



Bibliographic analysis of scientific research on critical barite raw materials: Trends in the global barite industry

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Received: 24 December 2025 / Accepted: 27 July 2026
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Abstract

Barite (BaSO_4) is a strategically significant industrial mineral utilized in drilling fluids, high-density construction materials, radiation shielding, and advanced engineered applications. Its increasing relevance to energy industries, import-dependent supply chains, and specialized technologies has intensified both scientific and policy interest in barite as a critical raw material. Despite this, global barite research across geology, exploration, materials science, and industrial applications has not yet been systematically reviewed. This study examines 3,133 barite-related publications indexed in the Web of Science Core Collection from 1990 to 2025 through bibliometric mapping and keyword co-occurrence analysis using VOSviewer. The findings delineate major research domains, including sedimentary–diagenetic systems, hydrothermal and polymetallic mineralization, magmatic–rare earth element (REE)/carbonatite associations, sulfide-related ore systems, radiation-shielding materials, and remote sensing and GIS-based exploration. Over time, the focus of barite research has expanded from geoscience to a broader interdisciplinary field encompassing materials science, applied physics, engineering, and geospatial exploration. The analysis indicates that research on barite-based materials is increasingly performance-oriented, whereas remote sensing and GIS remain emerging yet underdeveloped tools for exploration. The review highlights key future priorities, such as integrating deposit geology, ore quality, beneficiation behavior, industrial specifications, geospatial targeting, and critical raw material assessment. These results provide a structured framework for understanding the evolution of barite research and for guiding future studies at the interface of mineral resources, industrial applications, geospatial exploration, and supply-chain concerns.

Keywords Barite · Bibliometric analysis · Critical raw materials · Remote sensing and GIS · Mineral exploration · Industrial applications.

Introduction

Barite (BaSO_4) is an economically significant sulfate mineral valued for its high specific gravity, chemical inertness, and relative abundance (Hanor 2000; Deer et al. 2013). Its properties make it essential in petroleum drilling fluids, paint, glass, high-density construction, and emerging

engineered applications (Jóźwiak-Niedźwiedzka and Lessing 2019; Lee and Kweon 2020; Yang et al. 2022; Zayed et al. 2024; Ali et al. 2025; Jung et al. 2025). While the oil and gas sector dominates barite consumption, recent studies show growing interest in its use for specialized concretes, medical shielding, environmental applications, and advanced systems (Padigi et al. 2015; Zhang et al. 2025; Goharshadi et al. 2025).

Barite is increasingly discussed within critical raw material and resource security contexts due to its significance in energy industries, concentrated production, and the reliance of key consuming economies on imports (Schulz 2017; Hayes and McCullough 2018; Boyarko and Khatkov 2021; Boyarko and Bolsunovskaya 2023). Because critical mineral status varies among jurisdictions and reflects national industrial demand, supply vulnerability, import dependence, and geopolitical priorities, this study treats barite criticality

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as a policy and resource-security context rather than as a predefined bibliometric category. Production is focused in a few countries, with demand tied mainly to drilling markets (U.S. Geological Survey 2026) (Supplementary Materials: Tables S1A–D). However, economic viability requires more than the presence of barite mineralization; ore grade, purity, beneficiation, infrastructure, and market access are also critical. Therefore, understanding the scientific evolution of barite research is important for documenting publication trends and identifying where future research should focus to support exploration, processing, and application-driven utilization.

Geologically, barite occurs in various deposit types, including hydrothermal veins, sedimentary-exhalative systems, Mississippi Valley-type deposits, residual accumulations, and diagenetic or volcanogenic settings (Hanor 2000; Griffith and Paytan 2012; Tokunaga et al. 2016; Johnson et al. 2017; Li et al. 2023). This geological variety has direct implications for exploration strategy, ore quality, beneficiation requirements, and industrial suitability (Green 1994; Elswick and Maynard 2014 a; Huang et al. 2022; Light et al. 2023b; Li et al. 2024). For example, silica- or iron-rich barite ores may require beneficiation to meet drilling-grade or chemical-grade specifications, whereas higher-purity barite is more suitable for regulated uses such as medical shielding and barium chemicals (Ciullo and Hewitt 1999; Bridges and Robinson 2020; Penaloza et al. 2023).

Despite its broad scientific and industrial relevance, barite research remains fragmented across domains such as ore geology, geochemistry, exploration, materials science, radiation shielding, environmental studies, and policy. Because these domains are often examined independently, it is challenging to assess the field's evolution, dominant areas, or underdeveloped topics. The relationships among deposit studies, emerging exploration methods, and application-driven materials research have not been systematically evaluated using a bibliometric framework.

This study addresses this gap by analyzing 3,133 barite-related publications indexed in the Web of Science Core Collection (WoS-CC) from 1990 to 2025. Using VOSviewer, bibliometric mapping, and keyword co-occurrence were used to identify main thematic clusters, temporal shifts, and disciplinary patterns. The study aims to: (1) identify principal research domains; (2) evaluate shifts in priorities over time; (3) assess the emergence of remote sensing, GIS, radiation-shielding, and engineered-materials subfields; and (4) pinpoint research gaps relevant to exploration, beneficiation, industrial use, and raw material assessment. The review moves beyond publication statistics to synthesize how barite research has evolved and to show where future work can better connect geological knowledge, resource evaluation, processing, and demand.

Methodology

Data collection and literature selection

Bibliographic data from the WoS-CC were used to analyze the evolution of global research on barite, including its geological, industrial, exploration-related, and environmental applications. WoS-CC was chosen due to its provision of structured bibliographic metadata, indexed keywords, citation information, and appropriate category classifications for bibliometric analysis (Marlés-Sáenz et al. 2025).

The primary bibliometric search encompassed the period from 1990 to 2025 and was conducted as a topic search, including titles, abstracts, author keywords, and Keywords Plus (Fig. 1). The search strategy employed OR logic to combine principal terms (e.g., “barite”, “baryte”, “barium sulfate mineral”, “barite deposit”, “baryte mineralization”, “barite exploration”, “barite occurrence”) to identify publications directly related to barite as a mineral, raw material, exploration target, and industrial product. These terms were subsequently combined with deposit-related descriptors (e.g., “hydrothermal vein”, “stratiform barite”, “residual barite”, “SEDEX”, “Mississippi Valley Type”, “bedded barite”, “fault-controlled mineralization”) using OR logic to ensure the results were specifically focused on barite deposits and related topics (Table 1). The search was limited to articles, proceedings papers, and book chapters, resulting in an initial dataset of 7,107 records. A systematic screening process refined the dataset to include only English-language records with complete bibliographic metadata, indexed in WoS-CC from 1990 to 2025, and directly related to barite geology, mineralization, exploration, industrial applications, materials research, or environmental studies. Duplicates, records with missing data, and unrelated barium compounds were excluded. Following this screening, the final main bibliometric corpus comprised 3,133 publications.

Two additional focused thematic searches in WoS-CC were conducted to examine specialized research directions within barite studies. The first search targeted publications on barite-based radiation-shielding concretes and heavy-weight materials, yielding 188 records. The second search focused on remote sensing and GIS applications in barite exploration and mineral mapping, yielding 13 records. These focused datasets were analyzed separately from the main corpus using the same bibliometric approach to evaluate emerging subfields oriented toward applications and exploration that were not sufficiently resolved in the broader keyword network. The complete Boolean search strings used to construct the main bibliometric corpus and the two focused thematic datasets are provided in Supplementary Materials: Tables S2A and B.

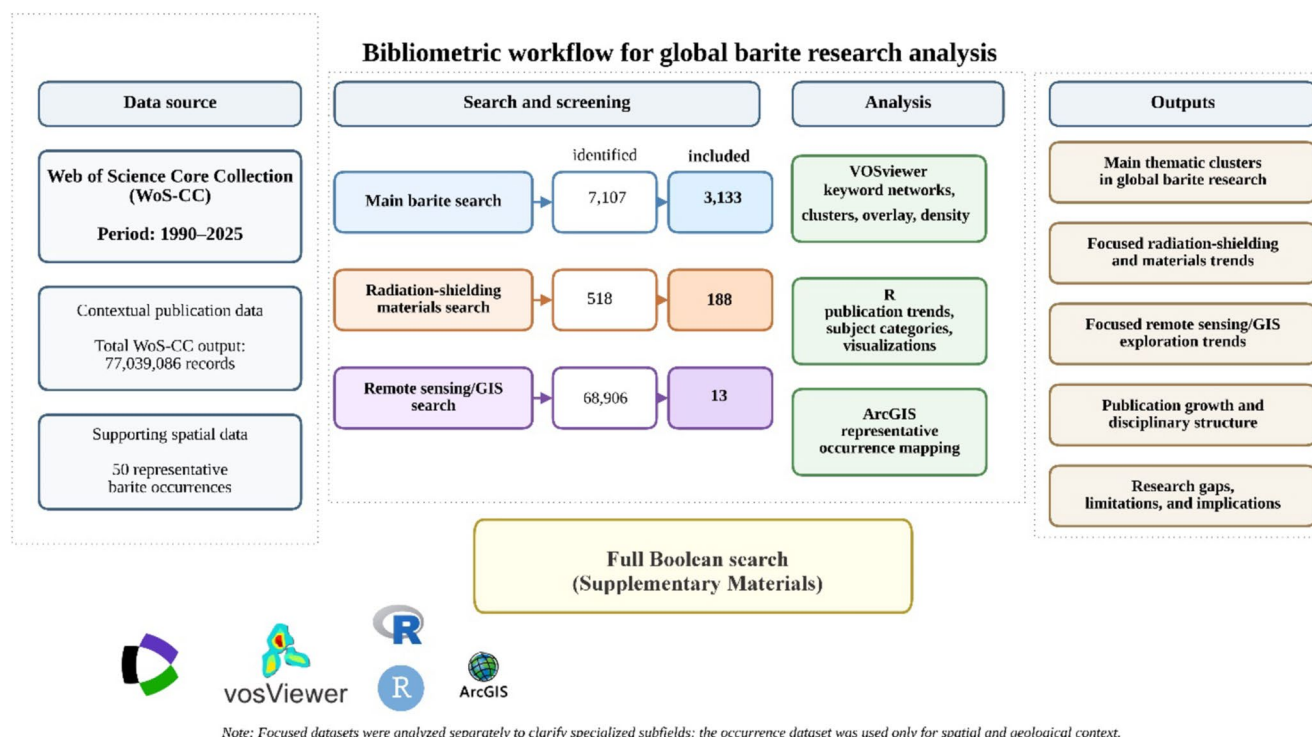


Fig. 1 PRISMA-style workflow summarizing the identification, screening, and selection of barite-related publications from the WoS-CC (1990–2025). Bibliometric mapping was performed using VOSviewer, and statistical analyses were conducted in R

Table 1 Summary of datasets and analytical roles used in the present study

Dataset	Records / entries	Source	Analytical role
Main bibliometric corpus	3,133 publications	Main WoS-CC search	Publication trends, keyword co-occurrence analysis, thematic clustering, and disciplinary analysis
Radiation-shielding dataset	188 publications	Targeted WoS-CC search	Focused analysis of barite-based radiation-shielding and heavyweight materials research
Remote sensing/GIS dataset	13 publications	Targeted WoS-CC search	Focused analysis of geospatial exploration approaches in barite research
Global barite occurrence dataset	50 representative occurrences	USGS, MRDS, Mindat, and published literature	Spatial visualization and geological context only

Bibliometric analysis and research trend assessment

Bibliometric analysis was conducted using VOSviewer version 1.6.20, a widely used software tool for constructing and visualizing bibliometric networks (van Eck and Waltman 2010, 2017). The analysis focused on keyword

co-occurrence networks, which reveal conceptual relationships among frequently used research terms and help identify thematic structures within a research field (van Eck and Waltman 2010; Radhakrishnan et al. 2017). Bibliometric approaches of this type are increasingly applied in mineral economics, resource policy, and geoscience studies to evaluate research development, technological change, and emerging priorities in mineral-resource systems (Su et al. 2023; Huang 2024; Liu et al. 2025; Cotrina-Teatino and Marquina-Araujo 2025; Bukar et al. 2025; Gao et al. 2025).

Keyword co-occurrence analysis was performed using a full-counting method. Clusters were generated using the VOSviewer modularity optimization algorithm, which groups strongly related keywords into thematic clusters. Three visualization formats were applied: network visualization to identify thematic relationships, overlay visualization to examine temporal shifts in keyword occurrence, and density visualization to identify research concentrations (see Supplementary Materials: Table S3A-C and Raw Data R1-6).

Annual publication counts were used to evaluate temporal growth in barite-related research between 1990 and 2025. To place this trend in context, barite-related publication growth was compared with total WoS-CC publication output over the same period. WoS subject categories were used to assess disciplinary structure and were grouped into six broader domains: Earth sciences; materials science and

applied physics; engineering and technology; environmental and water sciences; medical and biological sciences; and other/interdisciplinary fields. These grouped categories were used only to simplify the interpretation of disciplinary trends through time (See Supplementary Table S3 for groups).

Spatial visualization of representative barite occurrences

A global occurrence dataset was compiled to provide geological and spatial context for the bibliometric findings. The dataset included representative barite localities with standardized attributes, including locality name, country, latitude, longitude, and genetic deposit type. Occurrence data were compiled from published geological studies, national geological surveys, and established mineral databases, including USGS, MRDS, and Mindat.

The occurrence dataset was integrated into ArcGIS and projected using the WGS 1984 geographic coordinate system. Deposits were classified by genetic type based on published descriptions (Hanor 2000; Johnson et al. 2017; Li et al. 2023). Global geological base maps, including the Commission for the Geological Map of the World (CGMW) Geological World Map, were used to contextualize barite occurrences within major tectonic and metallogenic provinces. The global occurrence dataset was compiled only to provide spatial and geological context for the bibliometric

results. It represents selected barite localities from published literature and mineral databases and was not used for reserve estimation, supply assessment, or economic feasibility analysis. The full occurrence dataset is provided in Supplementary Materials Table S4.

Results

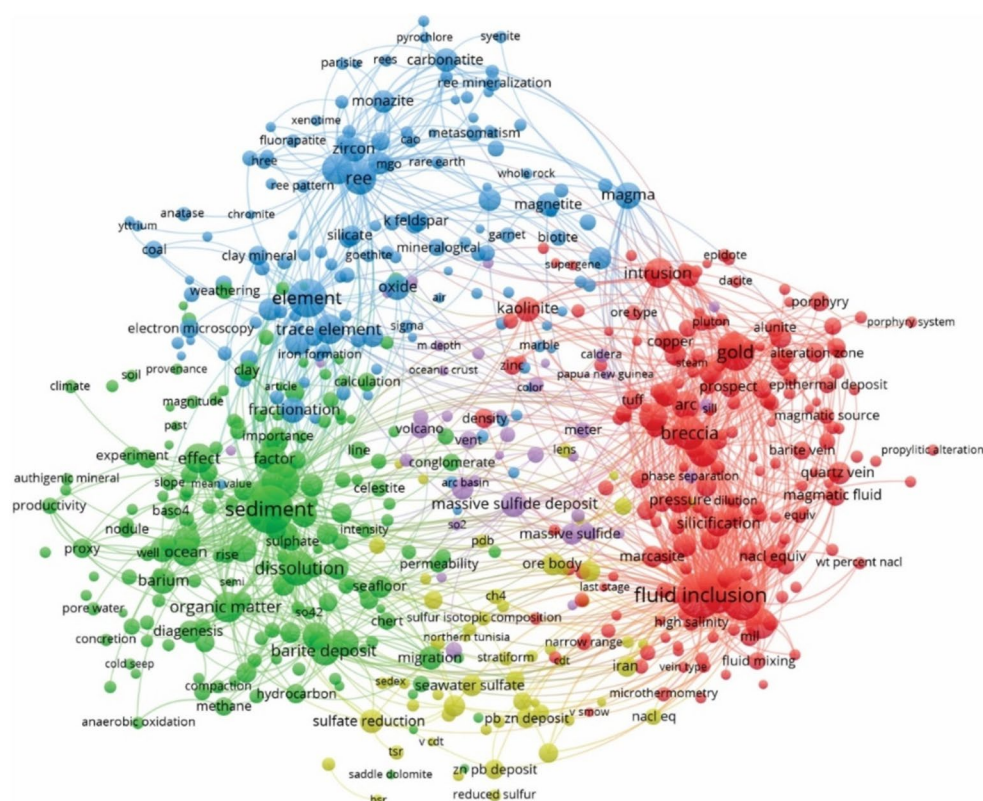
Bibliometric structure of barite-related research

Keyword co-occurrence analysis of the main barite corpus reveals a strongly interconnected research landscape structured around five principal thematic domains (Fig. 2). The network visualization shows that barite research is dominated by geological, geochemical, and ore-system studies, with secondary links to materials, exploration, and environmental themes.

The red cluster represents hydrothermal and polymetallic ore systems. It is defined by keywords such as “fluid inclusion,” “gold,” “breccia,” “quartz vein,” “porphyry,” “epithermal deposit,” “alteration,” “fluid mixing,” and “magmatic fluid.” This cluster indicates that a substantial part of barite research examines barite as a gangue mineral, fluid tracer, and associated phase in hydrothermal and polymetallic mineral systems.

The green cluster is associated with sedimentary, diagenetic, and biogeochemical processes. Dominant terms

Fig. 2 Keyword co-occurrence network of global barite-related research generated using VOSviewer. Node size represents keyword frequency, link thickness indicates co-occurrence strength, and colors denote thematic clusters



include “sediment,” “organic matter,” “sulfate reduction,” “dissolution,” “barite deposit,” “methane,” “burial,” “cold seep,” and “diagenesis.” This cluster reflects the importance of barite in sedimentary basins, sulfate–methane transition zones, organic-matter degradation, and barium–sulfate cycling.

The blue cluster links barite-related research with magmatic, alkaline, and REE-bearing systems. It includes high-centrality terms such as “REE” (577 links; total link strength 6201; occurrence 210) and “carbonatite” (313 links; total link strength 7231; occurrence 249), together with “zircon,” “monazite,” “magnetite,” “oxide,” “fractionation,” “feldspar,” and “magma.” This cluster highlights the connection between barite-related studies, alkaline–carbonatite systems, rare-earth element enrichment, and magmatic–hydrothermal processes.

The yellow cluster represents sulfide-associated and stratiform ore systems. It includes terms such as “massive sulfide deposit,” “ore body,” “Pb–Zn deposit,” “sulfide,” “hydrothermal vein,” “stratiform” and “reduced sulfur.” This cluster shows that barite is commonly investigated in relation to base-metal mineralization, volcanogenic massive sulfide systems, and stratiform ore-forming environments. A smaller purple cluster includes terms such as “MVT,” “dolomite,” “seawater sulfate,” and “saddle dolomite,” indicating carbonate-hosted and basin-related barite systems.

The overlay visualization (Fig. 3) shows a temporal shift in research emphasis. Earlier research was concentrated mainly on sedimentary and diagenetic topics, including “sediment,” “organic matter,” “sulfate reduction” and “dissolution”. More recent studies increasingly emphasize hydrothermal systems, fluid inclusions, trace elements, polymetallic mineralization, and magmatic–REE associations. The density visualization (Fig. 4) confirms that the most concentrated research areas occur around “fluid inclusion,” “gold,” “breccia,” “sediment,” “dissolution,” “organic matter,” “REE,” and “carbonatite.”

Taken together, the network, overlay, and density visualizations show that global barite research is primarily structured around geological processes and ore-system studies. However, exploration-technology terms are not dominant in the main keyword network. This indicates that geospatial exploration remains an underrepresented research direction within the broader barite literature, despite its increasing relevance for early-stage mineral targeting in underexplored terrains. To connect the bibliometric clusters with their geological meaning, Table 2 summarizes the principal genetic types of barite deposits and their diagnostic characteristics.

The broader overlay map also shows application-oriented terms, including “concrete,” “aggregate,” “cement,” “drilling fluid,” “mud,” “oil,” “glass,” “energy,” and “waste,” indicating that industrial and materials-related research directions are present within the main corpus but are less

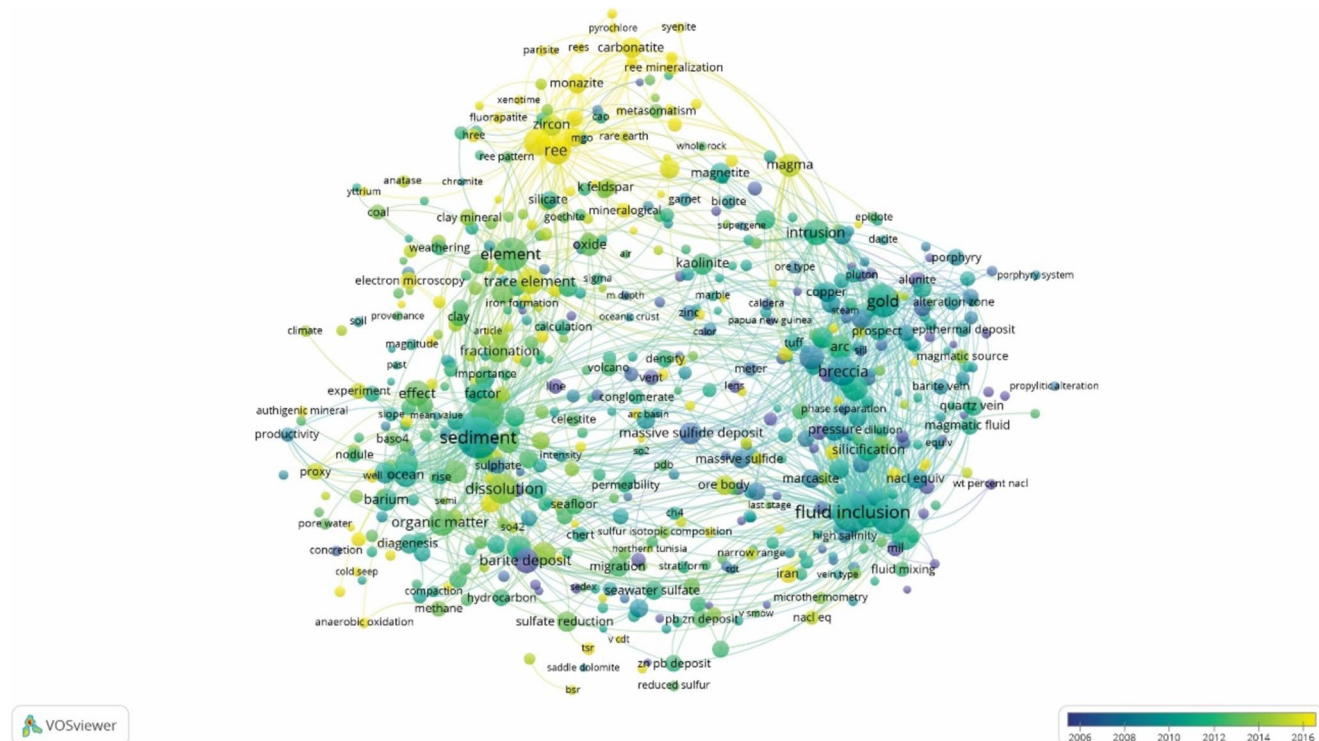


Fig. 3 Overlay visualization of keyword co-occurrence in global barite-related research. Node size represents keyword frequency, link thickness indicates co-occurrence strength, and color gradient indicates the average publication year of each keyword

structurally dominant than the geological and ore-system clusters (Supplementary Figure S1).

Bibliometric mapping of the focused radiation-shielding and engineered-materials dataset identifies three main clusters within barite-based materials research (Fig. 5). The first cluster is dominated by terms related to mechanical and physical performance, including “mechanical property,” “tensile strength,” “coarse aggregate,” “performance,” “mixture,” and “MPa.” This cluster reflects studies evaluating the influence of barite aggregate substitution on compressive strength, tensile behaviour, workability, density, and durability of heavyweight concretes (Badarloo et al. 2022; Tawfik et al. 2023).

al. 2022; Khan et al. 2024). The third cluster links terms such as “barite concrete,” “neutron radiation,” “gamma,” “detector,” and “concrete,” indicating studies focused on experimental dosimetry, radiation-transport modelling, and comparative evaluation of barite concrete against conventional shielding materials (Sharifi et al. 2013; Daungwilailuk et al. 2022).

The overlay visualization indicates a temporal shift from earlier studies focused mainly on aggregate characterization, attenuation coefficients, and conventional X-ray or gamma-ray shielding experiments toward more recent research on high-performance barite concretes and hybrid shielding composites (Al-Sarray et al. 2017; Ahmad et al. 2019). The density visualization confirms that “mechanical property,” “performance,” “radiation shielding concrete,” “neutron radiation,” and “mass attenuation coefficient” represent the principal research hotspots within this literature (see Supplementary Materials: Figures S2-3).

Representative formulations and performance parameters of barite-based concretes reported in recent experimental and modelling studies are summarized in Table 3. These data provide application context for the bibliometric clusters and show that current research increasingly evaluates barite both as a high-density aggregate and as a functional component in engineered shielding materials (Akman

Table 2 Deposit taxonomy: genetic types of barite deposits and their geological characteristics

Deposit type	Genetic environment / formation mechanism	Key mineralogical–geochemical features	Representative localities	Reference
Bedded–Sedimentary Barite	Precipitation from marine sulfate–barium mixing zones under oxidizing to sub-reducing conditions	Laminated barite layers, fine-grained, associated with shale or carbonate; $\delta^{34}\text{S}$ positive values	Mangampeta (India); Guizhou (China), USA	(Hanor 2000)
Sedimentary–Exhalative (SEDEX)	Hydrothermal venting of Ba-rich brines into marine basins	Stratiform barite with Pb–Zn sulfides; occurs in black shales	Kootenay (Canada); Rammelsberg (Germany)	(Ghorbani Derakhshani et al. 2020)
Hydrothermal / Vein-Type Barite	Precipitation from ascending hydrothermal fluids in faults/fractures	Coarse crystalline barite; quartz, sulfide, or fluorite association	Dalnégorsk (Russia); Bou Azzer (Morocco); Ariab (Sudan)	(Melekestseva et al. 2014; Kravchishina et al. 2023)
Volcanogenic / Magmatic–Hydrothermal	Barium enrichment in late-stage felsic or alkaline magmas and associated fluids	Silicified zones, Fe–Mn oxides, and barite; commonly gold-bearing (SBR)	Red Sea Hills (Sudan); Arabian Shield (Saudi Arabia) Eastern Desert (Egypt)	(Abu-Fatima et al. 2021; Daoud et al. 2025a)
Mississippi Valley Type (MVT)	Low-temperature hydrothermal brines circulating in carbonate sequences	Barite with galena–sphalerite; $\delta^{34}\text{S}$ near seawater; forms cavity fillings	Central Europe; Turkey	(Leach et al. 2010)
Residual / Eluvial Barite	Secondary enrichment from weathering of primary barite-bearing veins	Coarse detrital barite, earthy textures	Tanzania; UK; China	(Li et al. 2023)
Cold-Seep / Diagenetic Barite	Precipitation in sulfate–methane transition zones or during sulfate reduction	Nodular to concretionary barite; $\delta^{34}\text{S}$ depletion	Gulf of Mexico; Mediterranean basins	(Torres et al. 2003; Stevens et al. 2015)

et al. 2022; Jung et al. 2025). This trend also highlights a remaining research gap: materials studies rarely link shielding performance to barite deposit quality, mineral purity, beneficiation requirements, or feedstock variability.

Barite exploration: bibliometric trends in remote sensing and GIS applications

Bibliometric analysis of the focused remote sensing and GIS dataset identifies an emerging exploration-oriented research domain within barite studies (Fig. 6). Although remote sensing and GIS are now widely used in mineral exploration, their application to barite-specific exploration remains limited; the focused WoS-CC search identified only 13 publications directly linking barite or baryte with remote sensing, GIS, and mineral exploration. This indicates that geospatial exploration is not yet a dominant research domain within global barite studies, but rather an emerging and underdeveloped subfield. Despite its small size compared with the broader geology- and materials-focused barite literature, the keyword co-occurrence network shows a coherent thematic structure centered on multispectral imagery, alteration mapping, structural interpretation, and mineral-potential modeling (See [Supplementary Materials](#)).

The main exploration cluster is centered on keywords such as “barite”, “remote sensing”, “Landsat”, “Sentinel”, “structural control”, and “mineralization”. These terms indicate that remote sensing studies on barite commonly use multispectral satellite data to delineate prospective mineralized zones, identify alteration halos, and map structural lineaments that may control ore emplacement (Daoud et al. 2025a; El-Omairi et al. 2025; Kamaunji et al. 2025). The prominence of “structural control” within this cluster is particularly important, as it links geospatial methods directly to exploration needs in hydrothermal and structurally controlled barite systems (Behyari et al. 2019).

A second cluster is associated with alteration mapping and includes terms such as “alteration”, “caldera”, and related hydrothermal indicators. This cluster reflects the use of spectral mapping to detect silicification, argillic alteration, carbonate replacement, and iron-oxide enrichment, which may accompany barite and sulfide mineralization in hydrothermal systems (Van der Werff and Van der Meer 2015). A third cluster links “ASTER image”, “SWIR”, “XRD”, “accuracy”, and “mineral map”, indicating the integration of shortwave-infrared spectral analysis with mineralogical validation to improve mineral discrimination and automated mapping reliability (Thompson et al. 1999).

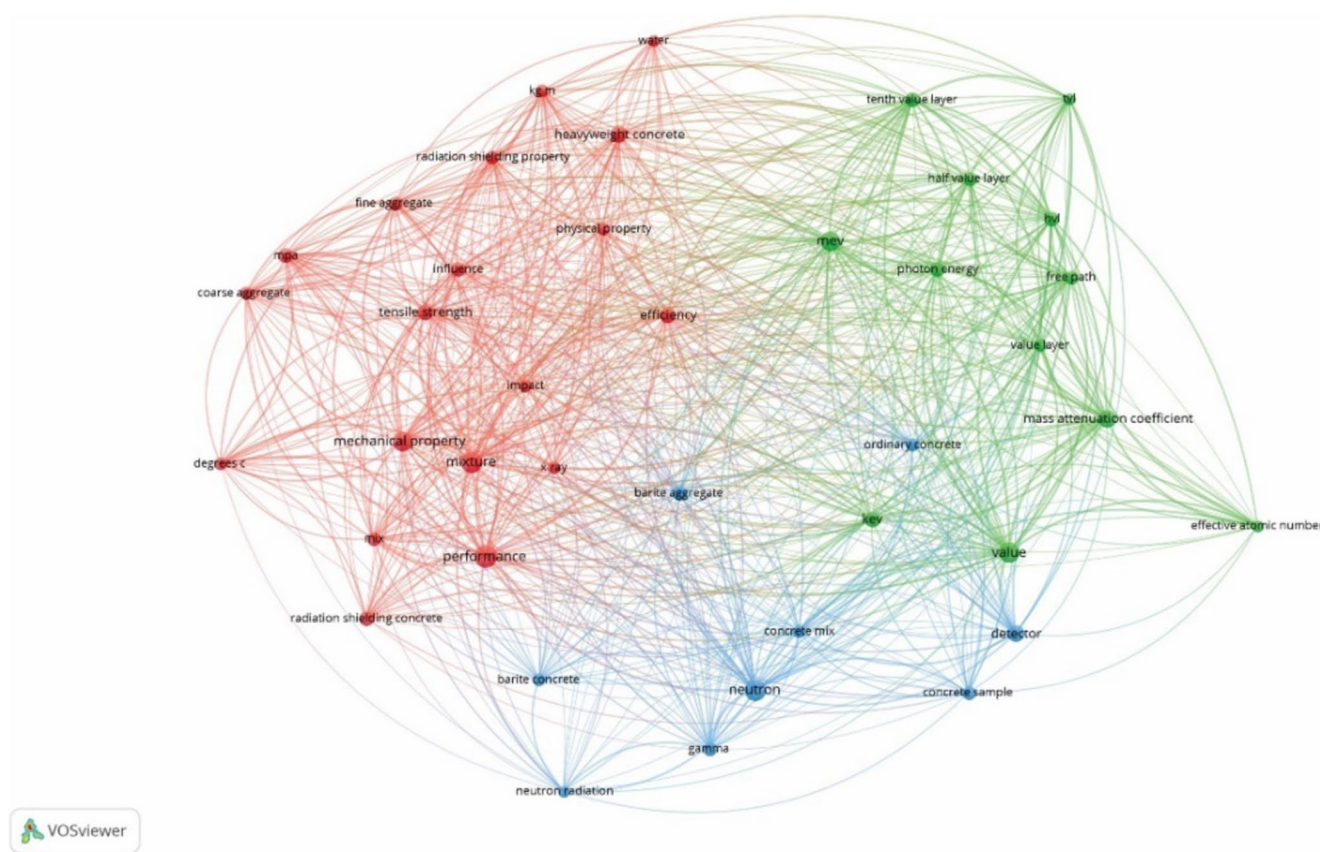


Fig. 5 Keyword co-occurrence network of barite-related radiation shielding and engineered materials research. Node size represents keyword frequency, link thickness indicates co-occurrence strength, and colors denote thematic clusters

The overlay visualization shows a methodological progression through time. Earlier studies relied mainly on ASTER imagery, SWIR-sensitive band ratios, and minimum-noise-fraction transformation for alteration detection. More recent studies increasingly incorporate Sentinel-2 imagery, GIS-based modelling, and quantitative mineral-potential mapping. This trend indicates a shift from descriptive alteration mapping toward integrated exploration workflows that combine spectral, structural, geological, and validation datasets (Supplementary Materials: Figure S4).

The density visualization identifies three principal research hotspots: ASTER-based alteration detection, spectral identification of barite and associated alteration minerals, and GIS-supported mineral-potential modelling. These hotspots demonstrate that remote sensing and GIS are increasingly used to support early-stage exploration; however, the limited number of studies indicates that this remains an underdeveloped research direction relative to the broader barite literature (Supplementary Materials: Figure S5).

Table 4 summarizes the principal spectral band ratios and image-processing techniques reported for detecting barite and associated alteration minerals using multispectral

and hyperspectral satellite datasets. These methods correspond closely with bibliometric keywords such as “SWIR”, “ASTER”, “Sentinel”, “alteration”, “structural control”, and “mineral map”, indicating that the remote-sensing literature is organized around a consistent set of spectral, structural, and validation-based approaches (see Supplementary Materials: Figure S6).

A unified synthesis of the thematic structures identified from the global barite, radiation-shielding, and remote sensing/GIS bibliometric networks is presented in Table 5. By linking dominant keywords with thematic interpretation, unresolved knowledge gaps, and practical implications, this synthesis moves the analysis beyond descriptive keyword mapping and clarifies what the field now requires. The results show that the principal limitation in current barite research is not simply the uneven distribution of publications across subfields, but the weak integration between deposit geology, resource quality, beneficiation behavior, engineered-material performance, geospatial exploration, and critical raw material assessment. Table 5 therefore translates the bibliometric evidence into research priorities for understanding barite as a geological resource, industrial material, and exploration target.

Table 3 Representative formulations, physical properties, and radiation-shielding performance of barite-based materials used in construction, medical, and environmental applications

ID	Material / mix designation	Binder system	Aggregate / filler composition	Density (kg m ⁻³)	Shielding parameters γ -energy	Energy (MeV)	Main findings highlight	References
BC-1 Conventional barite concrete	Conventional barite concrete	Ordinary Portland cement (OPC)	Natural sand + barite coarse aggregate (100%)	3 800–4 300	$\mu = 0.26$ – $0.29 \text{ cm}^{-1} \rightarrow$ HVL ≈ 2.4 – 2.7 cm; TVL ≈ 7.7 – 8.9 cm	0.662 (Cs-137)	Typical heavyweight concrete for nuclear / medical bunkers; ≈ 40 – 45% lower HVL than ordinary concrete	(Özen et al. 2016; Zayed et al. 2024)
BC-2 High-strength barite concrete (M25–M45 grades)	High-strength barite concrete (M25–M45 grades)	OPC + superplasticizer	Barite coarse + fine aggregates (100%)	3 800–4 600	$\mu = 0.27$ – $0.30 \text{ cm}^{-1} \rightarrow$ HVL ≈ 2.3 – 2.6 cm; TVL ≈ 7.5 – 8.3 cm	0.662	Shielding efficiency $\uparrow$ with density & cement grade; M45 ≈ 30 – 35% higher μ vs. ordinary concrete	(Liu et al. 2020; Ahmad et al. 2024)
BC-3 Barite–hematite composite	Barite–hematite composite	OPC + fly ash (10%)	70% barite + 30% hematite	4 400–4 700	$\mu = 0.27$ – $0.30 \text{ cm}^{-1} \rightarrow$ HVL ≈ 2.3 – 2.6 cm; TVL ≈ 7.5 – 8.3 cm	0.662	Combined γ + n shielding synergy; compressive strength ≈ 38 – 40 MPa	(Ahmad et al. 2019; Rasoul Abdar Esfahani et al. 2021)
BC-4 Barite–magnetite blend	Barite–magnetite blend	OPC + silica fume (5%)	60% barite + 40% magnetite	4 300–4 700	$\mu = 0.28$ – $0.31 \text{ cm}^{-1} \rightarrow$ HVL ≈ 2.2 – 2.5 cm; TVL ≈ 7.4 – 8.2 cm	0.662	High attenuation efficiency; moderate workability loss	(Lee and Kweon 2020; Yang et al. 2022)
BC-5 Polymer-modified barite mortar	Polymer-modified barite mortar	Epoxy / polyester matrix	Fine barite + BaSO ₄ powder filler (60–75%)	3 300–3 700	$\mu = 0.22$ – $0.30 \text{ cm}^{-1} \rightarrow$ HVL ≈ 2.3 – 3.2 cm; TVL ≈ 7.7 – 10.5 cm	0.662 (γ); 0.1 (X-ray)	Lightweight panels for diagnostic / radio-therapy rooms; very low permeability	(Penaloza et al. 2023)
BC-6 Nano-BaSO ₄ cement composite (modelled)	Nano-BaSO ₄ cement composite (modelled)	OPC + nano-silica (2%)	Micro / nano BaSO ₄ powder	4 000–4 500 (est.)	$\mu \approx 0.30$ – $0.35 \text{ cm}^{-1} \rightarrow$ HVL ≈ 2.0 – 2.3 cm; TVL ≈ 6.6 – 7.7 cm	1.25 (Co-60, avg E)	Monte Carlo simulations predict 5–10% higher μ than conventional barite mixes; awaiting experimental validation	(Akkurt and Boodaghi Malidarre 2022; Özdoğan et al. 2024)
BC-7 Optimized heavy-weight concrete (general design trend)	Optimized heavy-weight concrete – general design trend	OPC / HPC	Barite, hematite, magnetite (varied)	≥ 3 500	$\mu \approx 0.23$ – $0.30 \text{ cm}^{-1} \rightarrow$ HVL ≤ 2.3 – 3.0 cm; TVL ≈ 7 – 9 cm	0.662	Design guidelines for density $> 3500 \text{ kg m}^{-3}$ yield HVL ≤ 3 cm @ 0.66 MeV γ	(Barbhuiya et al. 2025)

Temporal evolution of the barite research and comparison with global publication trends

The temporal distribution of barite-related publications shows a sustained increase in research output between 1990 and 2025 (Fig. 7). At five-year intervals, the number of barite-related publications increased from 56 records in 1990 to 643 records in 2025 (Table 6). Over the same period, the relative share of barite publications within total WoS-CC

output increased from approximately 0.0056% to 0.0150%, indicating that barite-related research expanded faster than the general growth of indexed scientific publications.

Publication growth was gradual from 1990 to approximately 2015, followed by a marked acceleration after 2016 (Fig. 8). Annual publication counts remained substantially higher after 2019 than during the pre-2010 period, indicating a recent intensification of scientific attention. This increase is consistent with the thematic patterns identified

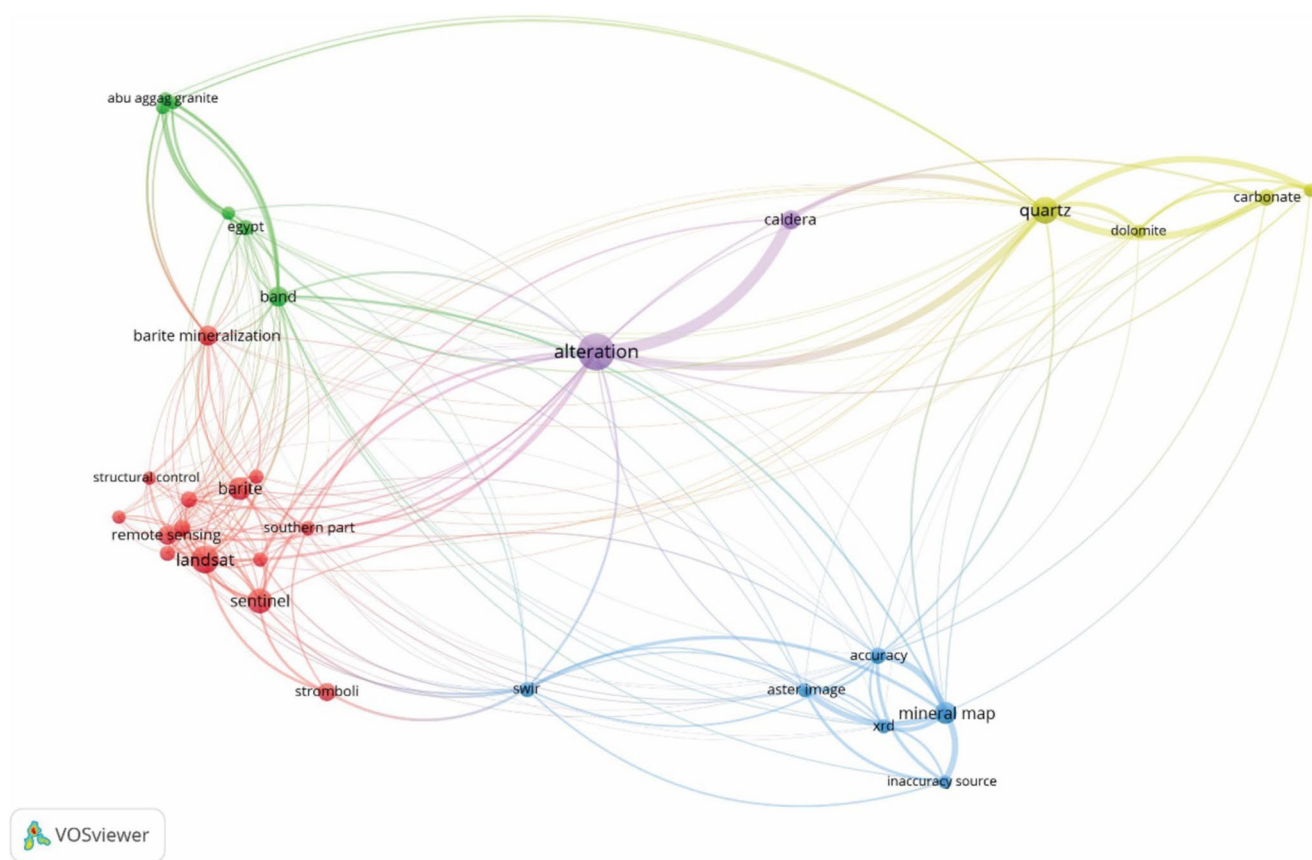


Fig. 6 Keyword co-occurrence network of remote sensing and GIS applications in barite exploration. Node size represents keyword frequency, link thickness indicates co-occurrence strength, and colors denote thematic clusters

Table 4 Common spectral band-ratio indices and image-processing techniques used to detect barite and associated alteration minerals from multispectral and hyperspectral satellite datasets

L9	S2	ASTER	PRISMA	Spectral feature targeted	Purpose	Reference
5/7	12/11	5/4	(149+154)/152 or (140/50)*(30/20)	Silica	Detects alteration minerals in SWIR	(Kokaly et al. 2017; Laukamp 2022; Chirico et al. 2023)
(5+7)/6	12/2	(6+9)/8	(149+154)/152	Carbonate	Identifies marbles	(Van der Meer et al. 2014; Ninomiya and Fu 2019; Pour et al. 2019)
(6/7)-(5/4)	11/2	5/4	PC5, MNF5,	Barite	Identifies barite feature (base-metals)	(Rockwell and Hofstra 2008; Madani and Emam 2011; Daoud et al. 2025a)
7/6	12/2–6/8A	(4+6)/5		Sulfides	Alteration of minerals and sulfide-rich zones	(Rockwell and Hofstra 2008; Kokaly et al. 2017; Rockwell et al. 2021)
(2/1)-(5/4)	11/8A	(10*12)/(11*11) (5+7)/6	IC9	Sulfates	Identifying barium sulfates	(Rockwell and Hofstra 2008; Madani and Emam 2011; Daoud et al. 2025a)
6/4	11/4	4/2	30/20	Gossans	Base metal deposits	(Van der Meer et al. 2012; Pour et al. 2019)

in the keyword networks, particularly the expansion of research on engineered materials, radiation shielding, geo-spatial exploration, and critical raw material-related applications (see Table 6; Figs. 8a). Between 2000 and 2015, publication output continued to increase more gradually, fluctuating between approximately 178 and 343 records per year (Fig. 8b). From 2016 onwards, a marked acceleration

is observed, with annual publications increasing from 362 in 2016 to consistently high levels exceeding 480 publications per year during 2019–2022. Although minor fluctuations are evident after 2022, publication levels remain substantially higher than those observed prior to 2010 (see Supplementary Materials). When normalized to the total dataset, the relative annual share of publications increases

Table 5 Synthesis of bibliometric themes, thematic interpretation, research gaps, and practical implications in global barite research

Evidence basis	Bibliometric theme / research domain	Dominant keywords	Thematic interpretation	Identified research gap	Practical implication / future priority
Main barite keyword network	Hydrothermal and polymetallic ore systems	fluid inclusion; gold; breccia; quartz vein; porphyry; epithermal deposit; alteration; fluid mixing; magmatic fluid sediment; organic matter;	Barite is commonly studied as a gangue mineral, sulfate phase, and fluid-evolution indicator in hydrothermal and polymetallic ore systems.	Genetic and fluid-evolution studies are rarely integrated with ore-quality assessment, beneficiation behavior, and exploration-scale targeting.	Integrating fluid-inclusion, isotope, structural, geospatial, mineralogical, and processing data could improve exploration models and resource evaluation.
	Sedimentary, diagenetic, and biogeochemical systems	sulfate reduction; dissolution; barite deposit; methane; burial; cold seep; diagenesis	This theme reflects barite formation, dissolution, and re-precipitation in sedimentary basins, sulfate–methane transition zones, cold-seep systems, and barium–sulfate cycling.	Process-based studies are not sufficiently translated into exploration criteria or resource-assessment frameworks.	Basin-scale genetic models linking sulfate–barium cycling, diagenetic pathways, stratigraphic controls, and deposit predictability could support exploration for stratiform, bedded, and diagenetic barite systems.
	Magmatic, carbonatite, and REE-associated systems	REE; carbonatite; zircon; monazite; feldspar; magnetite; oxide; fractionation; magma	Barite-related keywords occur with alkaline magmatism, carbonatite systems, REE enrichment, and magmatic–hydrothermal alteration.	The role of barite-related mineral assemblages in recording fluid evolution, element mobility, and alteration in REE- and carbonatite-related systems remains insufficiently synthesized.	Barite-bearing assemblages may provide supporting geochemical and mineralogical evidence for interpreting fluid evolution and alteration in alkaline–carbonatite and REE-bearing systems.
Focused radiation-shielding materials dataset	Sulfide-associated and stratiform ore systems	massive sulfide deposit; ore body; Pb–Zn deposit; sulfide; hydrothermal vein; stratiform; reduced sulfur	Barite is frequently associated with base-metal mineralization, volcanogenic massive sulfide systems, SEDEX-type environments, and stratiform ore settings.	The relationships among barite occurrence, sulfide mineralization, ore grade, mineral association, and processing requirements remain incompletely integrated.	Incorporating barite more explicitly into VMS, SEDEX, and Pb–Zn exploration models could improve targeting, deposit-scale interpretation, and resource evaluation.
	Carbonate-hosted and basin-fluid systems	MVT; dolomite; seawater sulfate; saddle dolomite; basin-fluid	This theme links barite to carbonate-hosted mineralization, basin-fluid circulation, MVT systems, and diagenetic fluid–rock interaction.	Basin-related barite studies are rarely connected to industrial-quality criteria, impurity constraints, and resource-development requirements.	Combining basin-fluid models with ore-quality, purity, impurity, and beneficiation studies could improve assessment of carbonate-hosted and stratabound barite systems.
	Radiation-shielding engineered barite materials	barite concrete; mechanical property; tensile strength; coarse aggregate; mass attenuation coefficient; half-value layer; neutron radiation; gamma radiation	Barite-based materials research is expanding around heavyweight concrete, radiation attenuation, mechanical performance, and engineered shielding composites.	Engineering studies rarely account for geological feedstock variability, barite purity, particle size, impurities, and beneficiation history.	Future research should link raw-material characteristics with shielding efficiency, durability, mechanical performance, and industrial standards for regulated applications.
Focused remote sensing/GIS dataset	Geospatial exploration and mineral mapping	remote sensing; Landsat; Sentinel; ASTER image; SWIR; alteration; structural control; mineral map; accuracy	Remote sensing and GIS form an emerging exploration-oriented subfield focused on alteration mapping, structural interpretation, and mineral-potential assessment.	Barite-specific geospatial studies remain limited, and many workflows require stronger field, spectral, mineralogical, and geochemical validation.	Multisensor, field-validated, and machine-learning-assisted approaches should be expanded for early-stage barite exploration, particularly in arid and structurally controlled terrains.
	External policy and supply-security context	critical raw material; supply risk; import dependence; resource security; industrial demand; trade concentration	Criticality is best interpreted as a policy and resource-security context rather than as a dominant bibliometric cluster. Barite relevance is linked to industrial demand, concentrated production, import dependence, and jurisdiction-specific critical-mineral assessments.	Critical raw material assessments of barite remain insufficiently integrated with deposit quality, beneficiation behavior, infrastructure constraints, market specifications, and trade dependence.	Future work should combine bibliometric evidence with geological, technological, economic, and supply-chain data to support evidence-based assessment of barite criticality.

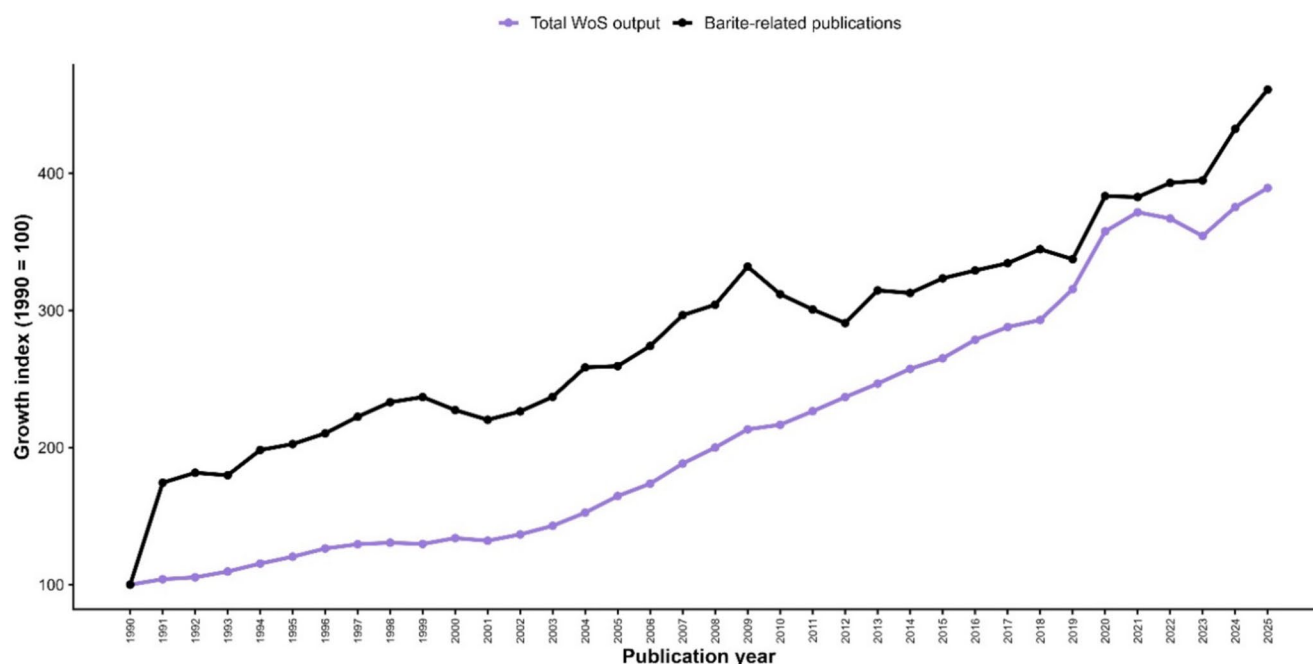


Fig. 7 Temporal evolution of barite publications compared with index growth of total WoS and barite related publications (1990–2025 publication growth index normalized to 1990 = 100)

Table 6 Temporal trends of barite publications within the global Web of Science output and their disciplinary distribution (1990–2025). Values for research domains are given as record counts with percentage share in parentheses

Year	Total WoS publications	Barite publications	Share (%)	Earth sciences	Engineering & technology	Environmental & water	Materials & physics	Medical & biological	Other / interdisciplinary
1990	1,007,376	56	0.0056	29 (37.66%)	7 (9.09%)	8 (10.39%)	5 (6.49%)	12 (15.58%)	16 (20.78%)
1995	1,212,411	127	0.0105	73 (35.78%)	23 (11.27%)	17 (8.33%)	18 (8.82%)	30 (14.71%)	43 (21.08%)
2000	1,348,919	182	0.0135	114 (39.58%)	57 (19.79%)	16 (5.56%)	30 (10.42%)	28 (9.72%)	43 (14.93%)
2005	1,657,950	234	0.0141	152 (39.38%)	59 (15.28%)	18 (4.66%)	60 (15.54%)	38 (9.84%)	59 (15.28%)
2010	2,181,847	277	0.0127	145 (31.25%)	78 (16.81%)	41 (8.84%)	83 (17.89%)	53 (11.42%)	64 (13.79%)
2015	2,670,252	343	0.0128	229 (38.55%)	89 (14.98%)	44 (7.41%)	118 (19.87%)	49 (8.25%)	65 (10.94%)
2020	3,701,448	548	0.0148	401 (39.43%)	181 (17.80%)	80 (7.87%)	169 (16.62%)	66 (6.49%)	120 (11.80%)
2025	4,283,012	643	0.0150	388 (35.08%)	248 (22.42%)	68 (6.15%)	179 (16.18%)	84 (7.59%)	139 (12.57%)

from 0.0056% in 1990 to approximately 0.0150% in 2025, indicating a pronounced intensification of research activity rather than a simple cumulative growth effect (see Fig. 8).

The disciplinary distribution further supports this transition. Earth sciences remained the largest individual research domain throughout the study period, generally accounting for approximately 31–40% of barite-related publications (Table 6; Fig. 9). This confirms the continued importance of geochemistry, mineralogy, ore geology, sedimentary processes, and deposit characterization in barite research. However, engineering and technology, materials science, and applied physics increased progressively through time, particularly after 2005. This shift reflects the growing role of barite in high-density composites, radiation-shielding concrete, functional ceramics, and other engineered materials.

Environmental and water-related research remained smaller but persistent, whereas medical and biological categories contributed more selectively (see Fig. 8b and Supplementary Materials: Table S3).

The comparison between barite-related subject categories and the overall WoS-CC database further highlights the disciplinary specialization of the field (Table 7). Barite research is strongly enriched in materials science, applied physics, ceramics, geochemistry, crystallography, mineralogy, and mining/mineral processing. These patterns confirm that barite research has evolved from a predominantly geological and resource-oriented field into a broader interdisciplinary domain linking mineral-resource geology, engineered materials, processing, and applied geo-science. At the same time, the persistence of mineralogy,

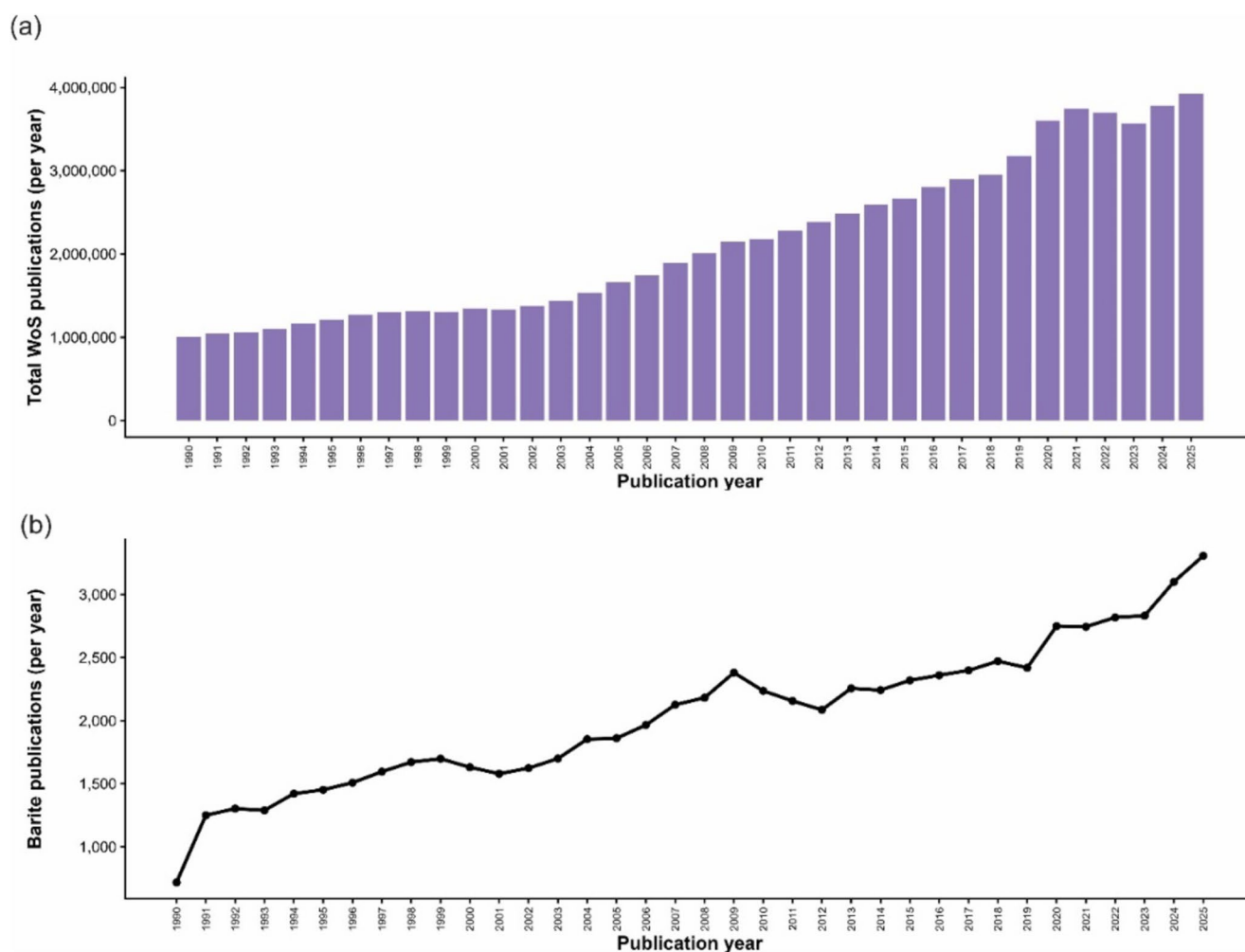


Fig. 8 (a) Annual total WoS publications (1990–2025); (b) annual barite publications

geochemistry, and mining-related categories indicates that deposit geology and ore characterization remain foundational to the field (see Supplementary Materials: Tables S3A–B and Figure S7).

Discussion

Geological significance of the bibliometric clusters

The correspondence between the genetic deposit types summarized in Table 2 and the keyword clusters identified in the global barite network indicates that the bibliometric structure of the literature is strongly controlled by established geological models of barite formation. Rather than forming a disconnected set of research themes, the main clusters reflect a continuum of barite-forming environments, ranging from sedimentary–diagenetic and basin-related systems to hydrothermal, polymetallic, magmatic, and carbonatite-associated settings.

The REE–carbonatite cluster highlights the increasing integration of barite research with alkaline magmatism, fractional crystallization, metasomatic enrichment, and late-stage magmatic–hydrothermal processes (Heinrich and Vian 1967; Ehya and Mazraei 2017; Weng et al. 2023; Zhang et al. 2024). This association is important because it positions barite not only as an industrial mineral, but also as a potential tracer of fluid evolution and element mobility in REE- and critical-metal-bearing systems. Similarly, the hydrothermal and polymetallic clusters emphasize the role of barite as a gangue mineral, fluid indicator, and associated phase in porphyry, epithermal, volcanogenic massive sulphide, and base-metal systems (Melekestseva et al. 2014; Abu-Fatima et al. 2021; Li et al. 2026; Satti et al. 2026).

The sedimentary and diagenetic clusters may reflect the long-standing importance of sulfate reduction, organic-matter degradation, methane-related processes, and barium–sulfate cycling in barite precipitation (Savage 2004; Elswick and Maynard 2014; Magnall et al. 2016; Light et al. 2023b). Together with the carbonate-hosted and MVT-related terms,

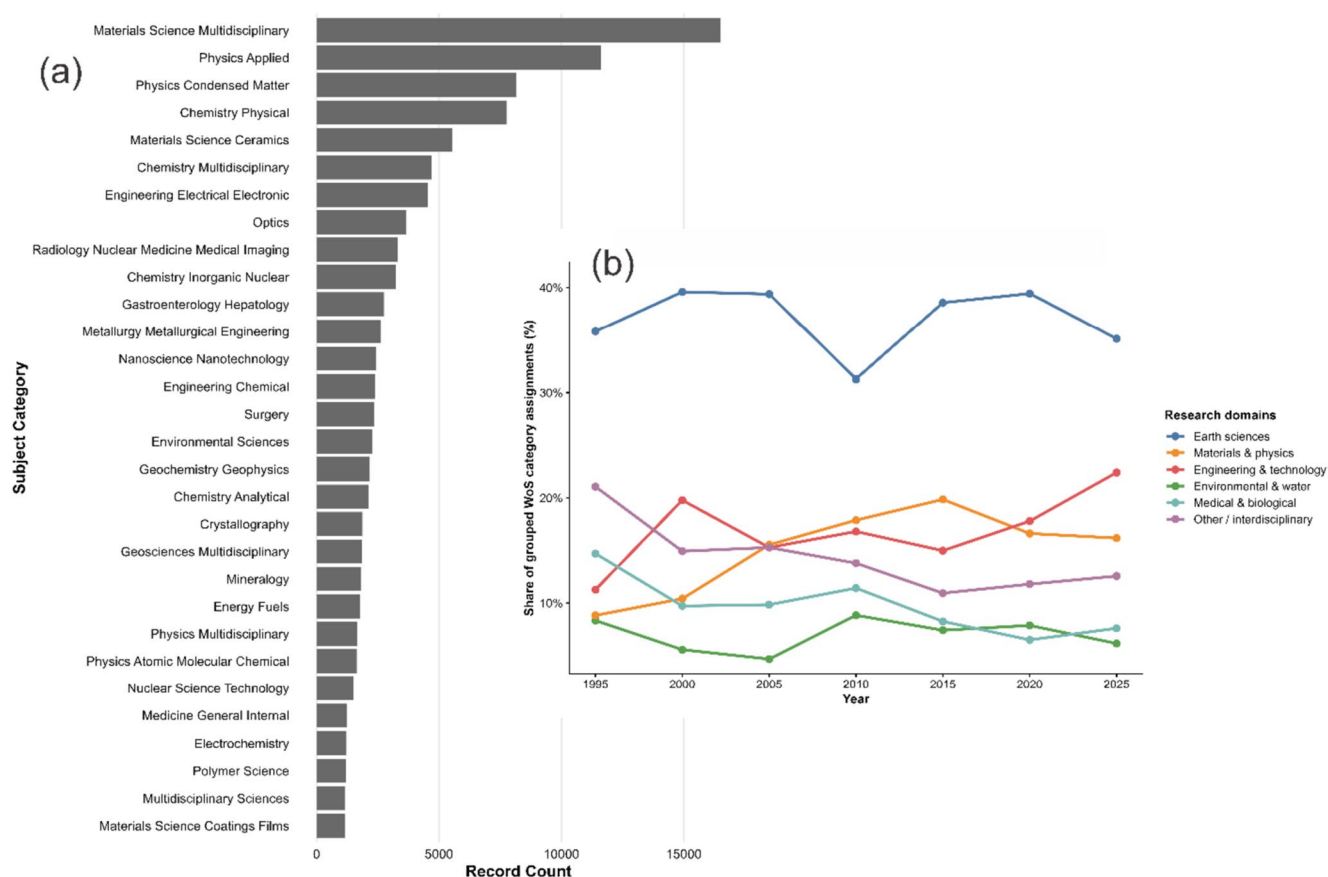


Fig. 9 (a) Top 20 subject areas enriched in barite related research; (b) temporal evolution of grouped WoS research domains in barite-related studies between 1990 and 2025, showing the changing relative contri-

bution of earth sciences, materials, engineering, environmental, and medical research fields

Table 7 Major Web of Science subject-category assignments associated with barite-related records compared with the overall WoS-CC database

Web of science category	Barite records	Barite %	All WoS %	Relative index*
Materials Science Multidisciplinary	16,493	20.449	4.443	4.60
Physics Applied	11,608	14.392	3.210	4.48
Physics Condensed Matter	8,156	10.112	1.571	6.44
Chemistry Physical	7,757	9.617	2.508	3.83
Materials Science Ceramics	5,546	6.876	0.309	22.25
Engineering Electrical Electronic	4,547	5.638	5.828	0.97
Chemistry Multidisciplinary	4,690	5.815	3.324	1.75
Optics	3,650	4.525	1.825	2.48
Radiology Nuclear Medicine Medical Imaging	3,302	4.094	1.391	2.94
Chemistry Inorganic Nuclear	3,229	4.003	0.571	7.01
Metallurgy Metallurgical Engineering	2,612	3.238	0.913	3.55
Engineering Chemical	2,376	2.946	1.568	1.88
Environmental Sciences	2,284	2.832	2.387	1.19
Geochemistry Geophysics	2,175	2.697	0.497	5.43
Crystallography	1,869	2.317	0.378	6.13
Mineralogy	1,808	2.242	0.143	15.67
Mining Mineral Processing	911	1.129	0.158	7.15

*Because Web of Science assigns multiple subject categories to individual publications, percentages do not sum to 100%. Values represent Web of Science subject-category assignments rather than unique publications. Because a single publication may be assigned to multiple WoS categories, category counts exceed the number of records in the main bibliometric corpus

these clusters show that barite research remains strongly anchored in fluid–rock interaction, redox evolution, sulfate availability, and basin-scale fluid migration (Griffith and Paytan 2012; Martinez-Ruiz et al. 2019; Feng et al. 2022; Weibel et al. 2022; Wu et al. 2022). Minor keyword clusters associated with extensional and volcanic-arc settings further emphasize the role of structural and tectonic controls in barite mineralization. These associations indicate that fault systems, fracture networks, and tectonically controlled fluid pathways commonly influence the localization of barite deposits (Kaiser et al. 1987; Kontak 2006; Alizadeh et al. 2023; Daoud et al. 2025a).

The co-occurrence of these terms demonstrates that contemporary barite research merges geochemical tracing, sedimentary diagenesis, and hydrothermal fluid evolution into a unified framework. Particularly, the strong link between fluid inclusion and sulfate reduction may indicate a growing emphasis on understanding the physicochemical parameters (salinity, temperature, redox potential) that control barite mineralization across different environments (Kravchishina et al. 2023; Salvioli et al. 2026).

The main geological implication is that barite research has moved beyond simple deposit description toward a more integrated interpretation of barite as a record of fluid sources, physicochemical conditions, and tectono-sedimentary setting. However, the synthesis also shows that many geological studies remain only weakly connected to resource quality, beneficiation behavior, and industrial end-use requirements. This represents a major research gap, because economic development depends not only on genetic setting or occurrence, but also on ore grade, mineralogical purity, processing behavior, infrastructure, and market accessibility.

Technological development and industrial implications of barite-based materials

Research on barite-based materials has evolved significantly in the past decade (see Fig. 9). Earlier studies focused mainly on radiation-attenuation properties of barite aggregates. Recently, research has increasingly integrated mechanical performance, durability, and radiation protection in optimized composite designs (Babeer et al. 2024; Elbauomy et al. 2025; Babajani et al. 2026; Syllisomchanh et al. 2026). The dual emphasis on mechanical strength and radiation attenuation observed in the bibliometric clusters underscores the importance of barite as a high-density aggregate that can enhance shielding performance in structural concrete (Vu et al. 2020; Light et al. 2023a; Syllisomchanh et al. 2025). In medical and nuclear infrastructure, barite concretes are studied for radiotherapy bunkers, diagnostic shielding walls, and radioactive-waste containment

systems (Onaizi et al. 2024). Beyond shielding, emerging research also explores barite-bearing materials for environmental engineering and specialized construction applications, including heavy-metal immobilization and durable eco-construction materials (Jenk et al. 2006; Syllisomchanh et al. 2025). The literature shows that barite-based materials are shifting from traditional heavyweight shielding concretes to multifunctional engineered composites for nuclear, medical, and specialized infrastructure applications (Al-Abdullah 2026). These developments will likely increase demand for barite products with consistent density and composition, especially in regulated industrial sectors.

The key implication is that future demand may increasingly depend on material specifications rather than bulk tonnage alone. Regulated applications require consistency in density, purity, particle-size distribution, chemical stability, and performance under service conditions. Yet the bibliometric synthesis shows that materials studies rarely connect engineering performance with deposit type, ore mineralogy, beneficiation requirements, or feedstock variability. Closing this gap is essential for linking barite resource geology with industrial standards and high-value applications.

Remote sensing and GIS as emerging tools for barite exploration

The remote sensing and GIS dataset confirms that geospatial approaches are emerging in barite exploration, but remain underrepresented relative to the broader geological and materials-science literature. This is important because remote sensing can support early-stage mineral targeting in underexplored regions where field access is difficult and geological mapping is incomplete.

The bibliometric evidence shows that current geospatial studies are organized around multispectral imagery, SWIR-sensitive alteration mapping, structural interpretation, and GIS-based mineral-potential modelling. These methods are particularly relevant for structurally controlled and hydrothermal barite systems, where mineralization may be associated with silica alteration, iron oxides, carbonate replacement, and lineament-controlled fluid pathways (Madani and Emam 2011; Behyari et al. 2019; Daoud et al. 2025a; El-Omairi et al. 2025; Kamaunji et al. 2025; Umaru et al. 2026). In arid and semi-arid terrains, where vegetation cover is limited and alteration minerals are exposed, multispectral and hyperspectral methods can provide cost-effective regional screening before field investigation.

Sudan illustrates the value of such approaches. In the Red Sea Hills, barite mineralization is commonly linked to structurally controlled hydrothermal systems in Neoproterozoic volcano-sedimentary rocks of the Arabian–Nubian

Shield and is associated with silica alteration, iron oxides, and polymetallic mineralization (Elsamani et al. 2001; Tucker Barrie 2009; Abu-Fatima et al. 2021; Daoud et al. 2025a, b; Satti et al. 2026). However, remote sensing cannot replace field validation, geochemical sampling, mineralogical characterization, or economic assessment. Its main contribution lies in improving targeting efficiency, reducing exploration uncertainty, and prioritizing areas for detailed ground-based work. To illustrate the global distribution of these deposit types, a geospatial compilation of 50 representative barite localities was assembled from published geological surveys, peer-reviewed literature, and mineral databases including Mindat and USGS Mineral Resources Data System (MRDS) (see Supplementary Materials: Table S4 and Figure S8).

Evolution of barite research and disciplinary shifts

The temporal and disciplinary patterns show that barite research has expanded beyond its traditional geoscience base into a broader interdisciplinary field (see Figs. 8 and 9). Earth sciences remain foundational, particularly through mineralogy, geochemistry, ore geology, sedimentary processes, and deposit characterization. However, the increasing contribution of materials science, applied physics, engineering, ceramics, and radiation-related categories indicates that barite is increasingly studied as a functional industrial material rather than only as a geological commodity.

This disciplinary transition is consistent with the increasing use of barite in high-density composites, radiation-shielding concrete, functional ceramics, drilling fluids, and specialized engineered materials (Jóźwiak-Niedźwiedzka and Lessing 2019; Zayed et al. 2024; Ali et al. 2025). The bibliometric evidence therefore indicates a dual evolution: geological studies continue to define the origin, distribution, and mineralogical characteristics of barite, whereas applied materials and engineering studies increasingly define its technological value.

The comparison with total WoS-CC output is particularly important because it shows that the increase in barite-related publications is not only a by-product of general scientific publication growth (see [Supplementary Materials](#)). The rising proportional share of barite publications indicates a modest but sustained increase in the relative scientific importance of the field. This trend aligns with the growing recognition of barite as a strategic industrial mineral used in energy, infrastructure, shielding, and advanced material systems (Hayes and McCullough 2018; Boyarko and Khatkov 2021; Boyarko and Bolsunovskaya 2023).

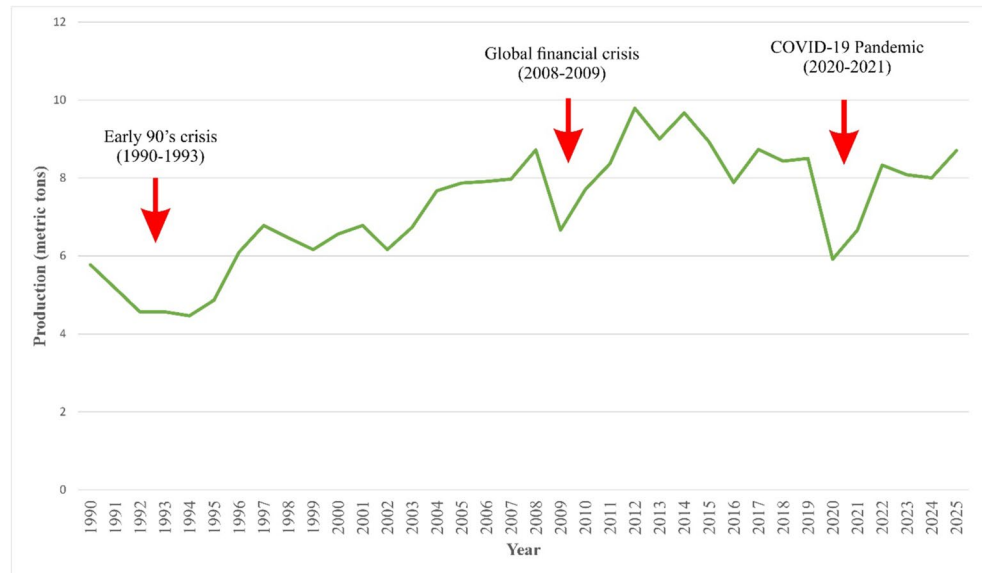
Critical raw material context and supply-related implications

The expansion of barite research across multiple disciplines provides an important context for understanding its increasing relevance in critical raw material and resource-security discussions. This framing is supported by the inclusion of baryte/barite in several critical or strategic mineral assessments, including the European Union critical raw materials list, the U.S. critical minerals lists, and recent resource-policy studies that explicitly discuss world barite resources as critical raw materials (Schulz 2017; Hayes and McCullough 2018; Boyarko and Khatkov 2021; Boyarko and Bolsunovskaya 2023; U.S. Geological Survey 2025, 2026). However, critical mineral classification is not governed by a single universal global standard. It varies among jurisdictions according to industrial demand, economic importance, supply vulnerability, import dependence, substitution potential, and geopolitical risk. Therefore, this study treats barite criticality as a policy and resource-security context rather than as a predefined bibliometric category.

Recent mineral commodity statistics show global barite resources exceed 2 billion tons. Identified resources are estimated at about 740 million tons (U.S. Geological Survey 2026). Global mine production is concentrated in a few countries. Notably, India, China, and Morocco collectively account for a significant proportion of total output. Over the past three decades, production has increased from about 4.5 million to over 8.0 million tons (see Supplementary Materials: Table S1D). Temporary declines occurred during economic crises such as 1990–1993, 2009–2010, and 2020–2021, but production declines were followed by recovery phases (Fig. 10). The long-term increase in barite-related publications broadly parallels the sustained industrial relevance of barite, although annual production fluctuations are more strongly controlled by drilling activity, economic cycles, and global market disruptions than by research output.

The spatial gap between barite production and consumption underscores its importance for resource security. The United States is highly import-dependent. Over 75% of domestic consumption is met by imports, mainly from India, China, Morocco, and Mexico (U.S. Geological Survey 2025, 2026). International trade data show that natural barium sulfate exports and imports follow a few main trade routes. Detailed production and trade statistics are in the [Supplementary Materials](#). These supply trends help explain the rising research focus on barite as both an industrial mineral and a functional material. However, they also reveal a key limitation: the presence of barite mineralization alone does not ensure economically viable supply diversification. Future assessments of barite criticality should combine bibliometric analyses with evaluations of deposit quality, ore purity, beneficiation performance, infrastructure limits,

Fig. 10 Global barite production between 1990 and 2025. Data source: U.S. Geological Survey Mineral Commodity Summaries, including the 2026 summary for 2025 estimates



trade dependencies, and market needs. This broad approach is essential for moving from a general, critical view of raw materials to an evidence-based resource evaluation.

Study limitations

Several limitations must be acknowledged when interpreting the results of this study. First, the bibliometric analysis is based primarily on the Web of Science Core Collection. While WoS-CC provides structured metadata and high-quality indexing, it does not encompass all relevant publications across Scopus, Google Scholar, regional repositories, governmental reports, or industry datasets. Consequently, studies published in regional or non-English journals may be underrepresented. Second, bibliometric analyses are influenced by search terms, keyword variation, language, indexing practices, and database coverage. Although the search strategy was developed to capture the primary terminology used in barite research, some publications may have been omitted due to disciplinary differences in terminology across geology, materials science, engineering, and environmental studies. Third, keyword co-occurrence analysis reveals thematic associations but does not assess deposit quality, technological readiness, economic feasibility, or market viability. Accordingly, bibliometric clusters should be regarded as indicators of research structure and scientific focus, rather than as direct measures of resource potential or industrial demand. Fourth, the global occurrence dataset comprises representative barite localities rather than a comprehensive global inventory. While it provides geological and spatial context, it does not constitute a reserve estimate, supply assessment, or economic evaluation. Therefore, the spatial distribution of occurrences should not be interpreted as evidence of economically viable supply diversification.

Finally, this review synthesizes bibliometric trends, geological context, geospatial visualization, and application-focused literature, but does not evaluate individual deposits in terms of grade, purity, beneficiation performance, extraction costs, infrastructure, or market conditions. These aspects necessitate separate economic, mineral-processing, and resource-assessment investigations.

Conclusions and implications

This study provides a bibliometric and literature-based synthesis of global barite research from 1990 to 2025 and clarifies its main scientific, applied, and strategic directions.

Four principal conclusions and contributions emerge from the synthesis:

- Barite research continues to focus on geological processes, with particular emphasis on fluid–rock interaction, sulfate–barium cycling, redox evolution, and tectono-sedimentary controls.
- The field has expanded from a primarily geoscience-oriented literature to a broader interdisciplinary domain that includes materials science, applied physics, engineering, and radiation-shielding applications.
- Research on barite-based materials increasingly prioritizes performance metrics; however, it remains insufficiently connected to deposit quality, ore purity, beneficiation characteristics, and feedstock variability.
- Remote sensing and GIS constitute an emerging but underdeveloped frontier in exploration, particularly in arid and structurally controlled terrains where alteration minerals and lineaments are prominently exposed.

Future barite research should more effectively integrate deposit geology, resource-quality assessment, beneficiation studies, geospatial targeting, industrial performance testing, and supply-chain analysis. This integration is essential for evaluating barite as both a conventional industrial mineral and a strategic raw material for energy, infrastructure, shielding, and sustainable resource development.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s13563-026-00688-x>.

Acknowledgements The authors gratefully acknowledge Clarivate Analytics for providing access to the Web of Science Core Collection database, which was used as the primary data source for the bibliometric analysis presented in this study. The authors acknowledge the financial and institutional support provided by the University of Debrecen Program for Scientific Publication.

Author contributions All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Abazar M. A. Daoud and Peter Rozsa. The first draft of the manuscript was written by Abazar M. A. Daoud and reviewed by Peter Rozsa. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding Open access funding provided by University of Debrecen.

Data availability All data supporting the findings of this study will be made available upon request.

Declarations

Competing interest The authors declare no competing interests.

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References

- Abu-Fatima M, Marignac C, Cathelineau M, Boiron MC (2021) Metallogeny of a Pan-African oceanic arc: VHMS and gold deposits in the Ariab-Arbaat belt, Haya terrane, Red Sea Hills (Sudan). *Gondwana Res* 98:76–106. <https://doi.org/10.1016/j.gr.2021.06.001>
- Ahmad I, Shahzada K, Ahmad MI, Khan F, Badrashi YI, Khan SW, Muhammad N, Ahmad H (2019) Densification of Concrete using Barite as Fine Aggregate and its Effect on Concrete Mechanical and Radiation Shielding Properties. *J Eng Res* 7:81–95. [https://doi.org/10.1016/S2307-1877\(25\)00636-4](https://doi.org/10.1016/S2307-1877(25)00636-4)
- Ahmad N, Idris MI, Hussin A, Abdul Karim J, Azreen NM, Zainon R (2024) Enhancing shielding efficiency of ordinary and barite concrete in radiation shielding utilizations. *Sci Rep* 14. <https://doi.org/10.1038/s41598-024-76402-0>
- Akkurt I, Boodaghi Malidarre R (2022) Monte Carlo simulation study on Barite Concrete for neutron-gamma photon. *Radiat Eff Defects Solids* 177:943–956. <https://doi.org/10.1080/10420150.2022.2098745>
- Akman F, Ozkan I, Ozel F, Aydemir H, Kaçal MR, Agar O (2022) Production of barite-doped yarns and testing their usability for ionizing and electromagnetic radiation shielding. *Radiat Phys Chem* 201. <https://doi.org/10.1016/j.radphyschem.2022.110464>
- Al-Abdullah T (2026) Sustainable and high-performance solutions for radiation shielding in concrete: Recent advances and future directions. *J Radiat Res Appl Sci* 19:102255. <https://doi.org/10.1016/j.jrras.2026.102255>
- Al-Sarray E, Akkurt I, Günoğlu K, Evcin A, Bezir N (2017) Radiation shielding properties of some composite panel. *Acta Phys Pol Pol Acad Sci* 490–492. <https://doi.org/10.12693/APhysPolA.132.490>
- Ali MAEM, Hafez MAY, Nagy NM, Abed NS (2025) Radiation shielding properties of sustainable concrete with novel plastering techniques. *Ann Nucl Energy* 211. <https://doi.org/10.1016/j.anucene.2024.110958>
- Alizadeh A, Hoseini C, Haji E (2023) Structural Conditions for Localization of Barite Mineralization in Tectonic Evolution of the Southern Sanandaj Zone, Iran. *Geotectonics* 57:820–834. <https://doi.org/10.1134/S001685212306002X>
- Babajani E, Heidari Sangestani S, Masti D, Hosseini M, Sepanloo K (2026) Improving radiation shielding and mechanical properties of concrete incorporating barite, magnetite, and serpentine aggregates. *Appl Radiat Isot* 235:112722. <https://doi.org/10.1016/j.apradiso.2026.112722>
- Babeer AM, Amin AM, Sayyed MI, Mahmoud AE, Abdo MA, Ellakwa TE, Sadeq MS (2024) Impact of mixed heavy metal cations (Ba and Bi) on the structure, optical and ionizing radiation shielding parameters of Bi₂O₃–BaO–Fe₂O₃–SrO–B₂O₃ glass matrix. *Ceram Int* 50:19245–19258. <https://doi.org/10.1016/j.ceramint.2024.03.024>
- Badarloo B, Lehner P, Doost RB (2022) Mechanical Properties and Gamma Radiation Transmission Rate of Heavyweight Concrete Containing Barite Aggregates. *Materials* 15. <https://doi.org/10.3390/ma15062173>
- Barbhuiya S, Das BB, Norman P, Qureshi T (2025) A comprehensive review of radiation shielding concrete: Properties, design, evaluation, and applications. *Struct Concrete* 26:1809–1855. <https://doi.org/10.1002/suco.202400519>
- Behyari M, Rahimsouri Y, Hoseinzadeh E, Kurd N (2019) Evaluating of lithological and structural controls on the barite mineralization by using the remote sensing, Fry and fractal methods, Northwest Iran. *Arab J Geosci* 12:167. <https://doi.org/10.1007/s12517-019-4298-z>
- Boyarko GYu K VYu (2021) Current state of production and consumption of barite raw materials in Russia. *Bulletin of the Tomsk Polytechnic University. Geo Assets Eng* 332:180–191. <https://doi.org/10.18799/24131830/2021/10/3403>
- Boyarko GYu, Bolsunovskaya LM (2023) World's barite resources as critical raw material. *Min Sci Technol (Russian Federation)* 8:264–277. <https://doi.org/10.17073/2500-0632-2023-02-85>
- Bukar UA, Sayeed MS, Amodu OA, Razak SFA, Yogarayan S, Othman M (2025) Leveraging VOSviewer approach for mapping, visualisation, and interpretation of crisis data for disaster management and decision-making. *Int J Inform Manage Data Insights* 5:100314. <https://doi.org/10.1016/j.jjimei.2024.100314>
- Chirico R, Mondillo N, Laukamp C, Mormone A, Di Martire D, Novelino A, Balassone G (2023) Mapping hydrothermal and supergene alteration zones associated with carbonate-hosted Zn-Pb deposits

- by using PRISMA satellite imagery supported by field-based hyperspectral data, mineralogical and geochemical analysis. *Ore Geol Rev* 152:105244. <https://doi.org/10.1016/j.oregeorev.2022.105244>
- Ciullo PA, Hewitt N (1999) Compounding materials. In: The rubber formulary. *Plastics Design Library*, William Andrew Publishing, Norwich, NY, pp 4–49. <https://doi.org/10.1016/B978-081551434-3.50003-8>
- Cotrino-Teatino MA, Marquina-Araujo JJ (2025) Circular economy in the mining industry: A bibliometric and systematic literature review. *Resour Policy* 102:105513. <https://doi.org/10.1016/j.resourpol.2025.105513>
- Daoud AMA, Shebl A, Abdelkader MM, Mohieldain AA, Csámer Á, Satti AMN, Rózsa P (2025a) Remote sensing and gravity investigations for barite detection in Neoproterozoic rocks in the Ariab area, Red Sea Hills, Sudan. *Remote Sens Appl* 37. <https://doi.org/10.1016/j.rsase.2024.101416>
- Daoud AMA, Shebl A, Nafi M, Elrasheed AA, Csámer Á, Rózsa P (2025b) Machine Learning-Based Lithological Mapping and Mineral Prospecting Using Hyperspectral and Multispectral Remote Sensing in Wadi Halfa, North Sudan. *J Afr Earth Sc* 105816. <https://doi.org/10.1016/j.jafrearsci.2025.105816>
- Daungwilailuk T, Yenchai C, Rungjaroenkiti W, Pheinsusom P, Panwisawas C, Pansuk W (2022) Use of barite concrete for radiation shielding against gamma-rays and neutrons. *Constr Build Mater* 326. <https://doi.org/10.1016/j.conbuildmat.2022.126838>
- Deer William A, Howie, Robert A, Zussman J (2013) An introduction to the rock-forming minerals, 3rd edn. Mineralogical Society of Great Britain and Ireland, London
- Ehya F, Mazraei SM (2017) Hydrothermal barite mineralization at Chenarvardeh deposit, Markazi Province, Iran: Evidences from REE geochemistry and fluid inclusions. *J Afr Earth Sc* 134:299–307. <https://doi.org/10.1016/j.jafrearsci.2016.11.006>
- El-Omairi MA, Garouani A, El, Abdellatif M, Garouani M, El, Boumehdi M, Shebl A (2025) Remote sensing and aeromagnetic data integration for mapping Cu, Mn, Co, Ba, and Fe Mineralization: A Case study from Ait Sengane, Anti-Atlas, Morocco. *Ore Geol Rev* 183:106701. <https://doi.org/10.1016/j.oregeorev.2025.106701>
- Elbauomy AK, Fathy IN, Nabil IM, Elgaby A, Hamdy GA, Saif MS (2025) Mechanical, microstructural, and radiation shielding characteristics of sustainable high-strength concrete incorporating recycled wastes blended powders. *Sci Rep* 15:40398. <https://doi.org/10.1038/s41598-025-23824-z>
- Elsamani Y, Almuslem AA, Tokhi M El (2001) Geology and geotectonic classification of pan-african gold mineralizations in the Red Sea Hills, Sudan. *Int Geol Rev* 43:1117–1128. <https://doi.org/10.1080/00206810109465064>
- Elswick ER, Maynard JB (2014) Bedded Barite Deposits: Environments of Deposition, Styles of Mineralization, and Tectonic Settings. In: *Treatise on Geochemistry*. Elsevier, pp 629–656
- Feng J, Luo M, Liang J, Yang S, Wang H, Li N, Sun X (2022) Possible links with methane seepage and gas hydrate dynamics inferred from authigenic barite records in the northern south china sea. *Front Earth Sci (Lausanne)* 10. <https://doi.org/10.3389/feart.2022.968504>
- Gao Z, Zhang C, McFadzean B (2025) A Bibliometric Analysis of Fluorite Resource Utilization Technology: Global and Chinese Development in the Past 25 Years. *Minerals* 15:679. <https://doi.org/10.3390/min15070679>
- U.S. Geological Survey (2025) Mineral commodity summaries 2025. U.S. Geological Survey, Reston, Virginia. <https://doi.org/10.3133/mcs2025>
- U.S. Geological Survey (2026) Mineral commodity summaries 2026. U.S. Geological Survey, Reston, Virginia. <https://doi.org/10.3133/mcs2026>
- Ghorbani Derakhshi M, Hosseinzadeh MR, Moayyed M, Maghfouri S (2020) Geological, isotope geochemical and fluid inclusion constraints on the Mishu SEDEX-type Barite (Pb-Cu-Zn) system, NW Iran. *Ore Geol Rev* 121. <https://doi.org/10.1016/j.oregeorev.2020.103493>
- Goharshadi K, Masoudpanah SM, Nasrinpour H, Namayandeh Jorabchi M (2025) Effects of Ba dopant on the structural, microstructural, and electrochemical properties of NCM811 cathode material (BaxLi1–xNi0.8Co0.1Mn0.1O2) for Li-ion storage. *Electrochem commun* 172:107878. <https://doi.org/10.1016/j.elecom.2025.107878>
- Green TH (1994) Experimental studies of trace-element partitioning applicable to igneous petrogenesis — Sedona 16 years later. *Chem Geol* 117:1–36. [https://doi.org/10.1016/0009-2541\(94\)90119-8](https://doi.org/10.1016/0009-2541(94)90119-8)
- Griffith EM, Paytan A (2012) Barite in the ocean - occurrence, geochemistry and palaeoceanographic applications. *Sedimentology* 59:1817–1835. <https://doi.org/10.1111/j.1365-3091.2012.01327.x>
- Hanor JS (2000) Barite–Celestine Geochemistry and Environments of Formation. *Rev Mineral Geochem* 40:193–275. <https://doi.org/10.2138/rmg.2000.40.4>
- Hayes SM, McCullough EA (2018) Critical minerals: A review of elemental trends in comprehensive criticality studies. *Resour Policy* 59:192–199. <https://doi.org/10.1016/j.resourpol.2018.06.015>
- Heinrich EW, Vian RW (1967) Carbonatitic barites. *American Mineralogist. J Earth Planet Mater* 52:1179–1189. <https://pubs.geoscienceworld.org/msa/ammin/article-abstract/52/7-8/1179/542273/Carbonatitic-Barites?redirectedFrom=fulltext>
- Huang Y (2024) Bibliometric analysis of GIS applications in heritage studies based on Web of Science from 1994 to 2023. *Herit Sci* 12:57. <https://doi.org/10.1186/s40494-024-01163-y>
- Huang G, Mitchell RN, Palin RM, Spencer CJ, Guo J (2022) Barium content of Archaeal continental crust reveals the onset of subduction was not global. *Nat Commun* 13:6553. <https://doi.org/10.1038/s41467-022-34343-0>
- Jenk U, Zimmermann U, Ziegenbalg G (2006) The use of BaSO₄ supersaturated solutions for in-situ immobilization of heavy metals in the abandoned Wismut GmbH uranium mine at Königstein. *Uranium in the Environment*. Springer, Berlin/Heidelberg, pp 721–727. https://doi.org/10.1007/3-540-28367-6_73
- Johnson CA, Piatak NM, Miller MM (2017) Barite (Barium). In: Schulz KJ, DeYoung JH Jr, Seal RR II, Bradley DC (eds) *Critical mineral resources of the United States—Economic and environmental geology and prospects for future supply*. U.S. Geological Survey Professional Paper 1802, pp D1–D18. <https://doi.org/10.3133/pp1802D>
- Jóźwiak-Niedźwiedzka D, Lessing PA (2019) High-density and radiation shielding concrete. *Developments in the Formulation and Reinforcement of Concrete*. Elsevier, pp 193–228. <https://doi.org/10.1016/B978-0-08-102616-8.00009-5>
- Jung KH, Seo S, Lee J, Kim MJ (2025) An alternative process using barium compounds recycling for producing battery grade lithium hydroxide from a crude Li₂SO₄ solution. *J Hazard Mater Adv* 17:100623. <https://doi.org/10.1016/j.hazadv.2025.100623>
- Kaiser CJ, Kelly WC, Wagner RJ, Shanks WC (1987) Geologic and geochemical controls of mineralization in the Southeast Missouri barite district. *Econ Geol* 82:719–734. <https://doi.org/10.2113/gsecongeo.82.3.719>
- Kamaunji VD, Sanislav IV, Kamaunji DZ, Nkom DO, Ahmed HA, Abdelfadil KM, Odumu OJ, Wilberforce D, Sami M (2025) Prospectivity mapping of high-purity barite mineralization in the Eastern Nigerian basement terrane using generalized algorithm-decoded thermal infrared data. *Ore Geol Rev* 187:106935. <https://doi.org/10.1016/j.oregeorev.2025.106935>
- Khan MH, Qiuhong Z, Sikandar MA, Khan B, Zhu H, Khan MS (2024) Evaluation of mechanical strength, gamma-ray shielding

- characteristics, and ITZ microstructural properties of heavy-weight concrete using nano-silica (SiO₂) and barite aggregates. *Constr Build Mater* 419:135483. <https://doi.org/10.1016/j.conbuildmat.2024.135483>
- Kokaly RF, Clark RN, Swayze GA, Livo KE, Hoefen TM, Pearson NC, Wise RA, Benzel W, Lowers HA, Driscoll RL, Klein AJ (2017) USGS Spectral Library Version 7. U S Geol Surv Data Ser 1035. <https://doi.org/10.3133/ds1035>
- Kontak DJ (2006) Structurally Controlled Vein Barite Mineralization in the Maritimes Basin of Eastern Canada: Geologic Setting, Stable Isotopes, and Fluid Inclusions. *Econ Geol* 101:407–430. <https://doi.org/10.2113/gsecongeo.101.2.407>
- Kravchishina MD, Prokofiev VY, Dara OM, Baranov BV, Klyuvitkin AA, Iakimova KS, Kalgin VY, Lein AY (2023) Fluid Inclusion Studies of Barite Disseminated in Hydrothermal Sediments of the Mohns Ridge. *Minerals* 13. <https://doi.org/10.3390/min13091117>
- Laukamp C (2022) Geological Mapping using Mineral Absorption Feature-Guided Band-Ratios Applied to Prisma Satellite Hyperspectral Level 2D Imagery. In: IGARSS 2022–2022 IEEE International Geoscience and Remote Sensing Symposium. IEEE, pp 5981–5984. <https://doi.org/10.1109/IGARSS46834.2022.9884015>
- Leach DL, Taylor RD, Fey DL, Diehl SF, Saltus RW (2010) A deposit model for Mississippi Valley. <https://doi.org/10.3133/sir20105070A>. -Type lead-zinc ores
- Lee JW, Kweon DC (2020) Assessment of dose reduction and image quality by barium composite shielding in head and chest CT. *Radiat Eff Defects Solids* 175:809–826. <https://doi.org/10.1080/10420150.2020.1768391>
- Li Y, Zou H, Said N, Liu H (2023) A new classification of barite deposits in China. *Ore Energy Resource Geol* 14:100019. <https://doi.org/10.1016/j.oreoa.2023.100019>
- Li Q, Zhao K-D, Zhu Z-Y, Palmer MR, Chen W, Jiang S-Y (2024) Barium isotope variations in highly-fractionated granites linked to tin mineralization: New insights into tin recycling and enrichment in the continental crust. *Chem Geol* 646:121914. <https://doi.org/10.1016/j.chemgeo.2023.121914>
- Li X-C, Deng G-X, Nan X-Y, Yuan X-Y, Fan H-R, Huang F (2026) Large-scale REE mineralization linked to intensive evolution of carbonatitic-alkaline magmas to brine-melts: Insights from Sr-Nd-Ba isotopes. *Geochemistry* 86:126390. <https://doi.org/10.1016/j.chemer.2026.126390>
- Light T, Garcia M, Prairie JC, Martínez-Ruiz F, Norris R (2023a) Water column barium sulfate dissolution and shielding by organic matter aggregates: Implications for the pelagic barite proxy. *Chem Geol* 636:121637. <https://doi.org/10.1016/j.chemgeo.2023.121637>
- Light T, Martínez-Ruiz F, Norris R (2023b) Marine barite morphology as an indicator of biogeochemical conditions within organic matter aggregates. *Geochim Cosmochim Acta* 358:38–48. <https://doi.org/10.1016/j.gca.2023.08.012>
- Liu H, Zhang Z, Gao C, Bai Y, Liu B, Wang W, Ma Y, Saijilafu, Yang H, Li Y, Chan A, Yang L (2020) Enhancing effects of radiopaque agent BaSO₄ on mechanical and biocompatibility properties of injectable calcium phosphate composite cement. *Mater Sci Engineering: C* 116:110904. <https://doi.org/10.1016/j.msec.2020.110904>
- Liu Z, Huang J, Li Y, Liu X, Qiang F, He Y (2025) A Bibliometric Analysis of Geological Hazards Monitoring Technologies. *Sustainability* 17:962. <https://doi.org/10.3390/su17030962>
- Madani AA, Emam AA (2011) SWIR ASTER band ratios for lithological mapping and mineral exploration: A case study from El Hudi area, southeastern desert, Egypt. *Arab J Geosci* 4:45–52. <https://doi.org/10.1007/s12517-009-0059-8>
- Magnall JM, Gleeson SA, Stern RA, Newton RJ, Poulton SW, Paradis S (2016) Open system sulphate reduction in a diagenetic environment – Isotopic analysis of barite ($\delta^{34}\text{S}$ and $\delta^{18}\text{O}$) and pyrite ($\delta^{34}\text{S}$) from the Tom and Jason Late Devonian Zn–Pb–Ba deposits, Selwyn Basin, Canada. *Geochim Cosmochim Acta* 180:146–163. <https://doi.org/10.1016/j.gca.2016.02.015>
- Marlés-Sáenz E, Gómez-Luna E, Guerrero JM, Vasquez JC (2025) Innovative Bibliometric Methodology: A New Big Data-Based Framework for Scientific Research. *Energies* (Basel) 18:2437. <https://doi.org/10.3390/en18102437>
- Martínez-Ruiz F, Paytan A, Gonzalez-Muñoz MT, Jroundi F, Abad MM, Lam PJ, Bishop JKB, Horner TJ, Morton PL, Kastner M (2019) Barite formation in the ocean: Origin of amorphous and crystalline precipitates. *Chem Geol* 511:441–451. <https://doi.org/10.1016/j.chemgeo.2018.09.011>
- Melekestseva IYu, Tret'yakov GA, Nimis P, Yuminov AM, Maslennikov VV, Maslennikova SP, Kotlyarov VA, Beltenev VE, Danyushevsky LV, Large R (2014) Barite-rich massive sulfides from the Semenov-1 hydrothermal field (Mid-Atlantic Ridge, 13°30.87' N): Evidence for phase separation and magmatic input. *Mar Geol* 349:37–54. <https://doi.org/10.1016/j.margeo.2013.12.013>
- Ninomiya Y, Fu B (2019) Thermal infrared multispectral remote sensing of lithology and mineralogy based on spectral properties of materials. *Ore Geol Rev* 108:54–72. <https://doi.org/10.1016/j.oregeorev.2018.03.012>
- Onaizi AM, Amran M, Tang W, Betoush N, Alhassan M, Rashid RSM, Yasin MF, Bayagoob KH, Onaizi SA (2024) Radiation-shielding concrete: A review of materials, performance, and the impact of radiation on concrete properties. *J Building Eng* 97:110800. <https://doi.org/10.1016/j.job.2024.110800>
- Özdoğan H, Üncü YA, Akman F, Polat H, Kaçal MR (2024) Detailed Analysis of Gamma-Shielding Characteristics of Ternary Composites Using Experimental, Theoretical and Monte Carlo Simulation Methods. *Polym* (Basel) 16. <https://doi.org/10.3390/polym16131778>
- Özen S, Şengül C, Erenoğlu T, Çolak Ü, Reyhancan İA, Taşdemir MA (2016) Properties of Heavyweight Concrete for Structural and Radiation Shielding Purposes. *Arab J Sci Eng* 41:1573–1584. <https://doi.org/10.1007/s13369-015-1868-6>
- Padigi P, Goncher G, Evans D, Solanki R (2015) Potassium barium hexacyanoferrate – A potential cathode material for rechargeable calcium ion batteries. *J Power Sources* 273:460–464. <https://doi.org/10.1016/j.jpowsour.2014.09.101>
- Penaloza I, Tita A, McNew E, Chu P (2023) Barite resources, production and recovery using froth flotation: A review. *Min Eng* 203:108327. <https://doi.org/10.1016/j.mineng.2023.108327>
- Pour AB, Park TYS, Park Y, Hong JK, Muslim AM, Läuffer A, Crispini L, Pradhan B, Zoheir B, Rahmani O, Hashim M, Hossain MS (2019) Landsat-8, advanced spaceborne thermal emission and reflection radiometer, and WorldView-3 multispectral satellite imagery for prospecting copper-gold mineralization in the northeastern Inglefield Mobile Belt (IMB), northwest Greenland. *Remote Sens* (Basel) 11. <https://doi.org/10.3390/rs11202430>
- Radhakrishnan S, Erbis S, Isaacs JA, Kamarthi S (2017) Novel keyword co-occurrence network-based methods to foster systematic reviews of scientific literature. *PLoS ONE* 12:e0172778. <https://doi.org/10.1371/journal.pone.0172778>
- Rasoul Abdar Esfahani SM, Zareei SA, Madhkan M, Ameri F, Rashidiani J, Taheri RA (2021) Mechanical and gamma-ray shielding properties and environmental benefits of concrete incorporating GGBFS and copper slag. *J Building Eng* 33. <https://doi.org/10.1016/j.job.2020.101615>
- Rockwell BW, Hofstra AH (2008) Identification of quartz and carbonate minerals across northern Nevada using aster thermal infrared emissivity data-implications for geologic mapping and mineral resource investigations in well-studied and frontier areas. *Geosphere* 4:218–246. <https://doi.org/10.1130/GES00126.1>
- Rockwell BW, Gnesda WR, Hofstra AH (2021) Improved Automated Identification and Mapping of Iron Sulfate Minerals, Other

- Mineral Groups, and Vegetation using Landsat 8 Operational Land Imager Data, San Juan Mountains, Colorado, and Four Corners Region. U.S. Geological Survey. <https://doi.org/10.3133/sim3466>
- Salvioli MA, Lajoinie MF, Recio C, Rainoldi AL, de la Cal HG, Lanfranchini ME, Cesaretti NN (2026) Isotopic (S-O-Sr) constraints on the evolution of the barite-polymetallic system in the Colipilli district, Neuquén Basin (Argentina). *J South Am Earth Sci* 175:106022. <https://doi.org/10.1016/j.jsames.2026.106022>
- Satti AMN, ElMakky AM, Khalil KI, Hassan MNM, Rózska P, Daoud AMA (2026) Mapping and genetic interpretation of VMS-related gossans in the Tagotieb region, Red Sea Hills, NE Sudan using multispectral indices and machine learning models. *J Afr Earth Sc* 240:106171. <https://doi.org/10.1016/j.jafrearsci.2026.106171>
- Savage D (2004) Barite as an indicator of cross-formational fluid flow. In *Eleventh International Symposium on Water-Rock Interaction*, (eds. R.B. Wanty and R.R. Seal), Saratoga Springs, USA, Balkema, Rotterdam, 303–306
- Schulz KJ, Jr DJH, SRR, I and, BDC (eds) (2017) Critical mineral resources of the United States—Economic and environmental geology and prospects for future supply. <https://doi.org/10.3133/pp1802>
- Sharifi Sh, Bagheri R, Shirmardi SP (2013) Comparison of shielding properties for ordinary, barite, serpentine and steel-magnetite concretes using MCNP-4 C code and available experimental results. *Ann Nucl Energy* 53:529–534. <https://doi.org/10.1016/j.anucene.2012.09.015>
- Stevens EWN, Bailey JV, Flood BE, Jones DS, Gilhooly WP, Joye SB, Teske A, Mason OU (2015) Barite encrustation of benthic sulfur-oxidizing bacteria at a marine cold seep. *Geobiology* 13:588–603. <https://doi.org/10.1111/gbi.12154>
- Su Z, Zhou S, Wang C, Sun J, Zeng Y, Zhang J, Zhang M, Wang L, Zhu Z, Li X (2023) A review of the selection and application of experimental materials in the study of physical simulation of engineering rock masses | 工程岩体物理模拟研究中实验材料的选择与应用. *Geol Rev* 69:1133–1149. <https://doi.org/10.1650/9/j.georeview.2022.11.011>
- Sylisomchanh L, Wongs A, Yenchai C, Ekprasert J, Rattanasak U, Sata V, Jaturapitakkul C, Chindaprasit P (2025) Novel heavyweight geopolymer concrete with mill scale and barite aggregates for sustainable radiation shielding applications. *Constr Build Mater* 503:144453. <https://doi.org/10.1016/j.conbuildmat.2025.144453>
- Sylisomchanh L, Wongs A, Yenchai C, Ekprasert J, Rattanasak U, Sata V, Jaturapitakkul C, Chindaprasit P (2026) Structural performance and radiation shielding of low-carbon heavyweight geopolymer concrete with barite aggregate. *Int J Sustain Eng* 19. <https://doi.org/10.1080/19397038.2026.2630466>
- Tawfik TA, Slany M, Palou MT (2023) Influence of heavyweight aggregate on the fresh, mechanical, durability, and microstructural properties of self-compacting concrete under elevated temperatures. *J Building Eng* 80:108104. <https://doi.org/10.1016/j.jobe.2023.108104>
- Thompson AJB, Hauff PL, Robitaille AJ (1999) Alteration Mapping in Exploration: Application of Short-Wave Infrared (SWIR) Spectroscopy. *SEG Discovery* 1–27. <https://doi.org/10.5382/SEGnews.1999-39.fea>
- Tokunaga K, Uruga T, Nitta K, Terada Y, Sekizawa O, Kawagucci S, Takahashi Y (2016) Application of arsenic in barite as a redox indicator for suboxic/anoxic redox condition. *Chem Geol* 447:59–69. <https://doi.org/10.1016/j.chemgeo.2016.10.016>
- Torres ME, Bohrmann G, Dubé TE, Poole FG (2003) Formation of modern and Paleozoic stratiform barite at cold methane seeps on continental margins. *Geology* 31:897. <https://doi.org/10.1130/G19652.1>
- Tucker Barrie C (2009) Hadal Awatib East Cu-Au VMS Deposit, Sudan Resource Estimates NI 43–101 Technical Report. <https://doi.org/10.13140/RG.2.1.1977.4883>
- Umaru AO, Hamman KI, Musa AL, Abubakar F, Abdulmalik NF, Caleb NK, Ishiaka AI, Mavoungou YB, Traore EM, Konate S (2026) Integrated remote sensing and geophysical methods for delineating barite mineralization zones in Dumne area, northeastern Nigeria. *Geosyst Geoenvironment* 100500. <https://doi.org/10.1016/j.geogeo.2026.100500>
- Van der Meer FD, Van der Werff HMA, Van Ruitenbeek FJA, Hecker CA, Bakker WH, Noomen MF, Van der Meijde M, Carranza EJM, de Smeth JB, Woldai T (2012) Multi- and hyperspectral geologic remote sensing: A review. *Int J Appl Earth Obs Geoinf* 14:112–128. <https://doi.org/10.1016/j.jag.2011.08.002>
- Van der Meer FD, van der Werff HMA, van Ruitenbeek FJA (2014) Potential of ESA's Sentinel-2 for geological applications. *Remote Sens Environ* 148:124–133. <https://doi.org/10.1016/j.rse.2014.03.022>
- Van der Werff H, Van der Meer F (2015) Sentinel-2 for mapping iron absorption feature parameters. *Remote Sens (Basel)* 7:12635–12653. <https://doi.org/10.3390/rs71012635>
- van Eck NJ, Waltman L (2010) Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics* 84:523–538. <https://doi.org/10.1007/s11192-009-0146-3>
- van Eck NJ, Waltman L (2017) Citation-based clustering of publications using CitNetExplorer and VOSviewer. *Scientometrics* 111:1053–1070. <https://doi.org/10.1007/s11192-017-2300-7>
- Vu HQ, Tran VH, Nguyen PT, Le NTU, Le MT (2020) Radiation Shielding Properties Prediction of Barite used as Small Aggregate in Mortar. *Eng Technol Appl Sci Res* 10:6469–6475. <https://doi.org/10.48084/etasr.3880>
- Weibel R, Whitehouse MJ, Olivarius M, Jakobsen FC, Mathiesen A, Midtgaard HH, Larsen M (2022) Bioclast-controlled patchy barite cementation – Origin and impact on reservoir properties in deeply buried Upper Jurassic sandstones, North Sea. <https://doi.org/10.1016/j.sedgeo.2021.106063>. *Sediment Geol* 428
- Weng Q, Yang W-B, Niu H-C, Li N-B, Shan Q (2023) Sulfur isotopes of carbonatite from the giant Maoniuping REE deposit, SW China. *Ore Geol Rev* 162:105694. <https://doi.org/10.1016/j.oregeorev.2023.105694>
- Wu J, Liu Z, Michard A, Tachikawa K, Filippidi A, He Z, Hennekam R, Yang S, Davies GR, de Lange GJ (2022) Effect of barite-bound Sr on detrital Sr isotope systematics in marine sediments. *Chem Geol* 587. <https://doi.org/10.1016/j.chemgeo.2021.120613>
- Yang P, Rampal N, Weber J, Bracco JN, Fenter P, Stack AG, Lee SS (2022) Synergistic Enhancement of Lead and Selenate Uptake at the Barite (001)-Water Interface. *Environ Sci Technol* 56:16801–16810. <https://doi.org/10.1021/acs.est.2c04413>
- Zayed AM, El-Khayatt AM, Mahmoud KA, Petrounias P, Masoud MA (2024) Evaluation of Some Heavyweight Minerals as Sustainable Neutron and Gamma-Ray Attenuating Materials: Comprehensive Theoretical and Simulation Investigations. *Arab J Sci Eng*. <https://doi.org/10.1007/s13369-024-09300-2>
- Zhang H, Zhao B, Liu J, Hu Z, Wang Y, Zhao J, Deng G, Gou L, Huang F (2024) Using barium isotopes to distinguish metamorphic and magmatic fluids for the gold deposits. *Ore Geol Rev* 175:106341. <https://doi.org/10.1016/j.oregeorev.2024.106341>
- Zhang Y, Cheng L, Zhu Y-J, Wu J, Yu H-P, Xie S, Li D, Wang Z, Li H (2025) Reversible Li plating regulation on graphite anode through a barium sulfate nanofibers-based dielectric separator for fast charging and high-safety lithium-ion battery. *J Energy Chem* 101:511–523. <https://doi.org/10.1016/j.jechem.2024.08.053>