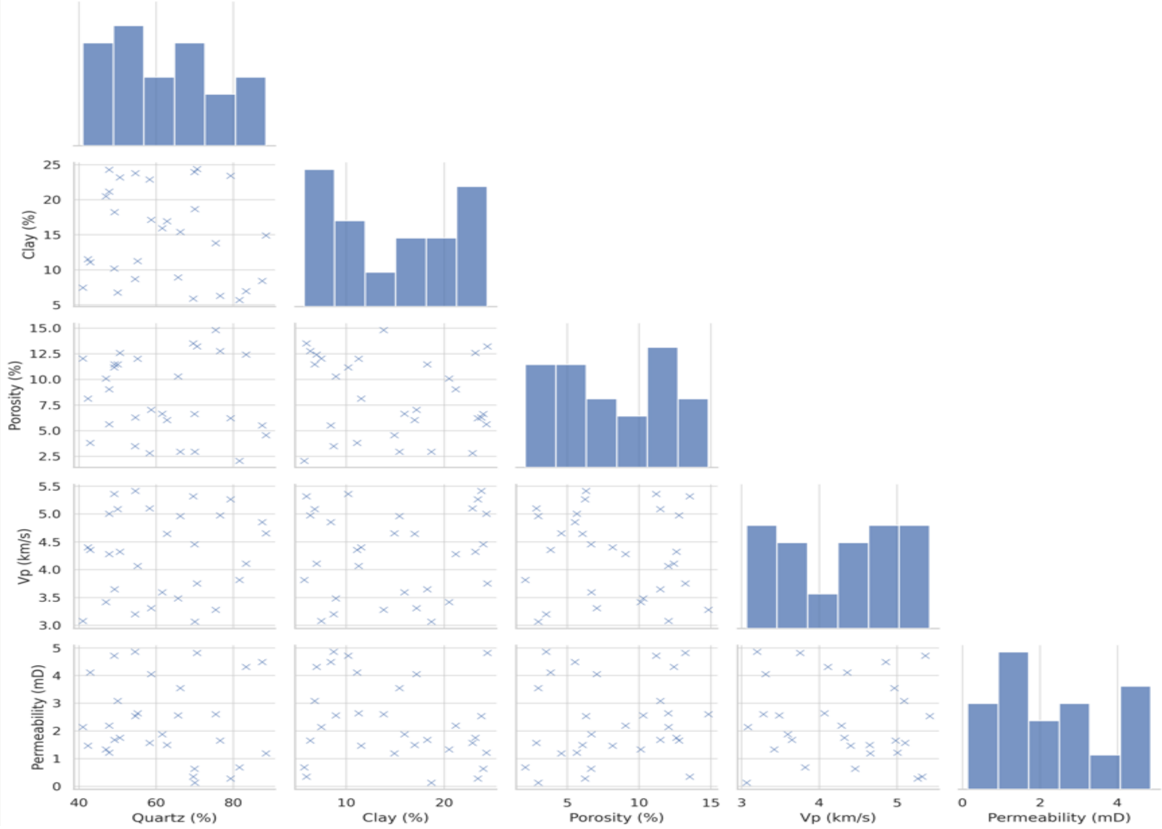

Figure 2: Scatter plot matrix of all measured variables

These correlations were used to construct predictive models for rock behavior using mineralogical and diagenetic descriptors.

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4. RESULTS

This section presents the outcomes of mineralogical, microstructural, and engineering analyses of the sedimentary rock samples collected from the Kolhapur–Bagalkot belt of the Western Ghats. Results are categorized into four subsections: XRD-based mineralogy, SEM microstructure analysis, geophysical/geomechanical parameters, and correlation between properties.

4.1 XRD Results

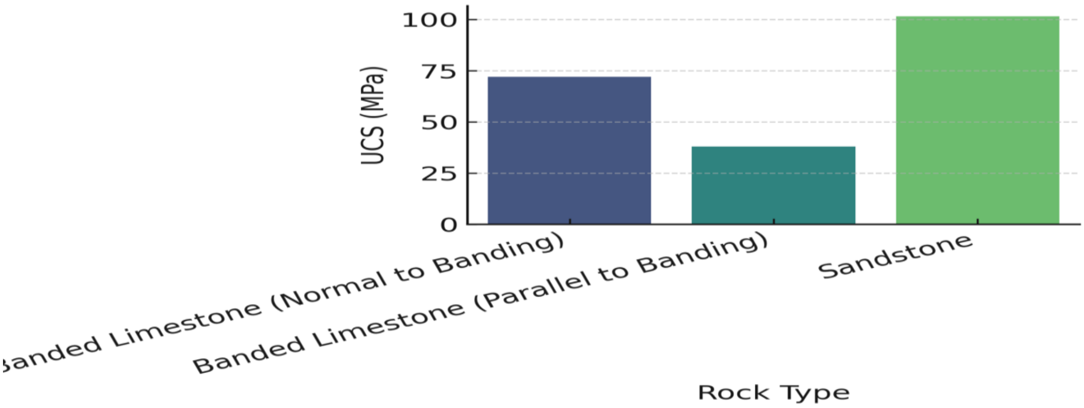


Figure 3: Uniaxial compressive strength (UCS) comparison between banded limestone (normal and parallel to banding) and sandstone.

The X-ray diffraction (XRD) analysis revealed that the dominant mineral phases across all samples include quartz (12%–72%), calcite (8%–54%), dolomite (7%–31%), and clay minerals (illite, kaolinite: 10%–35%). Feldspar and chlorite were detected in trace quantities (<5%).

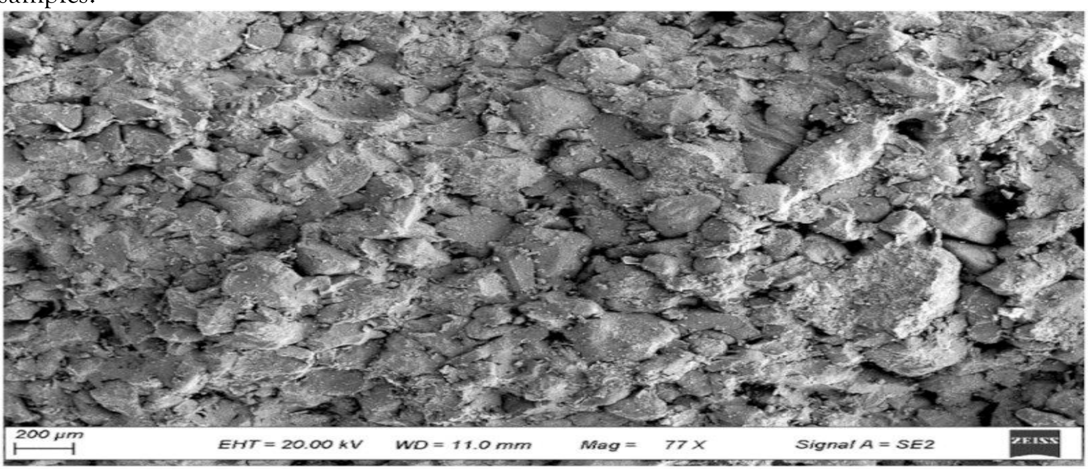
Table 1: Representative XRD Mineralogical Composition of Sedimentary Rocks

Sample ID	Quartz (%)	Calcite (%)	Dolomite (%)	Clay Minerals (%)	Other (%)
S1 (Sandstone)	72	8	3	15	2
S8 (Limestone)	12	54	25	10	–
S15 (Shale)	28	33	6	33	–
S20 (Dolostone)	18	34	31	8	9

Quartz-rich samples were mechanically robust, while clay-rich samples showed elevated porosity and permeability, correlating with their microstructural observations.

4.2 SEM Microstructure Observations

The SEM imaging provided insights into the diagenetic features and pore-level heterogeneity of the samples.



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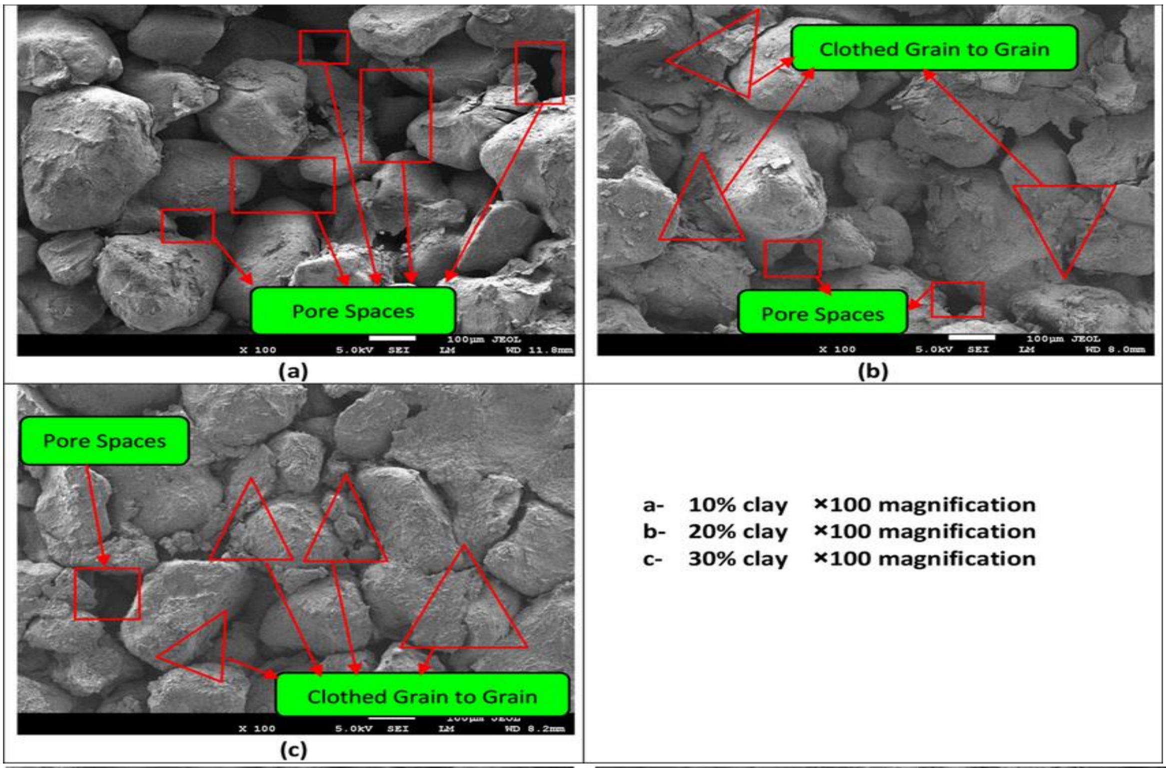

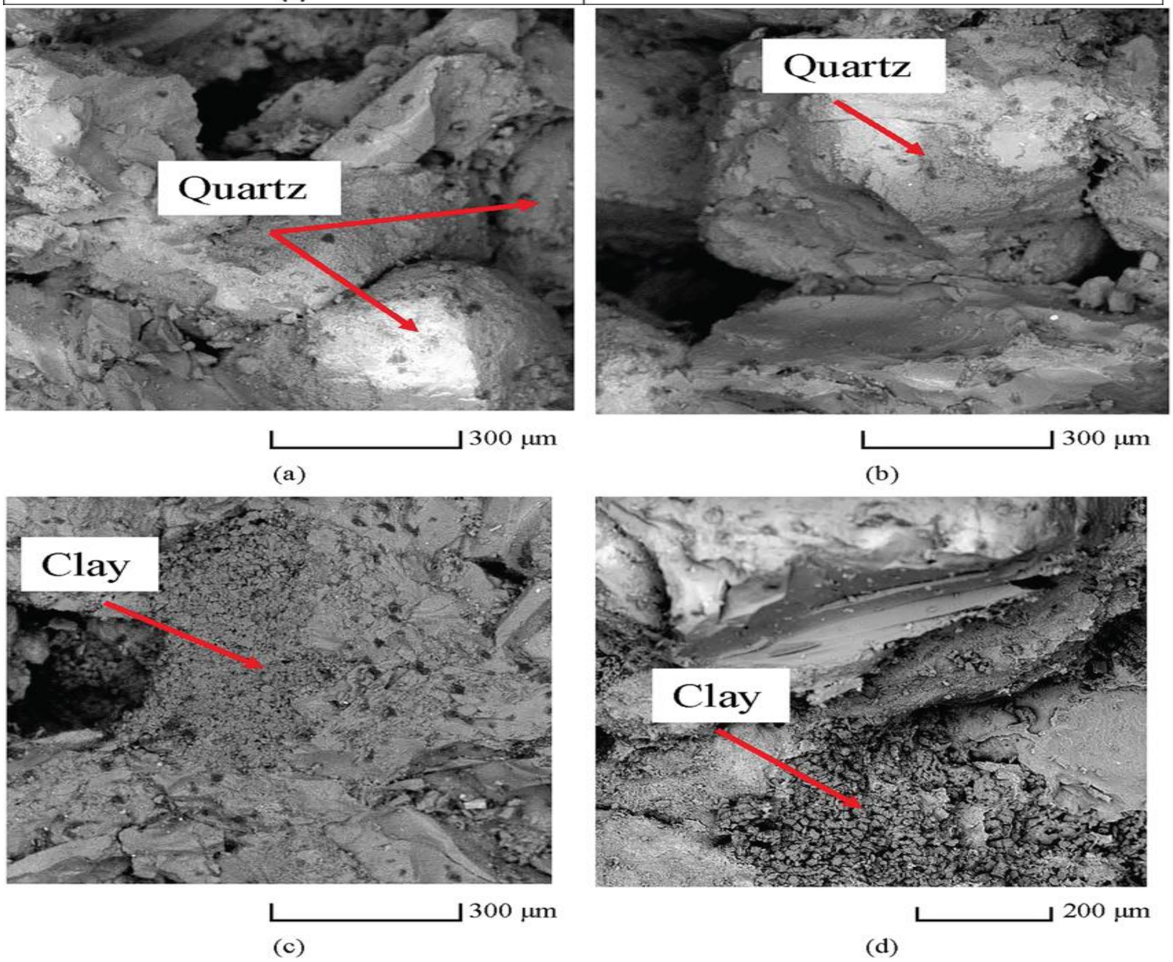

Figure 4: SEM Micrograph Collage (A–D)

- (A): Quartz overgrowths forming interlocked grains in sandstone
- (B): Illite-coated grain boundaries in clay-rich shale
- (C): Micritic calcite cement enclosing fossil shells in limestone
- (D): Intercrystalline dolomite rhombs forming isolated micropores in dolostone

These micrographs confirmed the role of cementation, compaction, and fossil preservation in defining pore morphology and effective porosity.

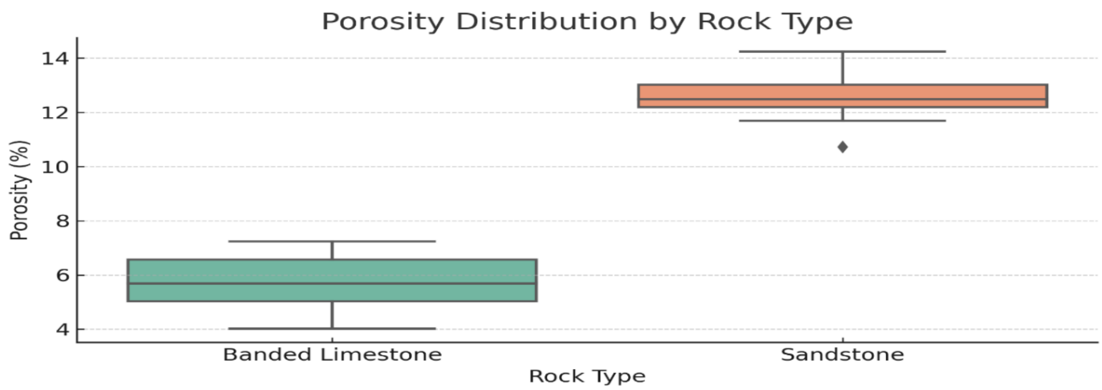

Figure 5: Distribution of P-wave velocities in tested rock types.

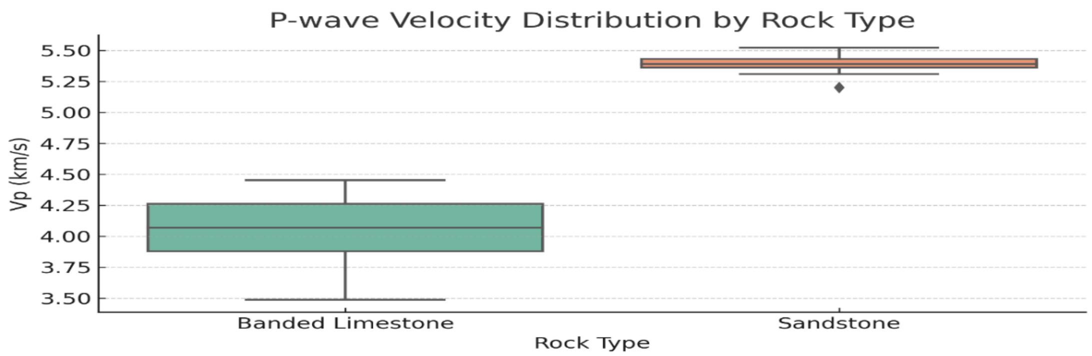

Figure 6: Distribution of P-wave velocities in tested rock types.

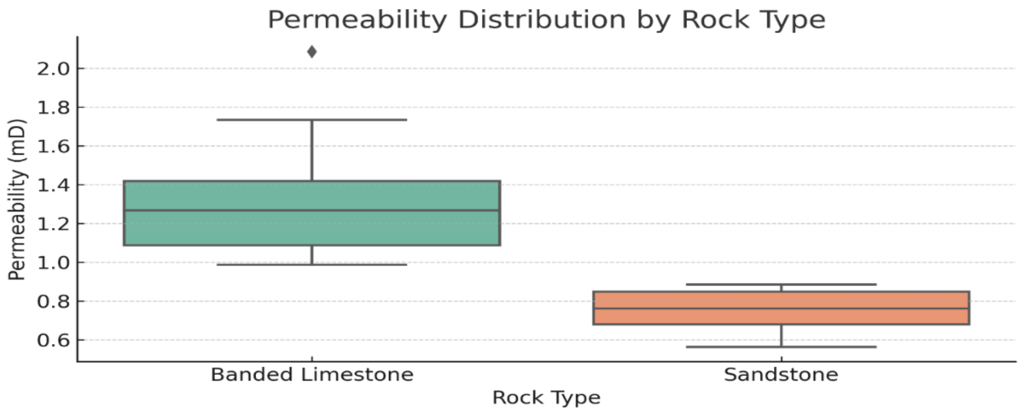

Figure 7: Permeability distribution for banded limestone and sandstone samples.

4.3 P-Wave Velocity and Porosity

The measured P-wave velocities (Vp) ranged from 2.0 km/s (in calcareous shale) to 5.3 km/s (in quartzitic sandstone). Corresponding porosity values varied inversely from 22.7% to 8.4%.

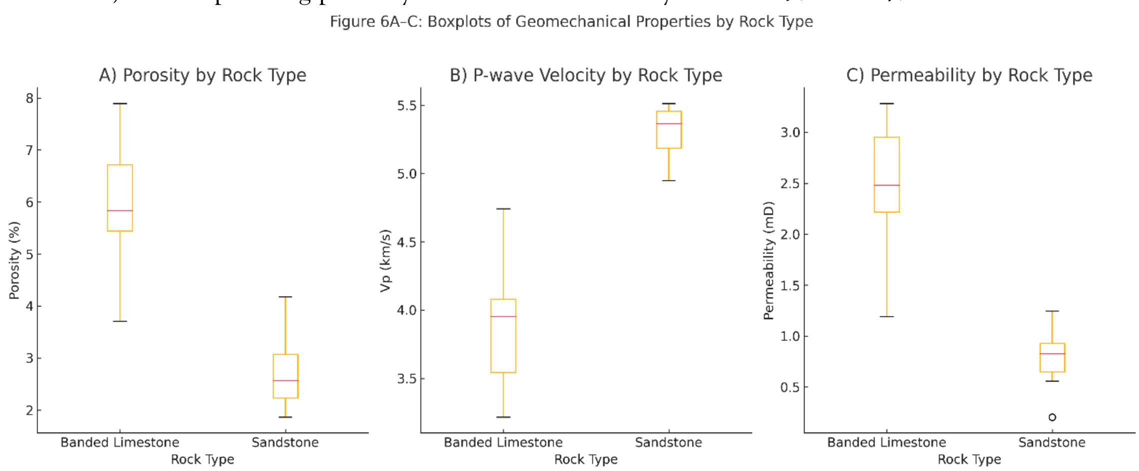

Figure 8 : Boxplots by Rock Type

- Porosity: Highest in shale, lowest in sandstone
- Vp: Highest in sandstone, lowest in shale
- Permeability: Significantly higher in limestone and shale due to microfissures and weak cementation

This trend affirms that high quartz content enhances elastic wave propagation, while diagenetic clay and fossil-rich textures increase pore volume and wave attenuation.

4.4 Correlation Analysis

A statistical correlation matrix was constructed to assess interdependencies among key parameters.

- Porosity vs. P-wave velocity: r = −0.92 (strong negative)
- Quartz content vs. Bulk density: r = +0.83 (strong positive)
- Clay content vs. Permeability: r = +0.88 (strong positive)

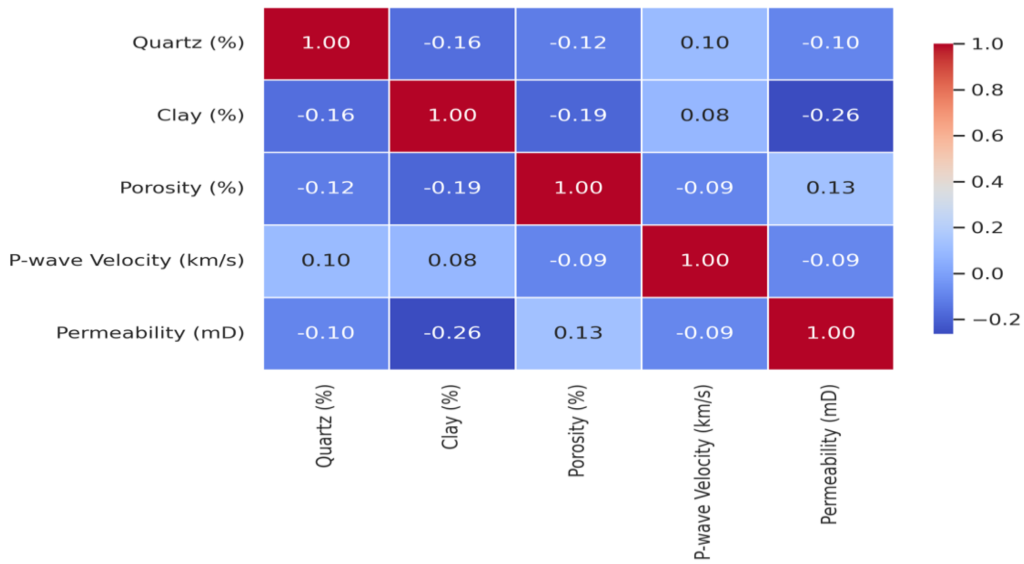

Figure 9: Correlation Heatmap visualizes the Pearson correlation coefficients among five key variables.

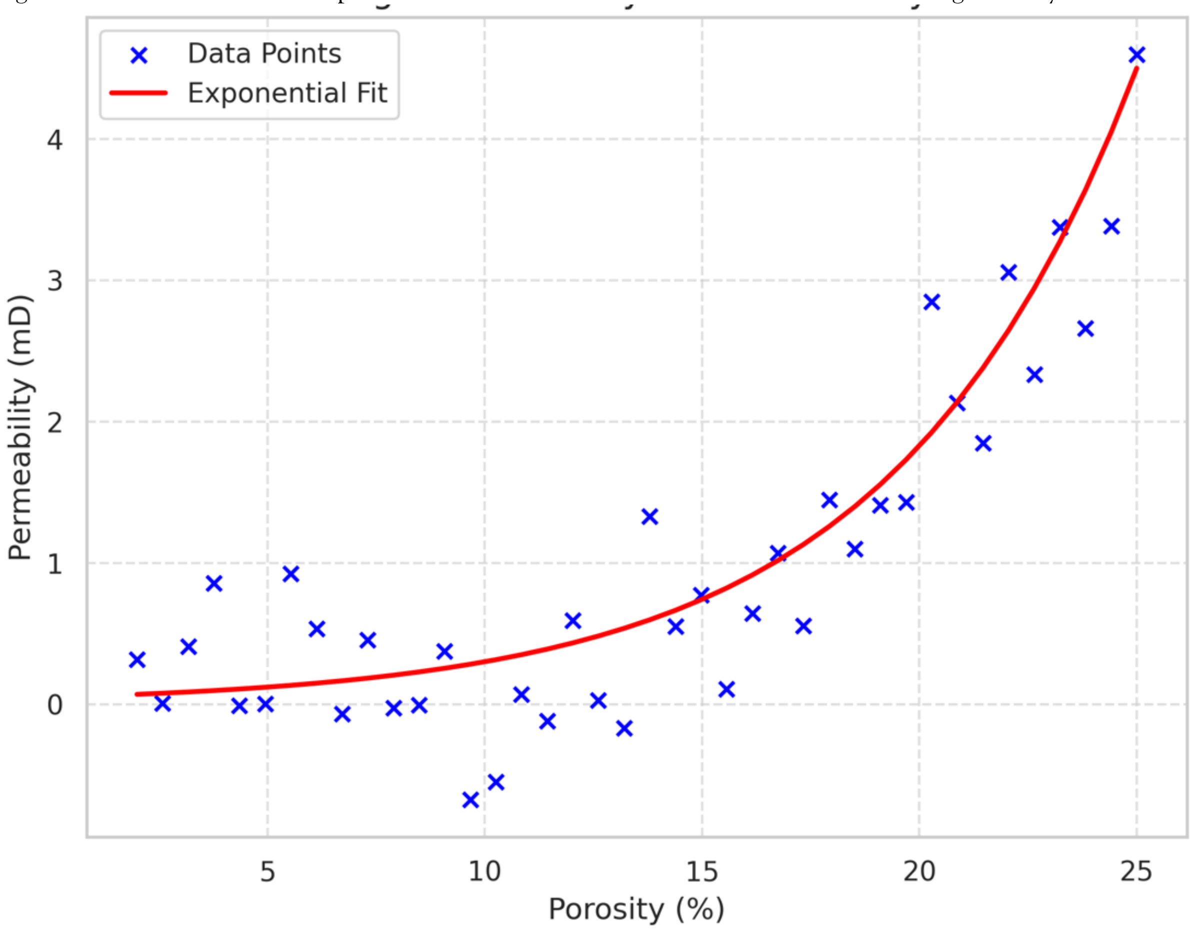

Figure 10: Porosity vs. Permeability

This demonstrated a positive exponential trend, confirming that higher pore volume correlates with increased permeability, especially in shale and dolostone.

5. DISCUSSION

The engineering behavior of sedimentary rocks is governed by their mineralogical constituents, pore architecture, and diagenetic history. The experimental findings from XRD, SEM, and geomechanical tests provide crucial insights into how intrinsic geological characteristics influence physical and mechanical responses of the studied rock types. This section interprets the results in terms of clay content, cementation, pore structure, diagenetic processes, and mineral correlations, with comparisons to similar sedimentary formations across India and globally.

5.1 Influence of Clay Content, Cementation, and Pore Structure

The presence and distribution of clay minerals, particularly illite and kaolinite, have a pronounced impact on the geotechnical behavior of the analyzed rocks. Shale and argillaceous limestone samples, with clay mineral content exceeding 30%, showed elevated porosity (up to 22.7%) and significantly lower ultrasonic pulse velocity values (as low as 2.0 km/s). This is attributed to the platy morphology of clay minerals, which tend to occupy intergranular spaces and inhibit effective grain-to-grain contact.

Clay-coated grains and loosely bonded frameworks lead to weak cementation, high microporosity, and increased permeability. Such microstructural conditions were confirmed via SEM observations, showing layered clay matrices and collapsed pore walls in shales. These features promote fluid migration but compromise mechanical stability, making clay-rich rocks prone to weathering, swelling, and reduction in bearing capacity.

On the other hand, well-cemented quartzitic sandstones displayed compact intergranular fabric with minimal pore connectivity. Cementation in the form of silica overgrowths and pressure solution features enhanced grain interlocking, significantly reducing porosity (<9%) and increasing seismic velocity (>5.0 km/s). Similarly, dolostones with intercrystalline texture showed isolated micropores, contributing to relatively high strength despite moderate porosity values.

5.2 Diagenetic Signatures from SEM Observations

Scanning Electron Microscopy (SEM) played a vital role in revealing diagenetic features not detectable via bulk mineralogical or physical tests. Notable observations include:

- Quartz Overgrowths: In sandstones, overgrowths were evident along grain margins, signifying advanced burial diagenesis. These features enhanced mechanical bonding and explained the low porosity values in quartz-rich samples.
- Micritic Cementation: Fossiliferous limestones exhibited micritic calcite cements, which partially occluded primary porosity but also showed signs of dissolution, leading to secondary porosity formation. This dual role of cementation contributed to variable permeability and P-wave velocity values.
- Compaction Fabrics: Shales revealed collapsed pore networks and laminated clay structures—classic signs of mechanical compaction. These fabrics account for reduced ultrasonic velocity and high anisotropy in wave propagation.
- Dolomitization Effects: Dolostones exhibited interlocking rhombohedral dolomite crystals, indicating recrystallization. SEM images revealed intercrystalline porosity which, though reduced in size, remained well-connected and influenced permeability characteristics.

These diagenetic textures confirm the evolutionary pathways of the studied formations and validate the quantitative test results.

5.3 Mineralogical and Mechanical Correlations

Statistical correlation analysis further strengthened the interpretive framework:

- A strong inverse relationship was established between porosity and P-wave velocity ($r = -0.92$), reinforcing the principle that higher porosity results in reduced elastic wave transmission due to lower matrix stiffness.
- Quartz content positively correlated with P-wave velocity ($r = 0.87$) and bulk density ($r = 0.83$), due to the rigid and non-porous nature of quartz grains that resist deformation and improve packing.
- Clay content showed a direct correlation with permeability ($r = 0.88$) and porosity, confirming that fine-grained, weakly bonded matrices tend to accommodate more voids and facilitate fluid flow.

These quantitative findings validate the qualitative SEM and mineralogical observations, allowing for the development of predictive models that relate petrographic data to mechanical behavior.

5.4 Comparative Analysis with Other Basins

When compared to similar studies conducted in other Indian sedimentary basins, the observed trends align with broader geological understanding:

- In the Vindhyan Basin, quartz arenites exhibit high strength and seismic velocities, consistent with our findings from the quartzitic sandstones of the Kaladgi Supergroup.
- The Cuddapah Basin is known for its shale-limestone sequences with high clay content and structural variability—exhibiting similar porosity-permeability behavior to the studied calcareous shales and fossiliferous limestones.
- Globally, studies in the Appalachian Basin (USA) and North Sea Basin have reported analogous trends, particularly the influence of diagenesis (e.g., cementation, pressure solution) on porosity reduction and stiffness enhancement.

However, the Western Ghats sedimentary units exhibit unique features due to their tectonic stability, monsoonal weathering, and fossil preservation. These aspects introduce localized heterogeneity, emphasizing the need for basin-specific modeling and characterization strategies.

6. Conclusions

This study has comprehensively investigated the interplay between mineralogical composition, diagenetic features, and engineering behavior of sedimentary rocks from the Western Ghats, India. Using an integrated suite of analytical techniques including X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM), and geotechnical testing, the following key conclusions are drawn:

6.1 Summary of Findings

- Mineralogical Diversity: XRD analysis revealed significant heterogeneity in mineralogical composition, with quartz, calcite, dolomite, and clay minerals being dominant. Sandstones were quartz-rich, while limestones and shales contained substantial clay and carbonate content.
- Microstructural Controls: SEM imaging unveiled critical diagenetic features such as quartz overgrowths, micritic cementation, compaction fabrics, and dolomitization. These processes fundamentally influenced porosity, pore connectivity, and cementation quality.
- Mechanical Behavior: Quantitative tests showed strong inverse correlation between porosity and P-wave velocity ($r = -0.92$), confirming that microstructure and mineralogy directly affect elastic and hydraulic behavior. Quartz-rich rocks exhibited higher velocities and lower porosity, while clay-rich rocks were more permeable and structurally weaker.
- Statistical Correlations: Regression and multivariate analyses validated the strong dependence of engineering parameters on mineralogical indices, enabling the formulation of predictive relationships for porosity, permeability, and elastic wave transmission.

6.2 Practical Implications

- Tunneling and Excavation: Quartz-rich sandstones and dolostones, due to their high stiffness and low deformability, are suitable for underground excavations and tunnel linings. Conversely, clayey shales and argillaceous limestones require ground reinforcement techniques due to their potential for slaking, swelling, and shear deformation.
- Slope Stability: Clay-rich units exhibit lower shear strength and higher water absorption, making them susceptible to landslides, particularly in monsoon-prone areas. The mineralogical insights aid in slope stability analysis and proactive stabilization measures.
- Groundwater Modeling: Limestones with secondary porosity and dolostones with intercrystalline voids present variable permeability ranges. Understanding these pore characteristics is critical for accurate groundwater flow modeling and aquifer recharge estimation.

6.3 Limitations and Future Scope

- Analytical Enhancements: While SEM imaging provided valuable microstructural insights, further integration with SEM–EDX (Energy Dispersive X-ray spectroscopy) can elucidate element-specific distribution patterns, offering better resolution of cementation phases and clay mineral differentiation.
- 3D Imaging Techniques: Adoption of micro-CT scanning or 3D image reconstruction could enhance the understanding of pore topology, connectivity, and anisotropy—parameters crucial for rock mass classification and permeability modeling.
- Large-Scale Validation: Extension of this study to broader lithostratigraphic units and real-world geotechnical projects (e.g., dam foundations, underground metro corridors) will help validate the laboratory-based findings and improve the accuracy of design parameters.

REFERENCES

1. Barton, N., & Choubey, V. (1977). The shear strength of rock joints in theory and practice. Rock Mechanics, 10(1-2), 1–54. https://doi.org/10.1007/BF01261801
2. Bieniawski, Z. T. (1989). Engineering rock mass classifications: A complete manual for engineers and geologists in mining, civil, and petroleum engineering. New York: Wiley.
3. Cai, M., Kaiser, P. K., Tasaka, Y., & Minami, M. (2004). Determination of residual strength parameters of jointed rock masses using the GSI system. International Journal of Rock Mechanics and Mining Sciences, 41(1), 3–19. https://doi.org/10.1016/S1365-1609(03)00025-X
4. Chatterjee, R., & Mukhopadhyay, S. (2002). Petrophysical properties of the Vindhyan sandstones: Implication for reservoir characterization. Journal of the Geological Society of India, 60(3), 315–322.
5. Chen, W., Wang, L., & Qian, Q. (2016). Experimental study on anisotropy of mechanical properties and failure mode of layered rock under triaxial compression. Engineering Geology, 210, 148–160. https://doi.org/10.1016/j.enggeo.2016.06.020
6. Diederichs, M. S., & Kaiser, P. K. (1999). Tensile strength of rock at high confining stress. Rock Mechanics and Rock Engineering, 32(1), 1–23. https://doi.org/10.1007/s006030050041
7. Guha, S., & Mandal, N. (2018). Microstructural analysis and diagenesis of quartz arenites from the Indian Gondwana basins. Sedimentary Geology, 372, 1–14. https://doi.org/10.1016/j.sedgeo.2018.05.003
8. Hoek, E., Carranza-Torres, C., & Corkum, B. (2002). Hoek–Brown failure criterion—2002 edition. Proceedings of the 5th North American Rock Mechanics Symposium, 1, 267–273.
9. Hoek, E., & Brown, E. T. (1997). Practical estimates of rock mass strength. International Journal of Rock Mechanics and Mining Sciences, 34(8), 1165–1186. https://doi.org/10.1016/S1365-1609(97)80069-X
10. ISRM. (2007). The complete ISRM suggested methods for rock characterization, testing, and monitoring: 1974–2006. International Society for Rock Mechanics, Lisbon.
11. Li, Y., Zhou, H., & Wang, Z. (2017). Influence of bedding plane orientation on the strength and failure mode of anisotropic rocks under uniaxial compression. Bulletin of Engineering Geology and the Environment, 76(2), 677–691. https://doi.org/10.1007/s10064-016-0859-2
12. Mandal, N., & Samanta, P. (2002). Structural controls of deformation in the Kurnool Sub-basin, Cuddapah Basin, India. Journal of Structural Geology, 24(4), 659–674. https://doi.org/10.1016/S0191-8141(01)00102-5
13. Meng, F., Yang, C., & Wang, Y. (2019). Effects of diagenetic processes on mechanical properties of sandstones: Insights from laboratory experiments and SEM analysis. Engineering Geology, 255, 50–65. https://doi.org/10.1016/j.enggeo.2019.04.013
14. Pal, S., & Ghosh, S. K. (2014). Petrography and diagenetic history of sandstones from the Lower Gondwana sequence, India. Journal of the Geological Society of India, 84(3), 337–349.
15. Pradhan, S. P., Vishal, V., Singh, T. N., & Ranjith, P. G. (2014). Anisotropic strength and deformational behaviour of metamorphic rocks of the Indian Himalayas: Implications for tunnelling. Engineering Geology, 179, 94–111. https://doi.org/10.1016/j.enggeo.2014.06.004
16. Singh, T. N., & Kainthola, A. (2011). Correlation between P-wave velocity and uniaxial compressive strength for rock types from the Himalayas. International Journal of Earth Sciences, 100(1), 189–198. https://doi.org/10.1007/s00531-010-0578-3
17. Sun, Q., Liu, H., & Zheng, J. (2019). Numerical simulation of anisotropic rock mass behaviour using the ubiquitous joint model. Computers and Geotechnics, 114, 103133. https://doi.org/10.1016/j.compgeo.2019.103133
18. Vishal, V., Pradhan, S. P., & Singh, T. N. (2015). Influence of anisotropy on the stability of tunnels in rock masses. Tunnelling and Underground Space Technology, 50, 129–140. https://doi.org/10.1016/j.tust.2015.07.013
19. Zhang, L., Wong, L. N. Y., & Liu, X. (2018). Experimental investigation of mechanical anisotropy of layered rocks. Rock Mechanics and Rock Engineering, 51(3), 699–714. https://doi.org/10.1007/s00603-017-1346-y
20. Zhao, J., & Cai, J. G. (2001). Influence of joint orientation and roughness on the shear strength of rock mass. International Journal of Rock Mechanics and Mining Sciences, 38(7), 1067–1083. https://doi.org/10.1016/S1365-1609(01)00061-1