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A. Zhumagaziev[1], *S. Kurbaniyazov[2], A. Damenova[3], A. Beskempirova[3]
[1]K. Dosmukhamedov Atyrau State University (Atyrau, Kazakhstan),
[2]Khoja Akhmet Yassawi International Kazakh-Turkish University (Turkestan, Kazakhstan),
[3]Muhammad Haidar Dulati Taraz Regional University (Taraz, Kazakhstan)

STRATIGRAPHY AND GEOCHEMISTRY OF SULFATE FORMATIONS IN THE SHERT GYPSUM DEPOSIT

Abstract. This article presents the results of a comprehensive stratigraphic and geochemical study of sulfate formations in the Shert gypsum deposit (Turkestan region, Republic of Kazakhstan). The gypsum-bearing strata are subdivided into two main horizons: Lower Paleogene (30–45 m thick) and Upper Miocene (15–25 m), with well-defined bedding and lateral continuity. The total forecast resources of gypsum exceed 12 million tons, with high lithological uniformity and low impurity content. Petrographic and mineralogical analysis reveals the predominance of alabastrine gypsum with celestine and carbonate inclusions, formed in a shallow, periodically evaporating lagoonal-lacustrine basin under an arid climate. XRD and SEM-EDS analyses confirm the fine-crystalline structure and high purity (***$CaSO_4{\cdot}2H_2O$ > 90%***). Geochemical profiles show increased ***Sr*** and ***Ca*** contents, supporting prospects for strontium extraction. Experimental testing demonstrated compressive strength values of 6.8–8.5 MPa, which meet industrial standards.
Key words: *sulfate-bearing deposits, stratigraphy, geochemistry, celestine, strontium, paleogene, miocene.*

Шерт гипс кен орнындағы сульфатты жыныстардың стратиграфиясы мен геохимиясы

Аңдатпа. Мақалада Қазақстан Республикасының Түркістан облысындағы Шерт гипс кен орнының сульфатты қабаттарының стратиграфиялық және геохимиялық ерекшеліктері қарастырылған. Гипс шөгінділері екі негізгі горизонтқа бөлінеді: төменгі палеоген (қалыңдығы 30–45 м) және жоғарғы миоцен (15–25 м), стратиграфиялық жағынан тұрақты және латералды таралуы жақсы. Гипстің болжамды қоры 12 млн тоннадан асады, құрамында қоспалар аз, литологиялық жағынан біртекті. Петрографиялық зерттеулер гипстің алебастр түрі, целестин және карбонатты қосындылар басым екенін көрсетті. XRD және SEM-EDS талдауы жоғары тазалықты (***$CaSO_4{\cdot}2H_2O$ > 90%***) және майда кристалдық құрылымды растады. Геохимиялық көрсеткіштер ***Sr*** және ***Ca*** элементтерінің мол екенін көрсетті, бұл стронцийді өндірістік жолмен бөліп алуға мүмкіндік береді. Сығымдауға төзімділік 6.8–8.5 МПа, бұл құрылыс стандарттарына сәйкес келеді.
Түйінді сөздер: *сульфатты шөгінділер, стратиграфия, геохимия, целестин, стронций, палеоген, миоцен.*

Стратиграфия и геохимия сульфатсодержащих отложений Шертского месторождения гипса

Аннотация. В статье изложены результаты стратиграфического и геохимического анализа сульфатсодержащих отложений Шертского месторождения гипса (Туркестанская область, Республика Казахстан). Гипсоносная толща подразделяется на два основных горизонта: нижнепалеогеновый (мощностью 30–45 м) и верхнемиоценовый (15–25 м), характеризующиеся устойчивым залеганием и lateral continuity. Прогнозные запасы гипса составляют более 12 млн тонн, при высокой литологической однородности и низком содержании примесей. Петрографический анализ выявил преобладание алебастрового гипса с включениями целестина и карбонатов, сформированных в условиях мелководного лагунно-озерного бассейна засушливого климата. Рентгенофазовый и SEM-EDS анализы подтвердили тонкокристаллическую структуру и высокую чистоту (***$CaSO_4{\cdot}2H_2O$ > 90%***). Геохимические данные выявили повышенное содержание ***Sr*** и ***Ca***, что определяет перспективность извлечения стронция. Экспериментальные испытания показали прочность на сжатие 6,8–8,5 МПа, соответствующую нормативам.
Ключевые слова: *сульфатсодержащие отложения, стратиграфия, геохимия, целестин, стронций, палеоген, миоцен.*

Introduction

Gypsum-bearing sulfate formations are of significant interest both in geological and industrial contexts, particularly due to their economic importance in the construction sector. The Turkestan region of southern Kazakhstan hosts a number of sulfate-rich deposits, among which the Shert deposit is one of the most prominent. These formations are typically associated with arid climate conditions, basin-type sedimentation, and complex diagenetic processes that contribute to the accumulation of evaporite minerals [1–2].

Numerous researchers have studied the geological and geochemical characteristics of sulfate deposits globally and regionally. International studies have addressed the stratigraphic control and geochemical zonation of evaporite basins [3], the mechanisms of gypsum and anhydrite precipitation [4], and the impact of paleoclimatic factors on sulfate mineral formation [5]. In Kazakhstan, researcher such as Saparov A. [6] have investigated the lithology and resource potential of sulfate and gypsum-bearing formations, particularly in southern and central regions.

In recent years, the growing demand for environmentally friendly and energy-efficient construction materials has renewed interest in natural gypsum resources. However, effective utilization of such resources requires a comprehensive understanding of their stratigraphic setting, mineralogical composition, and geochemical properties. The study of sulfate formation processes not only sheds light on the depositional environment and paleoecological conditions but also provides a scientific basis for the development of new technologies for processing gypsum materials [7].

This paper aims to investigate the stratigraphic and geochemical conditions of sulfate formation in the Turkestan region, with a specific focus on the Shert gypsum deposit. The objectives include the identification of lithological and mineralogical features of the deposit, characterization of its geochemical composition, and assessment of its technological suitability for construction purposes.

Scientific Value. This study provides a comprehensive stratigraphic and geochemical characterization of the sulfate-bearing formations of the Shert deposit, located in the Turkestan region. By integrating lithological, mineralogical, and geochemical data, the research enhances understanding of the conditions of gypsum and anhydrite formation in arid continental sedimentary basins. The results contribute to regional geological mapping and resource evaluation, serving as a scientific basis for assessing the industrial potential of sulfate minerals in Central Asia.

Scientific Novelty:

− For the first time, the stratigraphic succession of the Shert deposit has been analyzed in detail in the context of sulfate mineralization, with a focus on paleoenvironmental indicators.

− New data on the chemical composition of gypsum and associated minerals were obtained using modern analytical techniques (e.g., XRF, SEM-EDS).

− The research identifies a unique geochemical zoning pattern within the sulfate sequence, linked to paleoclimate dynamics and diagenetic processes.

– Technological evaluation of gypsum raw material from the deposit reveals promising industrial applications, particularly in cement production and agriculture, which have not been previously documented for this area.

Gypsum, as a widely available sulfate mineral, remains a critical raw material in the construction industry, particularly for the production of drywall, plasters, and cement additives. However, despite its abundance and favorable physical properties, several modern challenges constrain its effective industrial use.

One of the main issues is related to the energy-intensive processes involved in gypsum calcination, especially in the production of stucco ($CaSO_4 \cdot ½H_2O$). High fuel consumption and carbon emissions remain key barriers to the sustainability of traditional gypsum processing technologies [8]. This concern aligns with the global shift toward low-carbon construction materials, prompting the search for more energy-efficient and environmentally friendly production methods.

In addition, the quality and purity of natural gypsum deposits vary significantly depending on geological settings. High concentrations of impurities such as clay minerals, carbonates, and organic matter can reduce the mechanical strength and performance of gypsum-based products. Therefore, the development of pre-treatment and beneficiation technologies for raw gypsum is crucial to improve its usability and expand its applications. Another pressing issue is the increased use of synthetic gypsum (e. g., flue gas desulfurization gypsum), which, while solving waste management problems in the energy sector, introduces new environmental and logistical challenges such as storage, leaching potential, and transport [9]. In this context, local natural gypsum deposits like the Shert deposit may offer strategic advantages due to their accessibility and low transportation cost, provided that adequate processing technologies are developed.

Modern research also emphasizes the potential of gypsum in 3D-printing of building elements, composite material development, and soil stabilization, which opens new markets beyond traditional construction. These innovative directions demand interdisciplinary approaches, integrating geology, material science, and environmental engineering.

Thus, addressing the mineralogical variability of deposits, reducing energy consumption, and advancing processing technologies are central to the future industrial use of gypsum. The Shert deposit, as part of Kazakhstan's resource base, presents an opportunity for localized innovation and sustainable development in the construction materials sector.

Moreover, while the regional sulfate deposits in Kazakhstan have been studied at a reconnaissance level, the stratigraphic and geochemical detail of the Shert deposit remains underexplored. Compared to international analogs in arid regions such as Iran, Jordan, and the North African Basin, the Kazakh gypsum formations remain underutilized in terms of advanced mineral characterization and industrial innovation. Furthermore, the lack of systematic comparison between natural and synthetic gypsum sources highlights the importance of assessing local resources with modern analytical approaches to meet the evolving needs of sustainable construction technologies.

Materials and Methods

The research was conducted at the Department of Geoinnovative Technologies for Integrated Processing of Mineral Raw Materials of the State Institution «Institute of Mineral Resources» (Tashkent, Uzbekistan). The study employed a comprehensive approach combining field geological observations, petrographic analysis, geochemical investigations, and laboratory assessment of the technological properties of gypsum samples.

Stratigraphic logging and lithological characterization of the Shert gypsum deposit were carried out in accordance with regional geological standards. Field measurements were conducted using geodetic instruments and GPS systems, and a total of 25 representative samples were collected from different lithological varieties of gypsum, including massive, fine-crystalline, and laminated forms. Lithofacies were described in terms of color, texture, hardness, and bedding structures.

Petrographic analysis was performed on thin sections using a Leica DM2500P polarizing microscope to identify mineral associations, crystal textures, and microstructural features. Further examination was conducted using scanning electron microscopy (Hitachi SU5000), allowing for high-resolution imaging of fine-grained phases and impurity distribution. The mineralogical composition was determined by X-ray diffraction (Bruker D8 Advance), and clay fraction identification was conducted by the oriented aggregate method.

Geochemical analysis of the major and trace elements was performed at the Institute's Central Analytical Laboratory. The content of oxides such as CaO, SO_3, SiO_2, Al_2O_3, Fe_2O_3, and MgO was measured using X-ray fluorescence spectrometry (panalytical axios) and inductively coupled plasma-optical emission spectrometry (perkinelmer avio 500). The quality of the data was ensured through the use of certified reference materials, duplicate testing, and internal control standards.

To evaluate the technological suitability of the gypsum for industrial use, selected samples underwent laboratory calcination in a programmable muffle furnace at temperatures ranging from 150 to 180 °C. The physical and mechanical properties, including bulk density, setting time, compressive strength, and water absorption, were tested in accordance with international and regional (GOST 125–79) standards [10]. These tests provided essential data on the dehydration behavior, workability, and structural performance of the material for construction applications.

All analytical data were processed using Microsoft Excel and OriginPro 2023 software. The results were visualized and interpreted in accordance with regional stratigraphic frameworks using ArcGIS. The integrated geological, mineralogical, and geochemical data were used to assess the quality, spatial distribution, and industrial potential of the gypsum-bearing formations of the Shert deposit.

Results

The geological survey of the Shert deposit revealed a well-defined sulfate-bearing sequence, primarily associated with Lower Paleogene and Upper Miocene sediments. The productive layers vary in thickness from 25 to 80 meters and are mainly composed of gypsum and anhydrite beds interbedded with marls and claystones (tab.1). Stratigraphically, the sulfate sequence can be subdivided into three informal subunits based on lithological and mineralogical features: the lower unit is characterized by fine-grained anhydrite with dolomitized marl inclusions; the middle unit consists of massive alabastrine gypsum with minor clay partings and is considered the main industrial horizon; the upper unit includes banded gypsum alternating with carbonate and clay-silt layers, reflecting evaporitic cyclicity.

Sedimentary structures such as desiccation cracks, ripple marks, and fossil assemblages indicate deposition in a shallow lacustrine to lagoonal environment under arid continental climatic conditions with intermittent evaporation.

To characterize the lithostratigraphic structure of the sulfate-bearing series in the Shert deposit, representative samples were collected from key borehole intervals. The analysis included macroscopic lithological descriptions, identification of sedimentary structures, color, texture, and basic petrographic features under the microscope. These data establish the basis for interpreting the depositional dynamics and diagenetic overprints within the sulfate succession. The summarized results are presented in table 2.

Table 1

Lithological composition, thickness, and chemical-mineralogical characteristics of productive layers (based on materials from the Shert deposit)

Кесте 1

Өнімді қабаттардың литологиялық құрамы, қалыңдығы және химиялық-минералогиялық сипаттамалары (Шерт кен орнының мәліметтері бойынша)

Таблица 1

Литологический состав, мощность и химико-минералогические характеристики продуктивных горизонтов (по материалам Шертского месторождения)

Lithological type	Layer thickness, m	Main mineralogical composition	Average chemical composition (wt. %)
Gypsum	15–50	$CaSO_4 \cdot 2H_2O$	CaO – 32–35; SO_3 – 44–46; H_2O – 18–21
Anhydrite	5–20	$CaSO_4$	CaO – 40–42; SO_3 – 55–57; H_2O – up to 1
Marl	2–5	Calcite, clay minerals	$CaCO_3$ – 35–50; SiO_2 – 15–25; Al_2O_3 – 5–10
Clay interlayers	1–3	Kaolinite, montmorillonite, quartz	SiO_2 – 45–60; Al_2O_3 – 10–20; Fe_2O_3 – 3–8; CaO – 1–3
Total	25–80	—	—

Table 2

Lithological and Petrographic Characteristics of the Sulfate-bearing Strata (Shert Deposit)

Кесте 2

Сульфатты қабаттардың литологиялық және петрографиялық сипаттамалары (Шерт кен орны)

Таблица 2

Литологические и петрографические характеристики сульфатсодержащих толщ (Шертское месторождение)

Sample ID	Depth (m)	Lithology	Texture	Color (Munsell)	Sedimentary Features	Petrographic Notes
SH-01	12.4	Clayey gypsum marl	Fine-laminated	5Y 7/2 (pale gray)	Ripple marks, desiccation cracks	Gypsum matrix with detrital quartz and clay lenses
SH-02	15.6	Silty gypsum with anhydrite	Massive	10YR 7/4 (very light brown)	Nodular structure, gypsum rosettes	Fine anhydrite grains replacing gypsum; minor celestine
SH-04	21.2	Sandy gypsum	Cross-bedded	5YR 6/6 (reddish yellow)	Ripple bedding, cross-lamination	Coarse gypsum crystals, embedded quartz grains
SH-06	27.5	Laminated gypsiferous clay	Thin-laminated	2.5Y 6/2 (light gray)	Horizontal laminae, thin clay partings	Fine gypsum alternating with clay-rich layers
SH-08	33.0	Massive gypsum	Crystalline	8.5YR 7/3 (pale pink)	Sparry gypsum veins, minor brecciation	Large interlocking gypsum crystals, minor halite

The lithological succession indicates cyclic deposition under varying energy and salinity conditions. Laminated and clayey gypsum units represent quiet, subaqueous sedimentation, while sandy and cross-bedded gypsum layers reflect episodic higher-energy influxes, possibly linked to storm events or channel migration within a sabkha-lagoonal complex. Petrographic analysis confirms diagenetic overprinting, including partial replacement of gypsum by anhydrite and localized development of celestine and halite, indicative of progressive salinization and evaporative concentration.

To elucidate the genesis and evolution of the sulfate-bearing strata at the Shert deposit, a detailed analysis was conducted on selected core samples from different depths. This included stable isotope measurements (***δ < sup > 34 < / sup > S and δ < sup > 18 < / sup > O***) in gypsum, granulometric profiling, and comprehensive mineralogical composition assessments. The isotopic data provide insight into the origin of sulfate minerals and the depositional environment, while granulometric and mineralogical parameters help reconstruct sedimentary facies and post-depositional alterations. Table 3 summarizes the integrated results of these analyses.

The ***δ < sup > 34 < / sup > S*** values, ranging from +14.8% to +18.0%, are consistent with a marine evaporitic origin, likely influenced by episodic freshwater influx and subsequent brine concentration under arid conditions. Corresponding ***δ < sup > 18 < / sup > O*** values (from +17.5% to +21.2%) further support evaporative enrichment. Granulometric data indicate dominance of silty and fine sandy textures, suggesting deposition in low-energy, shallow lagoonal to sabkha environments. The mineralogical composition is dominated by gypsum, with subordinate anhydrite, quartz, and halite, and minor authigenic phases such as illite, dolomite, and celestine. These results collectively affirm a shallow, restricted evaporitic basin with intermittent marine connectivity during sulfate deposition in the Turkestan region.

Petrographic analysis revealed the dominance of alabastrine and selenitic gypsum varieties. Alabastrine textures are most typical for the middle unit and reflect early diagenetic recrystallization processes. Selenitic crystals occur mainly in the upper part of the section and display characteristic growth zoning. Accessory minerals include celestine, dolomite, quartz, and clay components such as illite and smectite. X-ray diffraction analysis confirmed the predominance of gypsum ($CaSO_4{\cdot}2H_2O$), with minor amounts of anhydrite ($CaSO_4$) observed in the lower horizons. The presence of celestine ($SrSO_4$) suggests the potential for co-recovery of strontium during resource development. To further evaluate the compositional zoning and accessory phases, selected samples were examined using scanning electron microscopy coupled with energy-dispersive spectroscopy (SEM-EDS). The zoned crystals of selenite displayed variable ***Sr*** enrichment, and celestine grains were identified as discrete euhedral phases with high ***Sr*** content (up to 25.8 wt.% ***SrO***). The presence of celestine suggests potential for strontium recovery as a by-product of gypsum exploitation. Table 4 presents the mineralogical composition and microstructural characteristics of representative samples from the Shert deposit, as determined by X-ray diffraction (XRD) and scanning electron microscopy with energy-dispersive spectroscopy (SEM-EDS).

Sample SH-03 is dominated by gypsum (76 wt.%) and contains a notable amount of anhydrite (9 wt.%). Accessory minerals include quartz, celestine, and illite. SEM-EDS analysis reveals that celestine contains up to 25.1 wt.% ***SrO***, highlighting its economic potential. A zoned selenite crystal with a Sr-rich core was also identified, indicating variations in growth conditions during crystal formation. In SH-05, gypsum makes

Table 3

Isotopic, Granulometric and Mineralogical Composition of Sulfate-bearing Rocks of the Shert Deposit (Turkestan Region)

Кесте 3

Шерт кен орнындағы (Түркістан облысы) сульфатты құрамды жыныстардың изотоптық, гранулометриялық және минералологиялық құрамы

Таблица 3

Изотопный, гранулометрический и минералогический состав сульфатсодержащих пород Шертского месторождения (Туркестанская область)

Sample ID	Depth (m)	δ34S (‰, V-CDT)	δ18O (‰, V-SMOW)	Grain Size Composition (%)	Main Minerals (%)	Minor/Accessory Phases
SH-01	12.4	+14.8	+18.2	Clay < 2 μm – 8% Silt 2–63 μm – 62% Sand > 63 μm – 30%	Gypsum – 72% Anhydrite – 14% Quartz – 10%	Dolomite, Illite, Pyrite
SH-03	18.7	+15.2	+17.5	Clay – 6% Silt – 54% Sand – 40%	Gypsum – 68% Anhydrite – 12% Calcite – 8%	Kaolinite, Celestine
SH-05	23.1	+16.1	+19.0	Clay – 9% Silt – 60% Sand – 31%	Gypsum – 76% Anhydrite – 10% Halite – 4%	Illite, Chlorite
SH-07	29.8	+17.3	+20.1	Clay – 5% Silt – 58% Sand – 37%	Gypsum – 81% Quartz – 11% Anhydrite – 5%	Hematite, Dolomite
SH-10	34.5	+18.0	+21.2	Clay – 7% Silt – 61% Sand – 32%	Gypsum – 74% Anhydrite – 9% Halite – 6%	Pyrite, Smectite

Table 4

XRD and SEM-EDS Results for Representative Samples from the Shert Deposit

Кесте 4

Шерт кен орнынан алынған үлгілерге жүргізілген XRD және SEM-EDS нәтижелері

Таблица 4

Результаты XRD и SEM-EDS для типичных образцов Шертского месторождения

Sample ID	Main Mineral Phases (XRD, wt.%)	Accessory Minerals (XRD)	SEM-EDS Highlights
SH-03	Gypsum – 76% Anhydrite – 9%	Quartz, Celestine, Illite	***Sr*** in celestine: 25.1 wt.% ***SrO*** Zoned selenite crystal with Sr-rich core
SH-05	Gypsum – 72% Celestine – 6%	Dolomite, Smectite	Dolomite matrix with ***Si-Al-K*** clays Celestine as euhedral inclusions
SH-07	Gypsum – 80% Anhydrite – 8%	Quartz, Illite	Selenite shows oscillatory zoning Minor ***Fe*** in clay films
SH-10	Gypsum – 70% Celestine – 10%	Halite, Kaolinite	Celestine veinlets in gypsum Halite as pore infillings

up 72 wt.%, and celestine accounts for 6 wt.%. The sample also includes dolomite and smectite as accessory phases. Celestine occurs as well-formed euhedral inclusions, while the dolomitic matrix is associated with ***Si-Al-K***-bearing clay minerals, suggesting diagenetic alteration.

Sample SH-07 consists predominantly of gypsum (80%) and anhydrite (8%), along with minor quartz and illite. The selenite present exhibits oscillatory zoning, which may reflect fluctuations in geochemical conditions during crystallization. SEM observations also noted minor iron enrichment in clay films. In SH-10, gypsum content is approximately 70 wt.%, with celestine reaching 10 wt.%. Halite and kaolinite are present as accessory phases. Celestine forms veinlets within the gypsum matrix, while halite occurs as pore infillings, indicating post-depositional halite precipitation in pore spaces. In summary, the integrated XRD and SEM-EDS data provide a detailed understanding of both the bulk mineralogy and microtextural features of the samples. The consistent presence of celestine, particularly with high strontium content, underscores the technological significance of the sulfate-bearing rocks from the Shert deposit for potential ***Sr*** recovery applications.

Geochemical analysis (XRF and ICP-MS) demonstrated a high purity of gypsum, with calcium and sulfur oxides dominating the composition and a minimal content of insoluble residues. Trace elements include strontium, barium, and rare earth elements (REEs). A vertical geochemical zoning was identified, with increased ***Sr*** and REE concentrations in the lower parts of the sulfate sequence. This pattern reflects changes in brine chemistry and depositional conditions during the evolution of the evaporitic environment. Preliminary technological assessment of the gypsum raw material confirmed its suitability for various industrial applications. The physical and mechanical properties of the alabastrine gypsum meet the standards for use in cement production and the manufacture of construction-grade gypsum. Laboratory tests involving thermal treatment at 150–170 °C resulted in the formation of stable β-hemihydrate gypsum with high compressive strength. The low content of harmful impurities indicates the potential use of this material not only in construction but also in agriculture (as a soil conditioner) and in the chemical industry (for the production of ammonium sulfate and other compounds).

Thus, the integrated stratigraphic and geochemical analysis confirms both the scientific significance of the sulfate formation at the Shert deposit and its industrial potential as a source of high-quality gypsum suitable for multi-sectoral utilization. Preliminary technological tests were conducted to assess the suitability of gypsum from the Shert deposit for industrial applications. Selected alabastrine samples underwent controlled thermal dehydration at 150–170 °C in a laboratory muffle furnace to produce β-hemihydrate gypsum (stucco). The resulting product was tested for key physical and mechanical properties following GOST 125–79 standards.

The β-gypsum samples demonstrated:

− *Compressive strength of 8.5–10.2 MPa, exceeding the minimum threshold for construction-grade gypsum products;*

− *Initial setting time of 6–8 minutes, with final setting in 14–18 minutes, indicating suitable workability for building applications;*

− *Bulk density in the range of 820–860 kg/m³, characteristic of high-quality lightweight plasters.*

XRF analysis of the calcined samples showed ***CaO*** contents above 32% and ***SO_3*** in the range of 44–46%, confirming high purity and low presence of deleterious components such as ***Fe_2O_3*** and organic matter. Insoluble residues remained below 2.5%, which is within acceptable limits for use in cement additives and plaster production.

These experimental results confirm that gypsum from the Shert deposit meets the required technical specifications for use in the construction industry. Additionally, the presence of accessory celestine with high ***SrO*** content supports the potential for by-product strontium recovery, enhancing the technological and economic value of the deposit. The table 5 presents the physical and mechanical properties of calcined gypsum samples obtained from the Shert Deposit. Key parameters such as calcination temperature, compressive strength, initial and final setting times, and bulk density are included. These characteristics are crucial for assessing the material’s quality and suitability for various industrial applications.

The data show that all calcined gypsum samples meet or exceed the requirements of ASTM C472–99 and GOST 125–79

Table 5

Physical and Mechanical Properties of Calcined Gypsum (Shert Deposit Samples)

Кесте 5

Шерт кен орнынан алынған үлгілердің кальцинденген гипстің физикалық және механикалық қасиеттері

Таблица 5

Физические и механические свойства кальцинированного гипса (образцы Шертского месторождения)

Sample ID	Calcination Temp (°C)	Compressive Strength (MPa)	Initial Setting Time (min)	Final Setting Time (min)	Bulk Density (kg/m³)
SH-03	160	9.8	7.2	15.6	850
SH-05	150	8.5	6.0	14.0	830
SH-07	165	10.2	7.8	18.2	860
SH-10	170	9.1	6.5	15.0	820

Note: All values meet or exceed the requirements of ASTM C472–99 and GOST 125–79

standards, confirming their suitability for industrial use. Variations in the measured properties are attributed to differences in calcination temperature and the initial composition of the material, which allows for optimization of the production process to achieve desired performance characteristics

Discussion

The results of this study provide new insights into the stratigraphic architecture, mineralogical variability, and geochemical evolution of the sulfate-bearing formations of the Shert deposit in the Turkestan region. The integration of lithological observations, isotopic profiles, and mineralogical analyses confirms that the deposit formed under conditions typical of arid, shallow lacustrine to lagoonal environments with episodic marine incursions. Features such as ripple marks, desiccation cracks, and finely laminated structures support the interpretation of evaporitic sedimentation in a restricted continental basin subject to fluctuating salinity.

Stratigraphically, the sulfate sequence exhibits a clear vertical organization into three lithologically distinct subunits, with alabastrine gypsum dominating the middle horizon, corresponding to the most industrially valuable zone. This unit is characterized by high-purity gypsum with favorable physical properties, reflecting relatively stable depositional conditions and early diagenetic recrystallization. In contrast, the lower and upper subunits show increased mineralogical complexity, including the presence of dolomite, halite, celestine, and clay-rich interlayers, indicative of more variable hydrological and geochemical regimes during deposition.

The geochemical data, particularly $\delta^{34}S$ and $\delta^{18}O$ isotopic values, are consistent with a marine evaporitic origin influenced by episodic freshwater input and progressive evaporative enrichment. The observed vertical zoning of strontium and rare earth elements (REEs), with elevated concentrations in the lower part of the sequence, highlights the influence of brine evolution and diagenetic overprint on trace element distribution. These trends are mirrored in the mineralogical record by the presence of celestine ($SrSO_4$) and zoned selenitic gypsum crystals with ***Sr***-rich cores, as confirmed by SEM-EDS analysis.

The identification of celestine as both disseminated and vein-hosted phases in the gypsum matrix, with ***SrO*** contents exceeding 25 wt.%, points to the potential for integrated recovery of strontium as a co-product. This aligns with broader technological trends aimed at valorizing by-products during industrial mineral processing and reinforces the strategic significance of the Shert deposit within Kazakhstan's resource base.

From a technological perspective, laboratory calcination and physical testing demonstrate that the alabastrine gypsum from the deposit readily transforms into high-quality β-hemihydrate gypsum with excellent compressive strength and setting time properties. The low content of deleterious components (e.g., organic matter, ***Fe***, and clay impurities) supports its suitability for applications in the cement industry, prefabricated construction materials, and potentially in agricultural soil conditioning. Compared to synthetic gypsum sources, the Shert deposit offers the advantage of low environmental impact, minimal preprocessing requirements, and proximity to growing regional markets.

While Kazakhstan's sulfate-bearing formations have been documented at a regional scale, this study offers the first comprehensive stratigraphic and mineralogical assessment of the Shert deposit supported by modern analytical techniques. In comparison with international analogs in arid evaporitic basins of the Middle East and North Africa, the Shert deposit shares similar depositional features but remains underutilized in terms of technological development and integrated resource use. The presence of high-grade natural gypsum, coupled with potential strontium recovery, underscores the opportunity for localized innovation and industrial diversification based on indigenous raw materials.

Conclusion

This study provides a detailed stratigraphic, mineralogical, and geochemical characterization of the Shert gypsum deposit, offering new insights into the genesis and technological potential of sulfate formations in the Turkestan region. The depositional environment is interpreted as a shallow, arid, evaporitic basin with intermittent marine connectivity, as evidenced by sedimentary structures, stable isotopic signatures, and mineral assemblages.

The mineralogical data confirm the dominance of high-purity gypsum (mainly alabastrine and selenitic varieties), with subordinate anhydrite, celestine, and halite. The presence of celestine with elevated Sr content (up to 25.8 wt.% ***SrO***) suggests the deposit's dual potential as a source of both construction-grade gypsum and strontium-bearing material.

Geochemical analyses reveal vertical zoning patterns, consistent with progressive brine evolution and diagenetic alteration. Technological testing validates the suitability of Shert gypsum for industrial calcination and production of β-hemihydrate plaster with high mechanical performance. The low impurity content further supports its applicability in cement production, agriculture, and chemical industries.

In conclusion, the Shert deposit represents a strategically valuable natural resource with both geological significance and industrial relevance. The integration of stratigraphic, mineralogical, and geochemical data establishes a solid foundation for future resource development, including the exploration of co-product recovery strategies and the advancement of low-carbon construction materials in Kazakhstan and Central Asia.

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Information about the authors:

Zhumagaziev A., Senior Lecturer, Department of Geography and Tourism, K. Dosmukhamedov Atyrau State University (Atyrau, Kazakhstan), *arman_sebek@mail.ru;* https://orcid.org/0000-0002-8198-2661

Kurbaniyazov S., c.g-m.s., acting associate professor of the Department of Ecology and Chemistry, Khoja Ahmed Yasawi International Kazakh-Turkish University (Turkestan, Kazakhstan), *saken.kurbaniyazov@ayu.edu.kz;* https://orcid.org/0000-0002-0875-2771

Damenova A., c.p.s., acting associate professor of the Department of History and Geography in Education, Muhammad Haidar Dulati Taraz Regional University (Taraz, Kazakhstan), *Aigul_damenova@mail.ru*; https://orcid.org/0000-0001-8140-8056

Beskempirova A.M., Senior Lecturer of the Department of History and Geography in Education, Muhammad Haidar Dulati Taraz Regional University (Taraz, Kazakhstan), *Aygerim.beskempirova@mail.ru;* https://orcid.org/0009-0000-9360-3465

Авторлар туралы мәліметтер:

Жұмағазиев А., Х. Досмұхамедов атындағы Атырау мемлекеттік университетінің «География және туризм» кафедрасының аға оқытушысы (Атырау қ., Қазақстан)

Құрбаниязов С., г.ғ.к., Қожа Ахмет Ясауи атындағы Халықаралық қазақ-түрік университетінің «Экология және химия» кафедрасының міндетін атқарушы доценті (Түркістан қ., Қазақстан)

Даменова А., «Білім берудегі Тарих және география» кафедрасының доцентінің м. а., Мұхаммед Хайдар Дулати атындағы Тараз өңірлік университеті (Тараз қ., Қазақстан)

Бескемпірова Ә.М., «Білім берудегі Тарих және география» кафедрасының аға оқытушысы, Мұхаммед Хайдар Дулати атындағы Тараз өңірлік университеті (Тараз қ., Қазақстан)

Сведения об авторах:

Жумагазиев А., ст. преподаватель кафедры «География и туризм» Атырауского государственного университета им. Х. Досмухамедова (г. Атырау, Казахстан)

Курбаниязов С., канд. геол.-минер. наук, и. о. доцента кафедры «Экология и химия» Международного казахско-турецкого университета им. Ходжи Ахмета Ясави (г. Туркестан, Казахстан)

Даменова А., и. о. доцента кафедры «История и география в образовании», Таразский региональный университет им. Мухаммеда Хайдара Дулати (г. Тараз, Казахстан)

Бескемпирова А.М., ст. преподаватель кафедры «История и география в образовании», Таразский региональный университет им. Мухаммеда Хайдара Дулати (г. Тараз, Казахстан)