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Episodes of phosphorus accumulation in the Cauvery Basin, South India: implications on palaeoclimate, productivity and weathering

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The Barremian–Danian strata of the Cauvery basin, exposed in the erstwhile Tiruchirapalli district, record three positive excursions of phosphorus, namely, during Albian, Cenomanian and Maastrichtian respectively, and a negative excursion across the Cretaceous–Tertiary boundary. Corroboration of the depositional history of the strata and comparison with the trends of relative sea level, Si, Sr and C_{Org} revealed that while the Albian episode was related with reduced inflow of siliciclastics and prevalent oxygen minimum owing to the sea-level highstand, the other two positive excursions resulted from sea-level lowstand and concomitant redistribution of intraformational sediments. The negative excursion across the Cretaceous–Tertiary was due to higher faunal turnover.

Keywords: Palaeoclimate, phosphorus, positive and negative excursion, weathering.

CHEMOSTRATIGRAPHY involves the application of elemental and isotopic geochemistry for the characterization of sedimentary sequences¹. This tool is based on the sedimentary record of changes in certain elements with time². Many studies^{3–6} have utilized this tool for stratigraphic correlation, fixation of geological boundaries and petroleum exploration. This communication documents the trends of phosphorus in sedimentary rocks of Barremian–Danian strata of the Cauvery basin to decipher causative factors.

A more or less complete Upper Cretaceous–Palaeocene succession is exposed in the Ariyalur–Pondicherry depression of the Cauvery basin⁷ (Figure 1). The Cauvery basin was initiated during Lower Cretaceous and continued to evolve till the end of Tertiary through rift, pull-apart, shelf sag and tilt phases, during which many episodes of transgression, regression, erosion and deposition took place to fill the basin⁸. Sea-level curve of this basin based on foraminiferal data documented the presence of six third order glacio-eustatic global cycles^{9,10}. Sea-level curve constructed based on lithofacies data is also similar to the curves based on foraminiferal data, excepting the addition of fourth-order sea-level cycles (Figure 2) of

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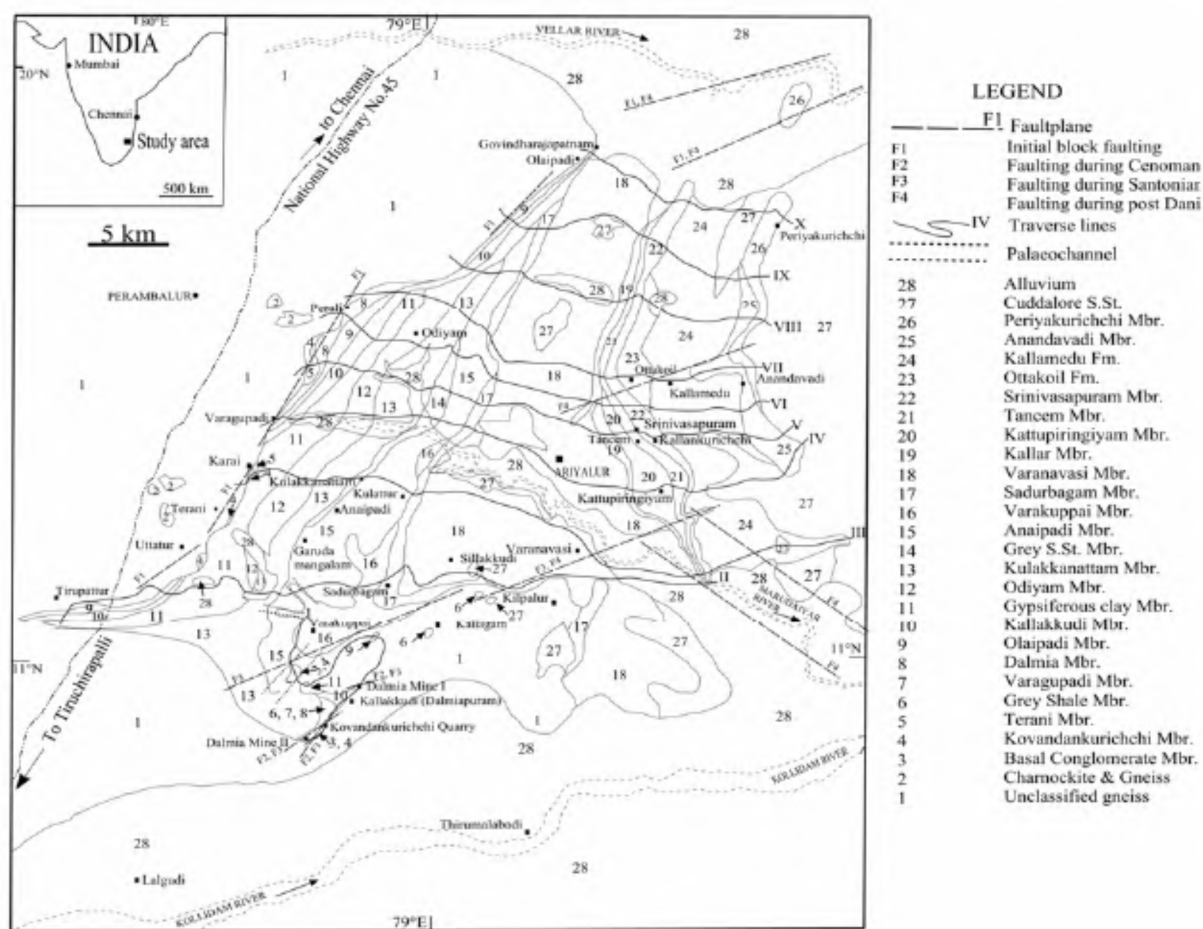


Figure 1. Location and geology of the study area.

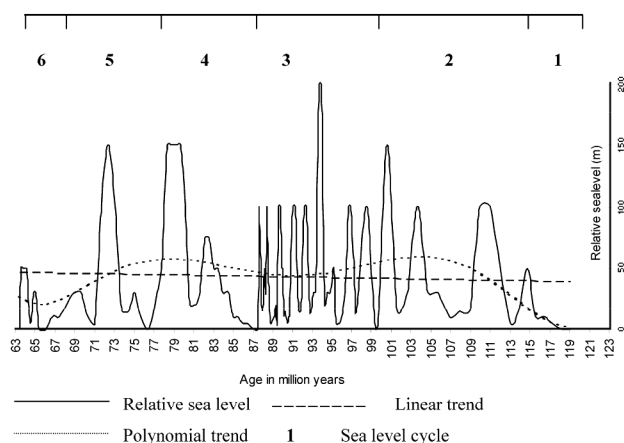


Figure 2. Relative sea-level curve of Barremian–Danian strata of the Cauvery basin.

glacio-eustatic origin¹¹. Since the Barremian until collision with the Eurasian plate (during which northward flight of the Indian plate took place), the climate of the Indian plate might have been influenced by temperature of surrounding waters as it remained as an island conti-

nent similar to present-day Australia, wherein climate is predominantly influenced by temperature of ocean waters. As the Cretaceous hosted extended greenhouse effect, where temperature gradient between the pole and the equator was less, even slight change in temperature from background values would have been sufficient to cause the glaciers to advance or retreat, resulting in sea-level fluctuations. Thus, the sea-level fluctuations of the Cauvery basin should be interpreted in resonance with the global sea-level cycles.

Figure 2 shows that the timespan from Barremian to Coniacian experienced frequent oscillations, while comparatively stable and less number of higher-order cycles were witnessed during Coniacian to Danian. The sea-level rise during Santonian–Early Campanian showed a steadily increasing pattern, which coincides with the period of reduced tectonic activities in the basin. Global sea-level peaks were observed to occur in this basin^{9,10}. Sedimentation took place in an epicontinental sea and the bathymetry was shallow–modest (<50 m, as indicated by the linear curve in Figure 2).

Systematic field mapping in the scale of 1 : 50,000 was conducted in and around Ariyalur, Perambalur and

Tiruchirapalli districts (erstwhile Tiruchirapalli district). Ten major traverses were made (Figure 1) to examine 308 locations for logging and sampling. A composite stratigraphic profile representing continuous stratigraphic record of Barremian–Danian strata (Table 1) was constructed which allowed selection of 157 representative whole-rock powder samples for analysing their trace elemental compositions. From these 157 samples, 70 were further selected and analysed for major elements. Trace and major elemental analyses were performed with XRF¹². Analyses of 157 samples for petrographic and bulk mineralogical data and 70 samples for clay mineralogical compositions were also performed. This communication discusses only the trends of phosphorus and on occasions, other data are also discussed in a supportive role. Figure 3 presents the geochemical curves of Si (Figure 3 *a*), P (Figure 3 *b*), Sr (Figure 3 *c*) and C_{Org} (Figure 3 *d*). Linear and best-fit polynomial trend lines were also drawn over these curves of absolute concentration. Though the absolute concentration of P and relative sea level show multitude of variations, they were found to be more or less uniform all through the basinal history, as indicated by their linear trend lines. That the depositional basin remained essentially a shallow epicontinental sea throughout the depositional history, which however, was inundated and exposed frequently, is evident from the linear trend line drawn over sea-level curve in Figure 2.

Phosphorus shows distinct positive anomalies during Albian, Cenomanian and Maastrichtian that are highly different from background values. This pattern itself is suggestive of the immediate cause for those anomalous values. Phosphorus is directly connected with oceanic productivity at global scale¹³, on timescales longer than several multiples of its residence time in sea water¹⁴. As primary productivity affects the global carbon cycle, change in fluxes and reservoirs of P may play a critical role in long-term global change. Identifying the cause of episodes of P accumulation requires a complete understanding of the tectonics, eustasy and oceanography^{15,16}, as well as the sedimentary flux and basin morphology. Excursions of P can be directly related to individual eustatic and tectonic events¹⁶. Several recent studies have assumed that weathering and P input to the oceans are similar to the weathering and input of strontium¹⁷. Comparison of excursions of Sr and P shows that while the Albian excursion of P coincides slightly with that of Sr, the other two episodes of P do not correlate. Hence it is inferred that episodes of P in this basin might have had other causes also. Occurrence of P peaks immediately succeeding sea-level changes (Figures 2 and 3) affirms the view that fluctuations in sea level and resultant changes in shelf area alter oceanic P mass balance, primarily induced by P redistribution¹⁵ within a sedimentary basin. Documentation¹⁸ of peaks of P during sea-level changes in the Magdalena basin supports plausibility of P redistribution in the Cauvery basin also following sea-

level change. The Albian deposits show the characteristics of higher primary productivity as evident from higher organic carbon accumulation (Figure 3 *d*) and preservation that may explain the P peak in the Albian deposits of this basin. Occurrence of strong upwelling during sea-level highstand is a common phenomenon that induces increased phosphate accumulation¹⁶. Enrichment of P during Albian must have occurred within the oxygen minimum zone (as indicated by the absence of bioturbation in the rocks) in an area of pervasive coastal upwelling and reduced terrigenous influx^{16,19}. Concomitant positive anomaly of P (Figure 3 *b*) and negative anomaly of Si (Figure 3 *a*) in the rocks under study affirm the interpretation of reduced terrigenous influx. Earlier studies^{11,20–24} of the basin strata suggested that deposition in the basin is a typical case of episodic influx of siliciclastics influenced by sea-level fluctuations owing to the hinterland topography which in turn supports the present interpretation.

The other two peaks might have resulted by sediment redistribution^{13,25} associated with sea-level fall, a feature also recorded in the Magdalena basin¹⁸. The rocks where these two peaks are observed contain cross-bedding, graded bedding, abundant abraded faunal remains and trace fossils, all indicative of storm events and deposition in oxygenated environment^{19,26,27}. Considering the restricted vertical and lateral distribution of the rocks containing these features, the association of P with reworked invertebrate remains and the exclusive occurrence of P in rocks deposited during sea-level lowstand, these two positive excursions are interpreted to be similar to the phosphatic episode associated with phosphatic graded beds¹⁶.

Phosphorus records negative excursion across the K/T boundary in this basin (Figure 3 *b*). Although many events have been advocated to occur across the K/T transition, a marked biotic turnover owing to nutrient depletion (resulting either from impact scenario or extensive volcanic eruption) has been found to be consistent world over^{20,28–30}. Similar observations could be made from the curves of P (Figure 3 *b*) and organic carbon (Figure 3 *d*) in this basin. Phosphorus forms an essential ingredient for primary production in the life cycle and any delay in additional input from terrestrial sources would be devastating, resulting in higher biotic turnover^{28,30}. Covariation of C_{org} along with nutrients such as P could also indicate purely marine source for the organic matter and non-influx of terrestrial organic matter³¹. The present observation of nutrient depletion in the Cauvery basin across the K/T boundary affirms the views of works cited above and also a view³² that the close of the Mesozoic era marks the beginning of climatic deterioration in the Indian subcontinent. As this climatic change is a global phenomenon, it is not surprising to find major lithological changes associated with various geochemical anomalies across this boundary^{29,33}. It is also to be noted that the negative

Table 1. Lithostratigraphy of Barremian–Danian strata of the Cauvery basin

Age	Formation	Number	Gross lithological characteristics		
63.6	Danian	Niniyur	Periyakurichi	Alternate beds of shelly limestone and calcareous marls; thin to thick, parallel and even bedded. L.st. beds rich in whole shells and bioclasts, primarily of corals and algae besides bivalvia.	
			Anandavadi	Uneven, thin to thick, mixed siliciclastic beds, isolated coral mounds and bioclastic L.st. beds.	
65.4	Maastrichtian	Kallamedu		Thin to thick bedded, siliciclastics; Poorly sorted sandstones with differential admixture of clay and clay lenses; clasts are texturally matured. Sporadic occurrence of <i>Caranosaur</i> bone fragments.	
			Ottakoil	Well sorted sandstone with frequent fining upward sequences, large scale cross bedding. Thick population of <i>Stigmatophygus elatus</i> , extensive ichnofauna of shallow marine environments.	
		Kallankurichi	Srinivasapuram	Thick-very thick bedded grypcean bank facies limestones with bioclasts	
			Tanceem	Cross bedded, HCS, bioclastic limestone beds, ranging from tidal channel-shallow shelf.	
			Kanpurangiyam	Very thick bedded, uniform textured limestone beds with unique population of inoceramus.	
74.5	Campanian	Kallar		Shallow coastal conglomerates and grypcean colonies. Show fining upward sequence.	
			Sillakkudi	Varanavasi	Calcareous sandstones with patchy occurrence of bivalves and gastropods besides ichnofauna. These are showing frequent occurrence of storm layers and resedimented intraformational clasts. Occurrence of cross bedded and HCS bedded interlayers, serpulid colonies and clay rich layers are also observed.
				Sadurbagam	Thin to thick bedded, fining upward, pebble-gravely conglomerates, typical of shallow coastal regions.
84		Santonian		Vanakuppai	Reverse graded lithoclastic conglomerates and large scale cross bedded ferruginous sandstones with thalassinoids. Geometry, lithological and faunal association indicate deposition in slowly drowning river/estuarine and adjoining regions.
87.5			Coniacian	Anaipadi	Thin to massive bedded ferruginous sandstones with variable populations of ammonites & bivalves.
88.5	Turonian	Garudamangalam	Grey Sandstone	Cyclic beds of alternate sandstone, arenaceous L.st. and localised shell colonies.	
			Kulakkanattam	Thick bedded calcareous and argillaceous sandstones with frequent arenaceous L.st. beds	
91	Cenomanian	Karaí	Odiyam sandy clay	Thick-massive bedded sandy clay.	
			Gypsiferous clay	Thin-massive clay with frequent occurrence of alternate beds of silty clay and arenaceous L.st. Extensive occurrence of belemnites, phosphatic nodules, and gypsiferous layers.	
		Dalmiapuram	Kallakkudi	Thick-very thick bedded sandstones and siltstones with recurrent fining upward sequences, bouma sequences and load casts.	
97.5			Olaipadi	Basinal clay deposits in which large chaotic blocks of older conglomerates, archaen rocks and biohermal limestones are embedded.	
	Albian	Dalmiapuram	Dalmia	Typical reef core comprising of coralalgal facies limestone deposits.	
			Varagupadi	Bioclastic limestone deposits, that show thin to thick, even, parallel bedded nature. Frequent interlayers of arenaceous limestone, sandstone and gypsum are also typifying this member.	
			Grey shale	Alternate beds of bioclastic limestone and calcareous shale. Thickness of L.st. beds increase towards top and shale beds cease to exist at top.	
113	Aptian	Sivaganga	Terani clay	White to brownish white massive clay deposits with abundant ptylophyllum leaf impressions.	
			Kovandankurichi	Thick bedded pebbly sandstones	
119	Barremian		Basal conglomerate	Lithoclastic conglomerate beds with clasts drawn from archaen rocks.	

After Ramkumar *et al.*¹¹.

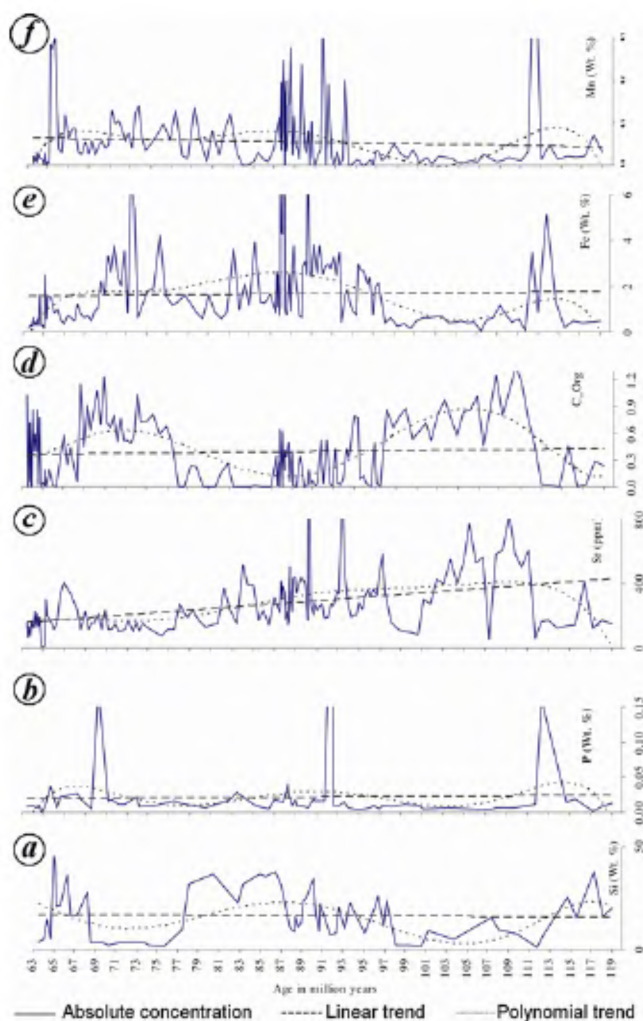


Figure 3. Geochemical profiles across Barremian–Danian strata.

anomaly across the boundary turns into positive excursion, signifying early Tertiary recovery of sedimentation and biological systems from environmental stress prevalent prior to and across the boundary, as could be observed elsewhere²⁰.

Highly anomalous phosphorus values were observed in Albian, Cenomanian and Maastrichtian strata of the Cauvery basin. Although variations of sediment chemistry in stratigraphic record are a normal phenomenon, highly differing values of phosphorus from background values warranted a closer examination. Comparison of the trends of P with other major and trace elements and sea-level curve of the basin revealed that sea-level fluctuation was the primary influence. It was inferred that during its northward flight, the Indian plate remained as an Island continent whose climate was influenced by the temperature of surrounding sea water. Owing to the greenhouse effect prevalent during Cretaceous, changes in sea water temperature might have influenced glaciers to advance and retreat and thus sea-level fluctuations, causing episodes of P accumulation in the Cauvery basin at times. A less

significant negative anomaly across the K/T boundary of the Cauvery basin was also recorded. As P forms one of the important nutrients in the marine environment, reduction in the availability of nutrient is interpreted to have caused higher faunal turnover across the K/T boundary. P enrichment during Danian supports the view of many workers that during Tertiary, significant recovery of biotic population occurred.

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