Influence of Deccan volcanism in the sedimentary rocks of Late Maastrichtian–Danian age of Cauvery basin Southeastern India: constraints from geochemistry

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Geochemical studies have been carried out on the Late Maastrichtian–Danian sedimentary rocks of Cauvery basin to understand the terminal Cretaceous events. Geochemically, the sedimentary rocks of Kallamedu and lower Niniyur formations are classified as litharenite, wacke, shale, Fe-shale and Fe-sand. Clastic rocks of the later part of Late Maastrichtian and Danian show high values of Cr and Ni and high Cr/Th ratio, which may be induced by Deccan Traps volcanism. Chondrite normalized REE patterns of the Late Maastrichtian and Danian rocks of Cauvery basin are more or less similar to basalt, weathered Deccan basalt and Maastrichtian Lameta beds of Central India. The presence of negative Ce anomaly in the non-marine sedimentary rocks of Kallamedu Formation (Kallamedu2, Rayambaram and lower part of Niniyur sections) strongly supports the view that these changes have been induced by the Deccan volcanism. Apart from this, the high content of Mg and Fe in the Kallamedu2 section suggests that the abnormal concentration of these elements is mainly influenced by Deccan volcanism. The influence of Deccan volcanism is more in the Kallamedu2 and Rayambaram sections than the Niniyur and Ellaikadambur sections.

Keywords: Cauvery basin, Danian, geochemistry, Deccan volcanism, Late Maastrichtian.

Volcanism may affect contemporary sedimentary environments in many ways¹. During the end of Cretaceous, India witnessed a huge amount of lava flows which initiated the formation of the Deccan volcanic province². Deccan volcanism in India represents one of the largest areas (>10⁶ km²) of continental flood basalts. During the Late Cretaceous, the Indian plate drifted towards north from an area east of Madagascar and south of the equator, over the head of a hot mantle plume³. About 65 million years ago, the mantle plume material travelled through India’s crust, created a hotspot volcano that exists even today in Reunion Island and is known as the Piton de la Fournaise volcano. The volcanic eruption produced enormous amount of lava and large quantities of CO₂, which disturbed the ecosystem and triggered rapid K/T transition greenhouse warming³ and K/T extinction. The initial area covered by Deccan volcanics is estimated around 2 × 10⁶ km², and half of the Deccan basalts have been eroded during the last 60 million years. The approximate volume of the basalt, considering its unexposed past and erosional losses is estimated at over ~2 × 10⁶ km³ (ref. 1) whereas few workers estimate extremely high volumes³ (8 × 10⁶ km³). The Deccan volcanic episode received more attention as it occurred around the Cretaceous–Tertiary boundary (KTB)⁴. Deccan volcanism undoubtedly straddles the KTB⁵ and has often been linked to the KTB mass extinction⁶. Deccan volcanism ejected 5 × 10¹⁷ moles of CO₂ into the atmosphere over a duration of 0.53–1.36 Ma (ref. 3). The release of vast amount of volcanic materials would have upset the equilibrium between mantle release and uptake by surficial sinks, triggering ecological instability³. According to Thierstein⁸, global ecological stability had prevailed prior to Deccan volcanism. The presence of local microclimates in the vicinity of volcanic provinces may lead to mock aridity⁹. According to them, the semi-arid conditions would have prevailed over hundreds to thousand thousands of years if the intense volcanism had prolonged for several million years.

The sedimentary rocks of Cretaceous–Palaeocene age developed in the Cauvery basin comprise both clastic and carbonate rocks. The great diversity of faunal niche in the huge sedimentary basin has attracted the attention of geologists not only from India but also from other countries since 1842. The continuous sections of Cretaceous–Tertiary sequences are rare in the outcrop areas but are moderately developed in the subsurface of the Cauvery basin. Few studies have already been undertaken on the palaeontological aspects of the Cauvery basin K/T boundary. However, sedimentological and geochemical studies on these sedimentary rocks are scanty. The Kallamedu Formation was deposited under fluvial environment during the Late Maastrichtian which represents

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terminal Cretaceous deposits, whereas the Niniyur Formation was deposited during the initiation of the Danian marine transgression. The purpose of this study is to identify the terminal Cretaceous events and their signatures on contemporary sedimentary rocks of Cauvery basin by examining the geochemistry of Late Maastrichtian–Danian sedimentary rocks exposed in the Ariyalur area. Geochemical characteristics of these rocks are compared with basalt to assess the influence of Deccan volcanism on the sedimentary rocks of Cauvery basin. The present study will also provide information regarding the changes in chemical weathering which occurred due to Deccan volcanism.

Geology and stratigraphy

The Cauvery basin has been considered as a rift basin\(^1\), which formed due to Mesozoic extension during the break up of Gondwanaland\(^1\). The basin consists of a 6 km thick pile of sediments deposited on Achaean basement and is situated along the southeast coast of India\(^1\). The sedimentary rocks of Cretaceous–Palaeocene age are well exposed in five isolated areas (Pondicherry, Vridhachalam, Ariyalur, Tanjore and Sivaganga) of the Cauvery basin\(^2\). Among these, the Ariyalur area exhibits thick sequence of elastic and carbonate rocks. The faunal diversity in this sedimentary basin has attracted the attention of geologists from India and all over the world\(^3\).

Studies on stratigraphy, palaeontology, depositional environments and tectonic evolution of the Cauvery basin have been carried out by many workers\(^4\)-\(^23\). Blanford\(^2\) divided the sedimentary rocks into three groups: Uttatur, Trichinopoly and Ariyalur (Figure 1). The Ariyalur group is better exposed than the other two groups of rocks. It was divided by Sastry et al.\(^14\) into four formations namely, Sillakkudi, Kalankurichi, Ottakkovil and Kallamedu (Table 1). A detailed lithostratigraphic analysis of the Cretaceous–Palaeocene rocks was proposed by Sundaram and Rao\(^15\) and they placed the Niniyur Formation under the Ariyalur group. The microtexture on quartz grains from the Sillakkudi, Kalankurichi and Ottakkovil formations reveals that these sediments were deposited in a marine environmental condition, whereas the Kallamedu Formation indicates a fluviat environment\(^20\).

No detailed and systematic study has been undertaken to determine the precise stratigraphic location of the K/T boundary in Ariyalur area. The Kallamedu Formation (Late Maastrichtian) is the youngest formation of the Ariyalur group which mainly comprises sandstones, siltstones and mudstones, and exhibits large variations in lithology. The only fossils known from this formation are dinosaurs within sandstone–siltstone beds\(^18,22-24\). The sandstone and siltstone beds of Kallamedu Formation exhibit tabular and trough cross stratification, which support the fluvial depositional environment\(^18,19\). The Kallamedu Formation is overlain by the Niniyur Formation (marine deposits), the dominant lithologies of which are calcareous sandstones, sandy claystone and limestones.

The sedimentary rocks of Late Maastrichtian and Danian age are poorly exposed in Ariyalur area of Cauvery basin. There is no continuous section encompassing terminal Cretaceous and Danian sedimentary rocks. So, samples have been collected from the isolated outcrops/sections in different localities of Ariyalur area to find out the terminal Cretaceous events. Kallamedu2, Rayambaram and Niniyur sections (Figure 2) were deposited in non-marine conditions, whereas the lithofacies of Ellaikadambur section suggest the marine environment.

The Kallamedu2 section mainly consists of shale, silty shale and sandstone\(^25\). The shale and silty shale beds have total thickness of 1 m, whereas the marl and sandstone beds are about 20 cm thick. The total thickness of the shale facies is 60 cm, and overlain by pale-green silty shales (40 cm). The silty shale facies encloses numerous clay-rich nodules of 2–5 mm size. The top of this sequence is sandstone which is 20 cm in thick, pale-green in colour, medium to coarse grained and contains lenses of clay.

The Rayambaram section reveals three types of beds, i.e. compact shale, siltstone and green shale\(^29\). The bottom unit of this sequence is compact shale (60 cm thick). The overlying siltstone bed is 20 cm thick. The succeeding green shale bed is 1.70 m thick.

Five beds are identified in the Niniyur section represented by elastic and carbonate rocks, i.e. sandstone, limestone (thin band), silty shale, greenish shale and yellowish shale layers\(^26\). The lower sandstone bed is (1.40 m thick) fine to medium grained, light grey to light brown and contains clay pockets. The overlying limestone bed is nodular in shape and has thickness of 10 cm. The succeeding bed of green silty shale is 10 cm thick and contains fine-grained quartz. The compact greenish shale bed is 15 cm thick and is overlain by a thin layer of yellowish shale (2 cm).

The Ellaikadambur section displays a succession of elastic and carbonate rocks, starting from the base lower sandstone, nodular limestone, middle sandstone, clay bed, upper sandstone and fossiliferous limestone\(^25\). The sandstone is fossiliferous, light brown, fine to medium grained in nature. The lower sandstone unit contains significant amount of clay materials whereas the middle and upper sandstone units are rich in calcareous materials.

Methodology

Samples were collected from the four sections of Kallamedu (Late Maastrichtian) and Niniyur formations (Danian) to find out the terminal Cretaceous events in the Ariyalur area of Cauvery basin. Sedimentary rocks of these formations were collected from stream sections (Kallamedu2 (south) and Ellaikadambur) and well sections.
(Rayambaram and Ninnyur). Totally 28 samples were selected for major, trace and rare-earth elements (REEs) study.

Fresh rock samples were powdered in an agate mortar and fused-glass beads were prepared for major element analysis (SiO$_2$, Al$_2$O$_3$, Fe$_2$O$_3$, CaO, MgO, Na$_2$O, K$_2$O, MnO, TiO$_2$ and P$_2$O$_5$) by a Phillips PW 1480 X-ray Fluorescence Spectrometer with a rhodium X-ray source. Total Fe content is reported as Fe$_2$O$_3$. The accuracy of SiO$_2$, Al$_2$O$_3$ and K$_2$O was better than ±1%, MnO better than ±2% and that of Fe$_2$O$_3$, CaO and MgO better than ±4%. The analytical accuracy of Na$_2$O, P$_2$O$_5$ and TiO$_2$ was better than ±5%.

Trace element (Ba, Co, Cu, Cr, Ni, Sc, Sr, V, Zn and Zr) concentrations were determined using Jobin Yvon 138 Ultrace inductively coupled plasma atomic emission spectrometer (ICP-AES). REE and additional trace elements (Cs, Hf, Nb, Pb, Rb, Th, U and Y) were analysed by a VG Elemental PQII plus inductively coupled plasma mass spectrometer (ICP-MS). United States Geological Survey standard MAG-1 was used for calibration to determine the accuracy of the results. The results obtained from the ICP-MS on these geological standards reveal that analytical values are within the range of certified values. The precision for trace elements such as Co, Cr, Cu, Ni, Nb, Sr, Pb and Y better than ±10%. The analytical precision for all REE was better than ±4%, except Tb, Dy, Ho, Tm and Lu for which it was better than ±10%. REE in samples were normalized by using a chondrite value$^{20}$.

**Geochemistry**

**Major elements**

The major elemental concentrations of individual samples are given in Figure 3. Using the geochemical classification diagram of Herron$^{27}$, the sedimentary rocks of Kallamedu and lower Ninnyur formations are classified as litharenite, wacke, shale, Fe-shale and Fe-sand (Figure 4). The clastic rocks from Kallamedu2, Rayambaram,
<table>
<thead>
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<th>Group</th>
<th>Formation</th>
<th>Lithology</th>
<th>Thickness (m)</th>
<th>Age</th>
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<td>Niniyr</td>
<td>Kallamedu</td>
<td>Calcareous sandstone, fossiliferous limestone and clay</td>
<td>50–100</td>
<td>Danian</td>
</tr>
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<td>Ottakkovil</td>
<td>Fossiliferous calcareous sandstone interbedded with claystone</td>
<td>0–60</td>
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<tr>
<td>I</td>
<td>Kallankurichi</td>
<td>Fossiliferous calcareous conglomeratic sandstone, fossiliferous</td>
<td>10–40</td>
<td>Maastrichtian</td>
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<tr>
<td>Y</td>
<td>Sillakkudi</td>
<td>Calcareous sandstone interbedded with claystone, sandy fossiliferous limestone and marl</td>
<td>300–500</td>
<td>Campanian</td>
</tr>
<tr>
<td>U</td>
<td></td>
<td>Unfossiliferous calcareous sandstone, fossiliferous calcareous sandstone interbedded with claystone and thin band of sandy limestone</td>
<td></td>
<td>Late Turonian to Santonian</td>
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Table 1. Lithostratigraphy of the Ariyalur Group (modified after Sastry et al.\textsuperscript{15})

Enrichment can be represented by SiO\textsubscript{2}/Al\textsubscript{2}O\textsubscript{3} and the relative concentration of alkalies can be represented by K\textsubscript{2}O/Na\textsubscript{2}O. Geochemical characters of clastic rocks have been used to decipher the provenance of the source region\textsuperscript{16}, particularly, SiO\textsubscript{2}/Al\textsubscript{2}O\textsubscript{3} ratio has been estimated to infer evolutionary changes in the composition of continental crust and provenance\textsuperscript{28}. The sandstone, silty shale and shale of Kallamedu Formation show large variations in SiO\textsubscript{2}/Al\textsubscript{2}O\textsubscript{3} ratios (3.54–9.30), with an average of 4.44, whereas sandstone and sandy clay of Niniyr Formation show least variation (4.88–7.71) with an average of 6.16. These values are higher than typical post-Archean shale (2.49–4.41) from Australia\textsuperscript{26}.

The clastic rocks of the Kallamedu2 section (8.14–12.21%) show high content of Fe\textsubscript{2}O\textsubscript{3} than the Rayambaram (2.04–6.40%), Niniyr (2.68–6.50%) and Ellaikadambur (1.37–2.49%) sections. High content of MgO is observed in the Kallamedu2 (3.87–4.09%) and Rayambaram (3.55–3.75%) sections than the Niniyr ((1.09–2.69%) and Ellaikadambur (2.12–2.94%) sections. TiO\textsubscript{2} content is generally low in the clastic rocks of Kallamedu and Niniyr formations. The upper part of the sandstone sequence in Niniyr section exhibits abnormal content of TiO\textsubscript{2} (2.10–2.19%). The observed high content of TiO\textsubscript{2} in this section is mainly due to increased amount of detrital input. The clastic rocks from Rayambaram, Niniyr and Ellaikadambur sections show low value of K\textsubscript{2}O which is mainly due to the presence of low amount of K-feldspar and illite in the sandstones and fine-grained (claystone, silty shale and shale) samples respectively.

**Trace elements**

Clastic rocks from the Kallamedu2, Rayambaram, Niniyr and Ellaikadambur sections show large variation in V, Cr, Co, Ni, Cu and Zn contents (Figure 5). V content is low in the Ellaikadambur (9–40 ppm) section, and moderate in Rayambaram (36–119 ppm) and Niniyr (9–117 ppm) sections, and high in the Kallamedu2 section (34–184 ppm). High content of Cr is identified in

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Figure 2. Location map of the study area.

Niniyr and Ellaikadambur sections exhibit a wide range of variations in most of the major elements. Silica enrichment can be represented by SiO\textsubscript{2}/Al\textsubscript{2}O\textsubscript{3} and the relative concentration of alkalies can be represented by K\textsubscript{2}O/Na\textsubscript{2}O. Geochemical characters of clastic rocks have been used to decipher the provenance of the source region\textsuperscript{16}, particularly, SiO\textsubscript{2}/Al\textsubscript{2}O\textsubscript{3} ratio has been estimated to infer evolutionary changes in the composition of continental crust and provenance\textsuperscript{28}. The sandstone, silty shale and shale of Kallamedu Formation show large variations in SiO\textsubscript{2}/Al\textsubscript{2}O\textsubscript{3} ratios (3.54–9.30), with an average of 4.44, whereas sandstone and sandy clay of Niniyr Formation show least variation (4.88–7.71) with an average of 6.16. These values are higher than typical post-Archean shale (2.49–4.41) from Australia\textsuperscript{26}.

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Kallamedu2 (10–299 ppm), Rayambaram (94–244 ppm), Niniyur (41–622 ppm) and Ellaikadambur (47–566 ppm) sections.

Co content is high in Kallamedu2 (15–50 ppm) and Niniyur (4–46 ppm) sections whereas it is low in Rayambaram (2–10 ppm) and Ellaikadambur (2–7 ppm) sections. Ni content is higher in Kallamedu2 (31–113 ppm) than Rayambaram, Niniyur and Ellaikadambur.

**Figure 3.** Major elements (%) variation in Kallamedu2, Rayambaram, Niniyur and Ellaikadambur sections.

**Figure 4.** Geochemical classifications of sedimentary rocks of Kallamedu and lower Niniyur formations.

**Figure 5.** Trace elements (ppm) variation in Kallamedu2, Rayambaram, Niniyur and Ellaikadambur sections.
sections (23–38 ppm, 12–46 ppm, 13–46 ppm, 7–11 ppm). Cu and Zn concentrations are higher in Kallamedu2 (13–70 ppm, 26–175 ppm respectively) than in other sections.

High content of Nb is found in certain intervals of Kallamedu2 (16.32 ppm) and Niniyur (9.18 ppm) sections. Nb is the least mobile trace element found during basalt weathering. The enrichment of Nb in certain intervals of Kallamedu Formation is comparable to that in weathered Deccan basalt.

Rare earth elements

Large variations in ŪREE content are observed in various sections of Late Maastrichtian and Danian age: Kallamedu2 (126.41–203.35 ppm), Rayambaram (27.37–46.29 ppm), Niniyur (30.72–313.12 ppm) and Eliaikadambur (26.69–73.53 ppm) sections (Figure 6). Clastic rocks from Rayambaram section are depleted in most of the REEs, relative to other sections of Kallamedu and lower Niniyur formations. The fine-grained clastic rocks of Rayambaram section are dominated by mixed-layers (illite/smectite: 87–100%) and illite (6–13%). The low content of REE in these sedimentary rocks is mainly due to poorly developed clay minerals and may be due to the presence of volcanic ash materials.

Significant variations are observed in trace and REE concentrations between different sections of Kallamedu and lower Niniyur formations. In chondrite-normalized REE plots, the clastic rocks of Kallamedu and lower Niniyur formations show LREE enriched and HREE depleted patterns with both negative and positive Ce and Eu anomalies (Figure 7 a–d). Although the total REE concentrations are significantly different in the clastic rocks from different sections, it is interesting to note that the elemental distribution patterns are more or less similar in nature.

Deccan volcanism

Deccan volcanics are mainly composed of theoleitic basalts and alkaline, acidic and carbonatitic lavas from minor components. Many workers related the Deccan Traps to the Reunion plume. The plume head formed the flood basalts and the tail of the plume has generated the track that ends in the active volcanoes on the Reunion Island. The duration of Deccan volcanism has been a matter of intense debate among various research groups. Some workers have proposed a short (≤0.5 Ma) duration for the peak volcanic activity, whereas few studies show a long span of 3–4 Ma. Raju et al. have also assigned long periods of 5–7 Ma for Deccan volcanic activity based on the fossil evidence of intertrappean sediments in the Krishna–Godavari basin.

The analysis of hotspot activity at K/T lines indicates that the starting plumes (Deccan) and many hotspots (around 20) were present in the Southern Hemisphere. This can be compared with two large, pre-existing hotspots (Greenland and Hawaii) and other hotspot sites in the Northern Hemisphere. Such a global distribution of impact and hotspots sites could produce greater basaltic signatures in southern K/T sites. A global climatic effects from volcanic eruptions in unevenly distributed in continental and oceanic masses during the K/T time which would further complicate an uneven distribution in volcanic and impact events.
The clastic rocks of the later part of Late Maastrichtian and Danian show high values of Cr (38–622 ppm) and Ni (7–103 ppm) and high Cr/Th ratios (3.73–76.73). High concentrations of Ni (50–130 ppm) and Cr (112–225 ppm) in flood plain sediments of the Cauvery River were reported and interpreted to be a result of weathering of mafic rocks\textsuperscript{38}. But, it is not supported by the concentrations of REEs, and REE pattern and distribution of other trace elements in the sedimentary rocks of the Kallamedu and lower Niniyur formations. Almost all rock types in the Dharwar Craton of southern India show significant enrichment in Cr–Ni content\textsuperscript{39}. High concentrations of Ni–Cr were also noticed in the Archean sedimentary rocks\textsuperscript{39} in the Dharwar Craton (source rocks of Cauvery basin) of southern India. The abnormally low values of these elements suggest that the source rocks for the sediments had high Ni–Cr content. If the source rocks from Dharwar Craton were contributing these elements in the latest Late Maastrichtian and Danian sedimentary rocks, then they ought to be frequently enriched in the Campanian, Maastrichtian and still older sediments in the Cauvery basin. But the Campanian and Maastrichtian sedimentary rocks of Cauvery basin show low values of Cr and Ni\textsuperscript{18}. The elevated concentrations of Cr–Ni are observed only in the later part of the Late Maastrichtian and Danian sediments. Our observations thus indicate that these abnormal values have not been influenced by source rock characteristics. Higher concentrations of Cr and Ni, and high Cr/Th ratios may be induced by Deccan Traps volcanism. High content of Cr and Ni has been identified in a certain sequence and certain interval which suggested that there was no complete ash-blanketing of the area preceding the K/T event.

The Kallamedu2 section exhibits mixed-layers (illite/smectite)–fibrous clays (palygorskite and sepiolite)–kaolinite assemblages\textsuperscript{50}. Sepiolite is authigenic in origin, which indicates the moderate to strongly alkaline environments\textsuperscript{89}. The shale sequence exhibits high content of Fe and Mg. Smeectites derived from the Deccan basalt show high content of Fe and Mg\textsuperscript{58}. Likewise, the smectite in the Lameta Formation (Late Maastrichtian) also exhibits high content of Fe and Mg\textsuperscript{50}. The high content of Fe and Mg in the shale sequence of Kallamedu Formation suggests that this abnormal enrichment was mainly due to the influence of Deccan volcanism.

Zr and Ti\textsubscript{2}O\textsubscript{5} contents increased suddenly in the upper part of the sandstone sequence in the Niniyur section. These elements are exclusively present in the detrital fraction. Sudden increase in these elements was influenced by the high silicate weathering and detrital input. Vigorous volcanism had produced the Deccan Traps during the Late Cretaceous and the Early Tertiary\textsuperscript{7,41}. Large amount of SO\textsubscript{2} and SO\textsubscript{3} as well as volcanic dusts were released during volcanic eruptions. These gases were readily converted into H\textsubscript{2}SO\textsubscript{4} aerosol causing acid rain. These volcanic gases and dusts can be transported globally by strong wind which initiates acid rainfall worldwide and enhances weathering\textsuperscript{52}. In Niniyur section,
the sandstone unit is overlain by thin nodular limestone band. The concentration of many elements decreases due to the dilution effect on carbonate. The limestone band in the Ninjur section shows negative carbon and oxygen isotopic values (~6.8% and ~4.81% respectively). The negative carbon isotopic values resulted mainly due to cooler climate during the later part of the Late Maastrichtian (prior to K/T boundary). Similar negative carbon isotopic shift far below K/T boundary has been observed by many authors\(^{35,44}\). They mentioned that the carbon isotopic shift might be associated with global climatic cooling and fall in productivity. Ba and Cr contents gradually increase, whereas V, Sc, Y and Nb decrease gradually in the silty shale and shale sequences of Ninjur section. High TiO\(_2\) content is observed in the silty shale unit whereas this content gradually decreases towards the top of the sequence, which suggests the gradual decrease in detrital input in the source region.

Roser and Korsch\(^{35}\) have established four major groups of rocks using discriminant function score of major element data, viz. mafic igneous, intermediate igneous, felsic igneous and quartzose sedimentary. In discriminant diagram (Figure 8), one sample from Kallamedu2 section and few samples from Rayambaram and Ninjur sections fall in the mafic provenance field, whereas the remaining samples are plotted in the quartzose sedimentary provenance. The REE patterns of sandstones of Silakkudai, Kallankurichi, Ottakkovil and Lower Kallamedu formations of Aryanur group suggest the felsic nature of the source rocks\(^{18}\). In addition, the microtextural study of the quartz grains from Lower Kallamedu Formation of Aryanur group reveals the presence of significant amount of recycled sediments\(^{20}\). Hence, the result drawn from the discriminant diagram is consistent with the earlier study, which supports the view that significant amounts of sediments were contributed by the quartzose sedimentary provenance during the Late Maastrichtian time. In addition, some samples fall in the mafic provenance field which also suggests that the Deccan volcanism might have contributed some amount of mafic materials to the sedimentary rocks of Cauvery basin during the end of Cretaceous.

The REE distribution patterns are similar in the Late Maastrichtian and Danian sedimentary rocks of Cauvery basin but show significant variations in \(\Sigma\)REE contents. Rayambaram and Ellaikadambur sections show low \(\Sigma\)REE contents whereas other sections show high \(\Sigma\)REE contents. The acid leaching greatly decreases the REE concentration in many clay minerals\(^{46,47}\). The depletion of REE in the Rayambaram and lower part of Ellaikadambur sections may be due to acid leaching of REE (induced by Deccan volcanism) without inter-elemental fractionation during weathering. Similar results of lower REE values have been documented in the sedimentary rocks of Anjar area of Deccan volcanic province\(^{48}\). The low content of REEs in the Rayambaram and lower part of Ellaikadambur sections may also be due to the inclusion of volcanic ash in these sediments.

The chondrite REE patterns of the present study are compared with basalt, weathered Deccan basalt and Lametas (Figure 9). The REE patterns of the present study are more or less parallel to those of basalt, weathered basalt and Lameta sediments. The REE pattern of Kallamedu2 is identical to basalt, weathered basalt and Lametas whereas the sedimentary rocks from the Rayambaram, Ninjur and Ellaikadambur sections also show similar trend but have depleted \(\Sigma\)REE content. Based on the geochemical signatures, it has been concluded that these sedimentary rocks preserve the Deccan volcanic signature and may be comparable to that of Maastrichtian Lameta beds of Central India.

The sedimentary rocks of Late Maastrichtian and Danian age show LREE enriched and HREE depleted patterns with or without Eu and Ce anomaly. Among the REE, Ce and Eu could exist in di- and tetra-valent states and their concentrations are dependent on redox conditions that prevailed in the system during their deposition\(^ {19}\). The sedimentary rocks of Late Maastrichtian age were deposited under fluvial environment\(^ {15,18,20}\). The negative Ce anomaly is mainly found in the sediments deposited under marine environment\(^ {19,50}\). Apart from this, Ce depletion is also documented in the pervasive basalt weathering\(^ {51}\). It has been documented that under oxidizing conditions, Ce gets oxidized to the +4 state and is removed from the reservoir.

The elastic rocks from Kallamedu2, Rayambaram and lower part of Ninjur sections show negative Ce anomaly, whereas the remaining sections show positive Ce anomaly. The Kallamedu2 Formation shows high content of both Fe and Mg. These sediments were mainly deposited under fluvial environments which were not conducive for the formation of authigenic Mg-rich minerals. The pre-

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**Figure 8.** Discriminant function diagram for sedimentary provenance using major elements\(^ {16}\).

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sence of negative Ce anomaly together with high content of Mg and Fe in the Kallamedu2 section suggests that these changes have been influenced by the Deccan volcanism. The influence of Deccan volcanism is more in the Kallamedu2 and Rayambaram followed by Niniyur and Ellaikadambur sections.

Conclusion

Geochemical studies on the Late Maastrichtian–Danian sedimentary rocks of Cauberry basin provide useful information regarding the terminal Cretaceous events. Clastic rocks of the later part of Late Maastrichtian and Danian show high values of Cr (38–622 ppm) and Ni (7–103 ppm) and high Cr/Th ratios (3.73–76.73). The higher concentrations of Cr and Ni and high Cr/Th ratios may be induced by Deccan traps volcanism. The chondrite REE patterns of the present study are compared with those of basalt, weathered Deccan basalt and Lametas. The REE patterns of the present study are more or less similar to those of basalt, weathered Deccan basalt and Lameta sediments, which suggest that the sedimentary rocks of the present study may be comparable to those of Maastrichtian Lameta beds of Central India. Kallamedu2, Rayambaram and lower part of Niniyur sections show negative Ce anomaly which supports the view that these changes are a result of the influence of Deccan volcanism. Apart from this, the high content of Mg and Fe together with negative Ce anomaly in the Kallamedu2 section suggests that the Deccan volcanic influence is clearly present in the sedimentary rocks of Cauberry basin. The influence of Deccan volcanism is more in Kallamedu2 and Rayambaram sections than the Niniyur and Ellaikadambur sections.

RESEARCH ARTICLES


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