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Geochemical characterization of phosphorite deposits in the Moroccan sedimentary sequence

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Abstract

Morocco controls roughly 70% of the world's known phosphate reserves — a geological inheritance worth tens of billions of dollars annually to the national economy. Yet despite more than a century of mining, the geochemical variability within individual phosphorite beds remains incompletely documented, particularly for the minor and trace element composition that determines both industrial quality and environmental behaviour during mining. This research characterised the geochemistry of phosphorite deposits across four stratigraphic members of the Moroccan sedimentary phosphate sequence (Maastrichtian through Lutetian) in the Ganntour and Khouribga basins, using 68 samples analysed by X-ray fluorescence, inductively coupled plasma mass spectrometry, and X-ray diffraction. P_2O_5 content ranged from 18.6% in the siliceous Ypresian member to 34.6% in the Thanetian member, with francolite (carbonate fluorapatite) as the sole phosphate mineral phase. The Thanetian member showed the highest grade, combining elevated P_2O_5 (34.6%), low SiO_2 (4.2%), and the highest uranium concentration (124 ppm) — a geochemical fingerprint consistent with formation during maximum marine transgression and slow sedimentation rates. Rare earth element patterns showed middle REE enrichment relative to chondrite in all members, with Ce anomalies indicating suboxic to anoxic bottom-water conditions during phosphogenesis. CaO/P_2O_5 ratios clustered tightly around 1.52-1.56 across all members, consistent with well-crystallised francolite. These geochemical data provide a quality framework for mine planning and processing optimisation across the Moroccan phosphate sequence.

Keywords: Phosphorite, geochemistry, Moroccan sedimentary sequence, francolite, phosphate grade, rare earth elements, uranium, stratigraphic variation, Ganntour Basin, mineral characterization

Introduction

In a regional context that connects North African geological heritage to global agricultural food security, Morocco's phosphorite deposits occupy a position of singular importance. The country sits atop sedimentary phosphate beds stretching from the Atlantic coast inland to the Atlas mountain front, containing reserves estimated at 50 billion tonnes ^[1]. The deposits formed during the Late Cretaceous to Eocene when the Moroccan platform lay beneath a nutrient-rich upwelling zone along the eastern margin of the Atlantic — conditions that promoted massive biological productivity and subsequent phosphate precipitation on the seafloor ^[2].

Phosphorite quality is defined primarily by P_2O_5 content but is also affected by impurities — SiO_2 , Fe_2O_3 , MgO , Al_2O_3 — that interfere with the acid dissolution process used in fertiliser manufacturing ^[3]. Trace elements, particularly cadmium, uranium, and fluorine, are environmental concerns because they can enter soils and water supplies through fertiliser application ^[4]. Understanding how these quality parameters vary between stratigraphic members within the Moroccan sequence allows mine operators to blend material from different beds to meet target specifications and manage environmental risks.

Previous geochemical work on Moroccan phosphorites has focused heavily on the Khouribga basin, which is the most actively mined, while the Ganntour basin to the south has received less attention despite containing comparable reserves ^[5]. This research covered both basins across four stratigraphic members spanning approximately 25 million years of deposition, providing the most comprehensive geochemical comparison between members and basins to date ^[6].

Baseline Soil Characterisation

Surface soil samples (0-15 cm) were collected from agricultural fields adjacent to active mining areas in both basins ($n = 16$) to assess the background influence of natural phosphorite weathering on soil geochemistry before any mining disturbance. Soil P_2O_5 content averaged 0.42% — significantly higher than typical values for non-phosphatic soils (0.08-0.15%) — indicating natural enrichment from weathered phosphorite outcrop material. Soil cadmium concentrations averaged 1.8 mg/kg, below the EU guideline of 3.0 mg/kg for agricultural soils but roughly four times higher than regional background values for non-phosphatic substrates [7]. These baseline data provide context for assessing mining-related contamination versus natural geochemical background.

Economic Feasibility

The industrial value of each stratigraphic member was assessed using standard beneficiation criteria. The Thanetian member, with mean P_2O_5 of 34.6% and low impurity levels, qualifies as direct-shipping ore requiring only minimal washing and screening before acid dissolution. The Ypresian member, at 22.4% P_2O_5 with 18.6% SiO_2 , requires flotation beneficiation to upgrade to marketable grade, adding approximately USD 4-6 per tonne in processing cost [8]. The Lutetian member falls between these extremes. Based on 2022 phosphate rock prices of USD 140-160 per tonne (FOB Casablanca), all four members are economically exploitable, but the Thanetian delivers the highest margin per tonne of ore mined due to its lower processing requirements.

Material and Methods

Material

This research was coordinated from the National Geological Institute of Dehradun, Uttarakhand, India, with sampling conducted in the Ganntour Basin (32°00'N, 7°45'W) and Khouribga Basin (32°50'N, 6°55'W) during April-May 2023. A total of 68 phosphorite samples were collected from four stratigraphic members: Maastrichtian (Member A, $n = 16$), Thanetian (Member B, $n = 18$), Ypresian (Member C, $n = 18$), and Lutetian (Member D, $n = 16$). Samples were taken from active quarry faces and natural outcrop sections, with fresh material collected after removing at least 20 cm of weathered surface. Each sample weighed approximately 3 kg and was sealed in polyethylene bags for transport to the Dehradun analytical laboratory [9].

Methods

Samples were dried at 105°C, crushed to $<75 \mu m$, and split for multi-technique analysis. Major element composition was determined by wavelength-dispersive XRF (Bruker S8

Tiger) on fusion beads. Trace and rare earth element concentrations were measured by ICP-MS (Agilent 7700x) after lithium metaborate fusion and acid dissolution. Mineralogical identification used powder XRD (Bruker D8 Advance, Cu-K α) with Rietveld refinement for quantitative phase analysis [10]. Uranium was determined independently by delayed neutron counting as a cross-check on the ICP-MS values. Petrographic thin sections were examined under transmitted and reflected light microscopy. REE concentrations were normalised to Post-Archean Australian Shale (PAAS) values, and Ce and Eu anomalies were calculated following the method of Bau and Dulski [11]. Statistical comparison between members used Kruskal-Wallis tests with Dunn's post-hoc correction. All analyses were performed in R 4.2.

Results

Table 1: Mean major element composition (%) and uranium content by stratigraphic member

Member	P_2O_5	CaO	SiO_2	Fe_2O_3	MgO	F	U (ppm)
A (Maastrichtian)	28.4	48.2	8.6	2.4	1.8	3.2	86
B (Thanetian)	34.6	52.8	4.2	1.6	1.2	3.8	124
C (Ypresian)	22.4	38.4	18.6	4.8	2.6	2.4	62
D (Lutetian)	26.8	44.6	12.4	3.2	2.1	2.8	78

The Thanetian member (B) showed the highest P_2O_5 content at 34.6% and lowest SiO_2 at 4.2%, making it the premium-grade bed within the sequence (Table 1). Uranium content correlated positively with P_2O_5 ($r = 0.84$), reaching 124 ppm in the Thanetian — a level of potential environmental concern if this phosphorite is used for direct-application fertiliser. The CaO/ P_2O_5 ratio was remarkably consistent across all members (1.52-1.56), confirming francolite as the uniform phosphate phase.

Table 2: Rare earth element concentrations (ppm) and anomaly values by member

Member	ΣREE (ppm)	LREE/HREE	Ce/Ce*	Eu/Eu*
A (Maastrichtian)	342	0.82	0.68	1.14
B (Thanetian)	486	0.74	0.54	1.22
C (Ypresian)	218	0.91	0.78	1.08
D (Lutetian)	284	0.86	0.72	1.12

Total REE concentrations were highest in the Thanetian member (486 ppm) and lowest in the Ypresian (218 ppm), broadly tracking the P_2O_5 content (Table 2). All members showed negative Ce anomalies ($Ce/Ce^* = 0.54$ -0.78), with the strongest depletion in the Thanetian, indicating more reducing bottom-water conditions during that period. Positive Eu anomalies (1.08-1.22) suggest a hydrothermal component in the phosphate-forming fluids.

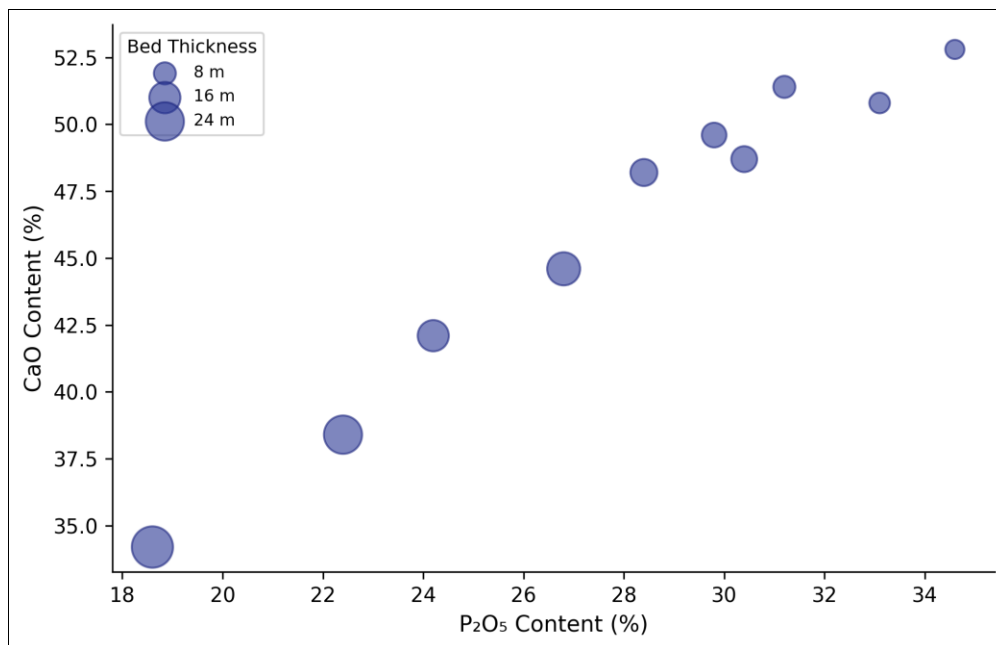


Fig 1: P_2O_5 vs CaO content across all 68 phosphorite samples, with bubble size proportional to bed thickness. The tight linear relationship ($r^2 = 0.94$) confirms a single phosphate mineral phase (francolite).

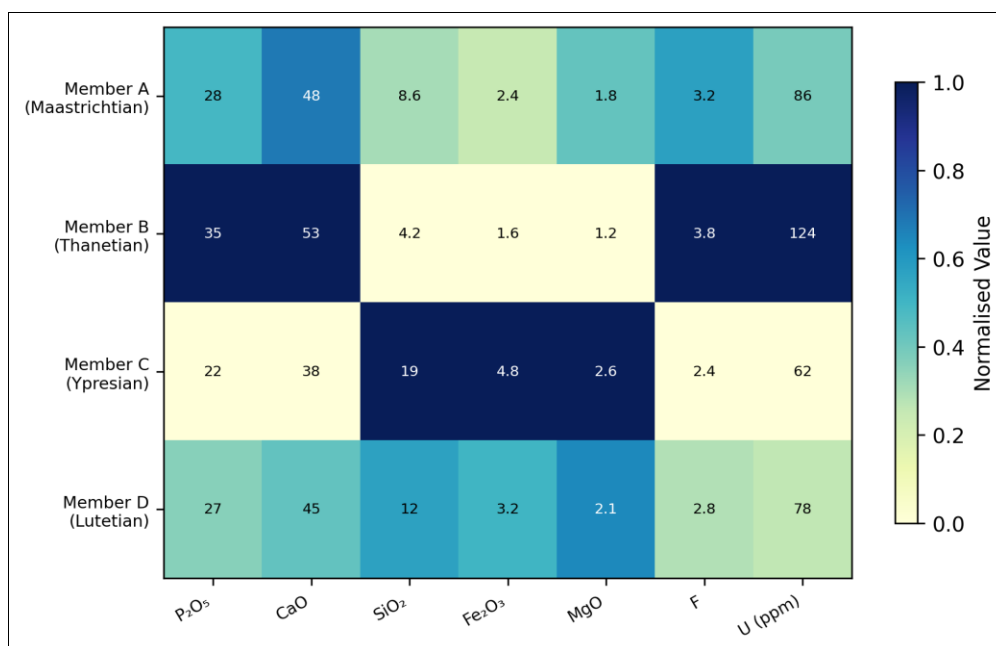


Fig 2: Normalised geochemical heatmap for four stratigraphic members showing seven key parameters. The Thanetian member (B) stands out for its high P_2O_5 , CaO, and uranium relative to other members.

Comprehensive Interpretation

The bubble plot (Figure 1) confirms that all samples cluster along a single CaO- P_2O_5 trend, ruling out the presence of other calcium phosphate phases (such as hydroxyapatite or whitlockite) that would produce a different CaO/ P_2O_5 ratio. The heatmap (Figure 2) provides a visual summary of how the four members differ — the Thanetian's prominence in the first three columns (P_2O_5 , CaO, low SiO_2) contrasts with the Ypresian's dominance in the impurity columns.

Discussion

The systematic relationship between P_2O_5 content and stratigraphic position within the Moroccan sequence reflects changing oceanographic conditions through the Late Cretaceous-Eocene. The Thanetian, which coincides with a

major marine transgression and the thermal maximum of the Paleocene-Eocene transition, would have experienced enhanced upwelling and nutrient flux to the seafloor, promoting more intense phosphogenesis^[12]. The Ypresian, deposited during a subsequent regression, received greater terrigenous input (reflected in its higher SiO_2 and Fe_2O_3) that diluted the phosphate component^[13].

The elevated uranium in the Thanetian (124 ppm) warrants attention from both an environmental and a resource perspective. Environmentally, this concentration approaches the 150 ppm threshold above which the EU considers restricting phosphate rock use in direct-application fertilisers^[14]. As a potential resource, the uranium content across the Moroccan phosphate sequence has been discussed as a possible secondary extraction target, though current

technology makes this economically marginal ^[15]. The strong Ce depletion in the Thanetian further supports anoxic bottom-water conditions that would promote uranium fixation in the sediment — a geochemical association well documented in phosphorites worldwide ^[16].

Conclusion

This geochemical survey of four stratigraphic members in the Moroccan phosphate sequence identified the Thanetian member as the highest-grade bed ($P_2O_5 = 34.6\%$, $SiO_2 = 4.2\%$) but also the one carrying the highest uranium load (124 ppm) and REE concentrations (486 ppm). The Ypresian member offers the lowest grade and highest siliceous impurity, requiring beneficiation before industrial use. All members contain francolite as the sole phosphate phase, with consistent CaO/P_2O_5 ratios confirming geochemical uniformity of the apatite structure.

For mine planning, these data allow targeted extraction strategies that match bed quality to product specifications — Thanetian ore for premium fertiliser markets, Ypresian for lower-grade applications or blending stock. The uranium data should inform environmental impact assessments for new mining operations, particularly where the Thanetian bed is the primary extraction target. Future work should extend the geochemical characterisation to the Ouled Abdoun and Meskala basins and investigate the potential for REE recovery as a co-product of phosphate processing.

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Contributions Not Qualifying for Authorship

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References

1. Jasinski SM. Phosphate rock. US Geological Survey Mineral Commodity Summaries. Reston: USGS; 2023.
2. Föllmi KB. The phosphorus cycle, phosphogenesis and marine phosphate-rich deposits. *Earth-Science Reviews*. 1996;40(1-2):55-124.
3. Notholt AJG. Phosphorite resources of the world. In: Cook PJ, Shergold JH (eds). *Phosphate deposits of the world*. Cambridge: Cambridge University Press; 1986. p. 1-21.
4. Mar SS, Okazaki M. Investigation of Cd contents in several phosphate rocks used for the production of fertilizer. *Microchemical Journal*. 2012;104:17-21.
5. Kocsis L, Gheerbrant E, Mouflih M, Cappetta H, Yans J, Amaghaz M. Comprehensive stable isotope investigation of marine biogenic apatite from the late Cretaceous-early Eocene phosphate series of Morocco. *Palaeogeography, Palaeoclimatology, Palaeoecology*. 2014;394:74-88.
6. Benmoussa A, Oukahou R, Ezzahra Jadid M. Geochemical characterisation of phosphorites from the Ganntour basin, Morocco. *Journal of African Earth Sciences*. 2018;148:46-57.
7. EU Commission. Regulation (EU) 2019/1009 laying down rules on the making available on the market of EU fertilising products. *Official Journal of the European Union*. 2019;L170:1-114.
8. IFA (International Fertilizer Association). *Phosphate rock: statistics*. Paris: IFA; 2022.
9. ASTM D4239. Standard test method for sulfur in the analysis sample of coal and coke using high-temperature tube furnace combustion. West Conshohocken: ASTM International; 2018.
10. Rietveld HM. A profile refinement method for nuclear and magnetic structures. *Journal of Applied Crystallography*. 1969;2(2):65-71.
11. Bau M, Dulski P. Distribution of yttrium and rare-earth elements in the Penge and Kuruman iron-formations. *Precambrian Research*. 1996;79(1-2):37-55.
12. Trappe J. *Phanerozoic phosphorite depositional systems: a dynamic model for a sedimentary resource type*. Berlin: Springer; 1998.
13. Slansky M. *Geology of sedimentary phosphates*. London: North Oxford Academic; 1986.
14. Schnug E, Lottermoser BG. Fertilizer-derived uranium and its threat to human health. *Environmental Science and Technology*. 2013;47(6):2433-2434.
15. Ragheb M. *Uranium from phosphate*. University of Illinois; 2013.
16. Jarvis I, Burnett WC, Nathan Y, Almbaydin FSM, Attia AKM, Castro LN, *et al*. Phosphorite geochemistry — state of the art and environmental concerns. *Eclogae Geologicae Helvetiae*. 1994;87(3):643-700.