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Clay minerals from the Lameta Formation of Pandhari area, districts Amravati, Maharashtra and Betul, Madhya Pradesh: Its paleoclimatological implications

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This report highlights the record of clay minerals from the Lameta Formation of a new locality of central India. A 9-m thick argillaceous column represented by various shades of grayish-greenish-brownish-yellowish coloured clay to silty-clay has been investigated. The clay has been separated from the host sediment by pipette method which has been further subjected to XRD analysis. The peaks identified are of palygorskite, sepiolite, illite, montmorillonite and kaolinite. The assemblage is interpreted to be a product of arid to semi-arid climatic condition due to weathering of pre-existing rocks. The depositional site also shows the possibility of short term marine incursion.

Keywords. Clay minerals; Lameta; paleoclimate; palygorskite–sepiolite.

1. Introduction

Clay minerals derived from various physical processes are useful palaeoclimatic indicator that gives the idea about the environment in which they were formed (Chamley 1989; Adatte *et al.* 2002). Various clay minerals are formed in different climatic conditions that also depend upon water/rock ratio and fluids of different chemical composition (Velde 1985; Clauer and Chaudhari 1995). In the present study, clay minerals from 9-m thick, argillaceous column of the Lameta succession, exposed at Pandhari area (lat. 21°22′00.71″N, long. 77°33′00.13″E), lying at the border of districts Amravati, Maharashtra and Betul, Madhya Pradesh have been studied for their quantitative representation and palaeoclimatic inferences. The Lameta sediments exposed at Pandhari area is a part of newly proposed inland basin for Lameta sedimentation in central India, viz., Salbardi–Belkher inland basin by Mankar and Srivastava (2015) (figure 1). This basin is demarcated on the basis of 4–5 large, isolated, scattered exposures of Lameta sediments along with many others of small dimensions. These successions are continuously under study from last decade because of revised palaeogeographic boundary of Lameta sedimentation in India (Mankar and Srivastava 2015), dinosaurian remains including egg nests (Srivastava and Mankar 2013, 2015a), facies architecture and depositional environment (Srivastava and Mankar 2015b), trace fossils (Srivastava and Mankar 2012) and calcareous algae (Srivastava *et al.* 2018). However, clay minerals have not been attempted besides having significant value in palaeoclimatic reconstruction and the same is the prime object of this study.

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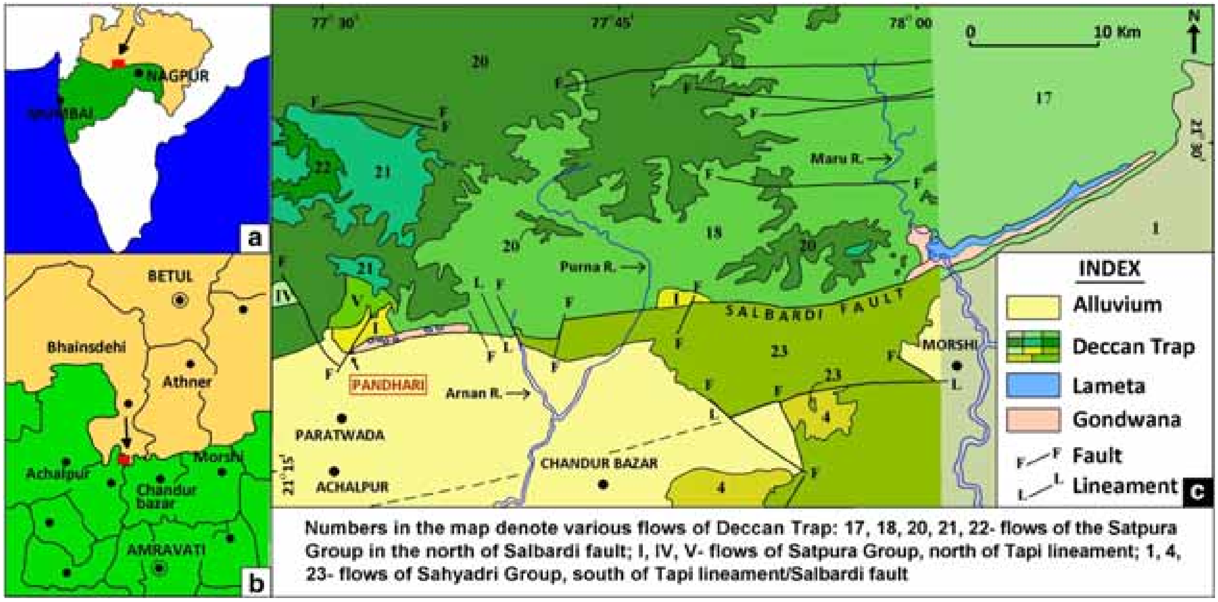

Figure 1. Map showing (**a, b**) study area in regional set-up and (**c**) geological map showing locations of the study area of Pandhari along with other adjacent localities of Lameta exposures, viz., Bairam, Belkher and Salbardi (GSI 2001, 2002).

2. Geological setup of the area

In regional framework, the Lameta Formation disconformably overlies the upper Gondwana sediments which rest unconformably over the basement of quartz-feldspathic gneiss of Archaean age. Hard and compact, regionally exposed basalt of the Deccan Trap, overlies the Lameta sediments with a sharp boundary. The Gondwana rock having preservation of abundant gymnosperm and pteridophytic mega floral remains suggest Upper Jurassic to Lower Cretaceous age, correctable with the Jabalpur Formation (Srivastava *et al.* 1996, 1999). Alluvium and soil of Quaternary age form top-most horizon.

The Lameta sediments of Pandhari area under investigation constitute about 37-m thick lithocolumn which is broadly divisible into three units, i.e., argillaceous lithocolumn forming lower part, middle part by arenaceous sediments whereas, calcareous lithounit constitute upper part of the succession (figure 2). The argillaceous succession, represented by grayish-greenish-yellowish-brownish clay, silty-clay and marl, constitutes the lower 9 m succession that overlies the upper Gondwana sediments ($\sim$Jabalpur Formation) with a disconformable boundary. In the studied section, this argillaceous lithounit is exposed having a vast lateral extent, however, many isolated, small and weathered debris belonging to this succession can be noticed in the surrounding area. The lower 2–3 m column of this succession is represented by massive, loosely packed friable clay of grayish-black colour which also shows isolated, small pockets of medium gray, massive clay (figure 3a). Scattered occurrences of light yellow, irregular, spherical to elliptical calcareous-marl concretions, ranging from 2–5 cm in diameters, have also been noticed (figure 3b). It is overlain by greenish-gray clay of equal thickness having same depositional attributes as of previous, however, with increasing content of silt, it grades to massive to feebly laminated, friable, slightly calcareous, 2 m thick grayish-greenish silty clay (figure 3c). Preservations of 20–40 cm thick, light to medium gray, discontinued beds of calc-marl showing local chertification have also been noticed. These calcareous patches are significant as having preservation of calcareous algae showing short duration marine incursion (Srivastava *et al.* 2018). Overlying clay of yellowish-brown colour having 1 m thickness constitutes the top of succession. It is slightly hard in nature and preserves grayish-black chert lenses.

The argillaceous lithounit is distinctly overlain by 19-m thick arenaceous succession marked by diversified nature of sandstone beds, i.e., brownish-greenish-violet coloured, parallel to cross bedded, medium to coarse grained sandstones. This entire column is constituted broadly by medium and coarse grained sandstones. The previous is brownish gray to grayish brown, medium scale cross to parallel bedded, poor to medium sorted and occasionally, bioturbated in nature. The coarse sandstone is poorly sorted having pebbles and concretionary

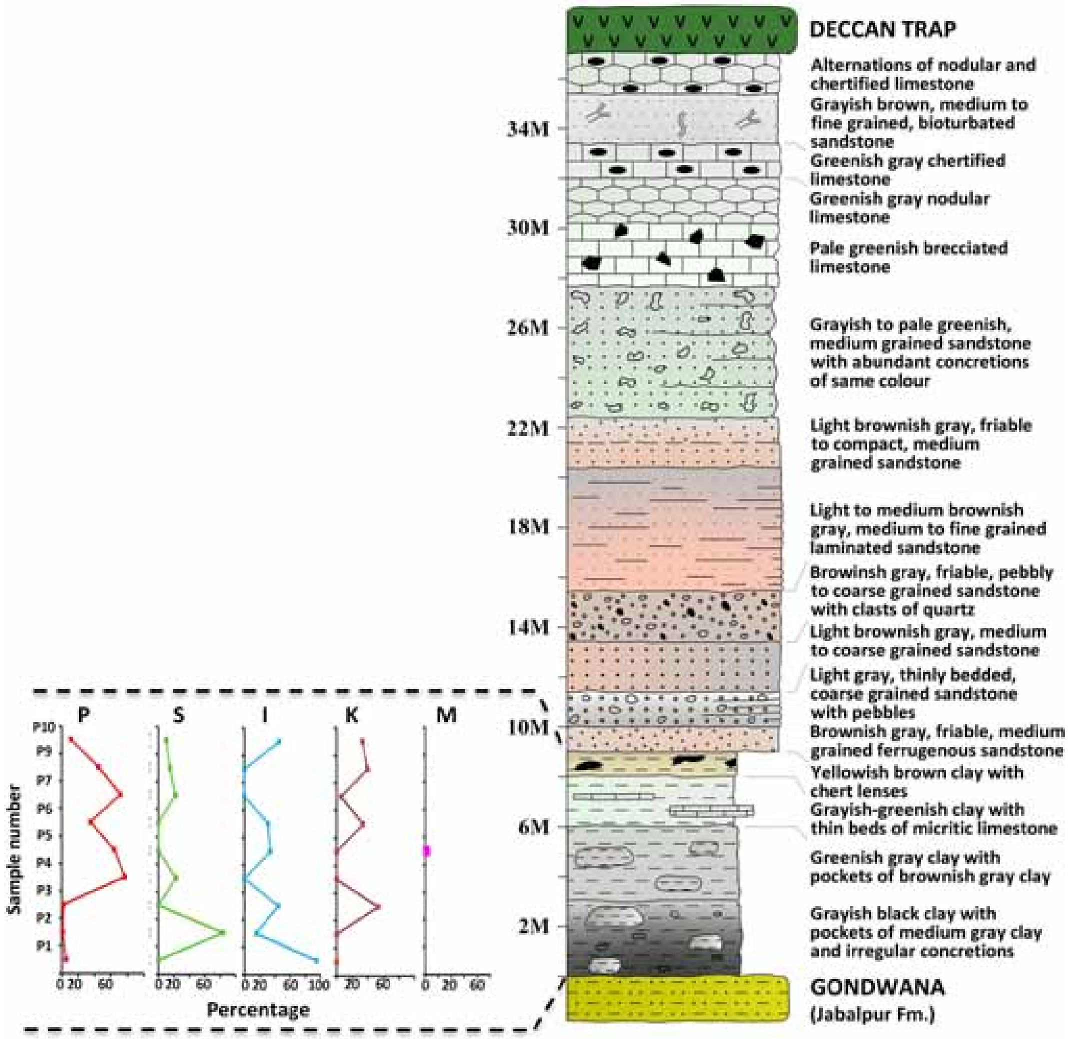

Figure 2. Detailed sedimentary log of the Lameta succession exposed at Pandhari area and temporal distribution of various clay minerals in the studied samples from the lower argillaceous lithounits (P: Palygorskite, S: Sepiolite, I: Illite, K: Kaolinite, M: Montmorillonite).

nodules. Overlying calcareous succession is about 9-m thick and represented by typical lithounits of the Lameta Formation exposed in type and paratype localities, i.e., pale greenish, brecciated limestone; greenish-gray, silicified, hard and compact nodular limestone and greenish-gray, hard and compact chertified limestone. The first two lithounits, i.e., brecciated and chertified limestones are well developed in the study area, whereas the nodular limestone is comparatively reduced (Srivastava and Kandwal 2016; Srivastava *et al.* 2018).

3. Sampling and methodology

Total of nine representative samples (P1–P7, P9–P10) have been collected from the argillaceous lithounit at the intervals of about 1 m with due consideration of change in colour, composition and texture of the host bed (table 1). Separation of the clay fractions has been carried out through pipette method (Krumbein and Pettijohn 1938). These fractions were further subjected to XRD analysis using PANalytical 3 kW X'Pert PRO X-ray Diffractometer for identification of individual clay minerals. Five different minerals, viz., palygorskite, sepiolite, illite, kaolinite and trace montmorillonite have been identified on the basis of their d-spacing values as proposed by Carroll (1970) (figure 4). Quantitative estimations of various clay minerals were made with the help of PANalytical X'Pert High Score Plus software. Figure 2 and table 2 show quantitative values of various clay minerals and the same has also been shown in vertical profile of the succession representing their irregular temporal trends.

Figure 3. Field photographs showing: **(a)** lower part of argillaceous succession represented by grayish-black clay overlain by greenish-gray clay, **(b)** grayish-black clay showing scattered occurrences of calcareous nodules (Pen – 10 cm) and **(c)** massive, loosely packed, friable greenish-gray clay (Hammer – 25 cm).

Table 1. *Physical attributes and nature of clay samples under study (in stratigraphic order).*

Sl. no.	Sample no.	Details of the host rock in stratigraphic order
1	P10	Yellowish-brown, compact clay with grayish-black colour, chert lenses in upper part of the succession
2	P9	Grayish-green, friable silty-clay having 20–40 cm thick beds of light to medium gray coloured micritic limestone preserving calcareous algae
3	P7	Brownish-gray, friable silty-clay occurring as pockets in greenish-gray clay having concretions
4	P6	Greenish-gray, friable silty-clay. Percentage of silt is comparatively more
5	P5	
6	P4	Grayish-black, friable silty clay, concretions are absent
7	P3	
8	P2	Medium gray, friable silty-clay having abundant irregular, spherical to elliptical calcareous concretions
9	P1	

4. Results and discussion

Clay minerals identified show a decreasing trend of their average values in the order of palygorskite (average 34.64%) >illite (average 29.43%) >sepiolite (average 18.54%) >kaolinite (average 17.14%) and >montmorillonite (average 0.22%). Palygorskite $(Mg,Al)_2Si_4O_{10}(OH) \cdot 4(H_2O)$ is an Mg rich clay mineral which is the most dominant in the present assemblage and identified in all the samples with significant amount. It is normally found associated with sepiolite but differentiable because of less Mg content and more structural diversity (Chamley 1989). Dominant peak values for identified palygorskite lie at 8.77 Å, 4.49 Å, 3.36 Å, and 2.46 Å. It is maximum in sample P7 (71.7%), whereas minimum in sample P2 (1%). Sepiolite $(Mg_4Si_6O_{15}(OH)_2 \cdot 6H_2O)$ is identified by their reflections at 2.58 Å, 3.36 Å, 1.87 Å. Its maximum and minimum values of 53.5% and 6.1% are recorded in sample P3 and P7, respectively. Illite

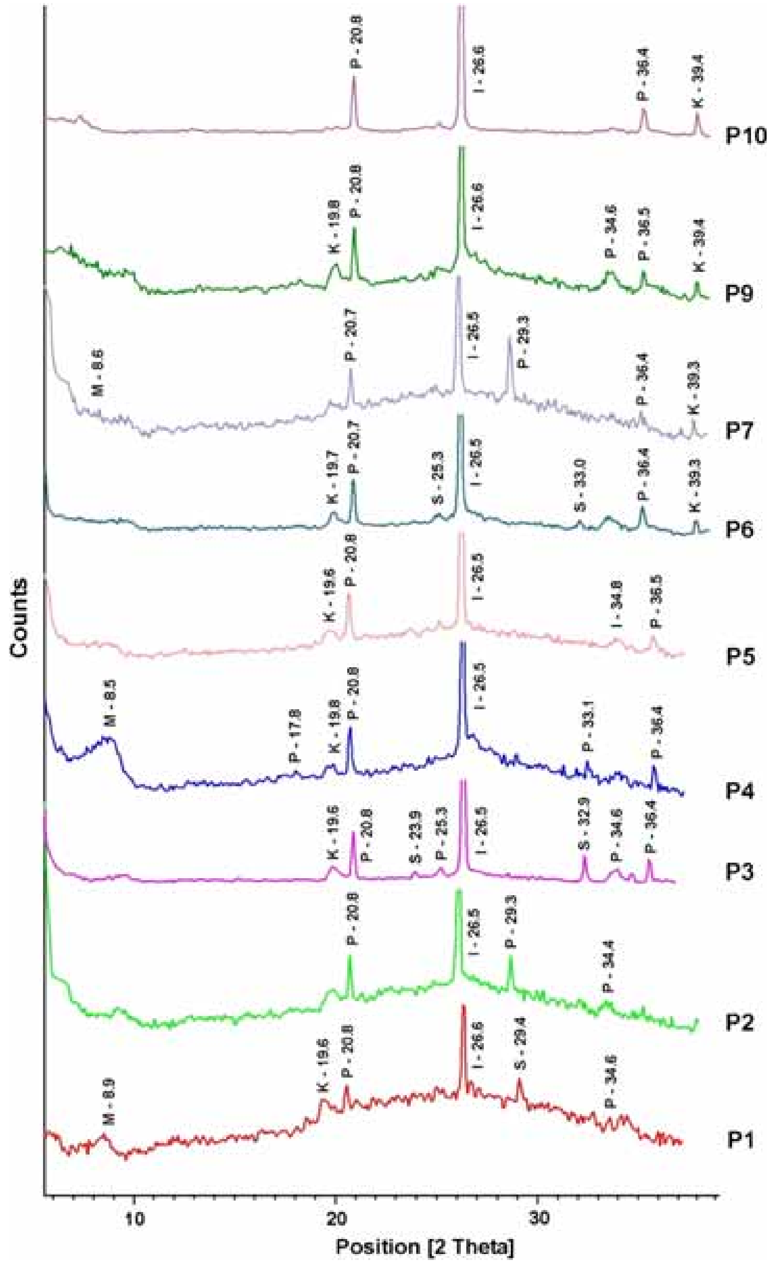

Figure 4. X-ray diffractogram pattern of the clay fraction of the samples showing peaks of various identified minerals (P: Palygorskite, S: Sepiolite, I: Illite, M: Montmorillonite, K: Kaolinite).

$(K, H_3O)(Al, Mg, Fe)_2(Si, Al)_4O_{10}[(OH)_2,(H_2O)]$ in the present study is reflected dominantly at 3.36 Å followed by 10.02 Å, 2.59 Å, 2.48 Å. Montmorillonite $[(Na, Ca)_{0.33}(Al, Mg)_2(Si_4O_{10})(OH)_2 \cdot nH_2O]$ has restricted occurrence and observed only in sample P5 (2%). It is identified by the presence of its peaks at 10.40 Å, 15.60 Å. Kaolinite $(Al_2Si_2O_5(OH)_4)$ with characteristic peaks at 4.48 Å, 2.46 Å, 2.60 Å is observed in sample numbers P2, P4, P7, P8 and P10 with the maximum of 84% and minimum of 10.1% from P10 and P2 samples, respectively (table 2).

Temporal distribution of various clay minerals plotted across the vertical column of the argillaceous unit, exhibits domination of palygorskite followed by sepiolite, kaolinite and illite in most of the column except the lower 2–3 m and the top parts of the succession, in which, illite, kaolinite and sepiolite are high (figure 2). Palygorskite indicates prevalence of semi-arid to arid climatic condition during their transformation, when water is drawn to the surface by capillary action followed by evaporation (Singer 1989; Bellanca *et al.* 1992). Sepiolite is a fibrous clay of continental to marine environments (Chamley 1989). In continental

Table 2. *Various clay minerals identified and their percentages in the samples under study.*

Sample no.	Clay minerals identified and their percentage					Dominant minerals
	Palygorskite	Sepiolite	Kaolinite	Montmorillonite	Illite	
P10	11.1	33.3	10.1	–	45.5	P, S, I
P9	45	40	15	–	–	P, S, K
P7	71.7	6.1	22.2	–	–	P, K, S
P6	35	34	–	–	31	P, S, K
P5	64	–	–	2	34	P, I
P4	77	–	23	–	–	P, K
P3	2	53.5	–	–	44.4	S, I
P2	1	–	84	–	15	K, I
P1	5	–	–	–	95	I

Note: P: Palygorskite, S: Sepiolite, I: Illite, K: Kaolinite, M: Montmorillonite.

areas, it commonly occurs in lakes (Singer 1989) and indicates moderate to strong alkaline environment of deposition (Bellanca *et al.* 1992). Both these minerals are early diagenetic in nature and formed in arid regions (Weaver 1989). Palygorskite along with sepiolite are reported from various environmental settings, i.e., marine, lacustrine, continental soils, and also in association with igneous rocks (Jones and Galan 1988). Association of these two minerals is reported from the late Cretaceous (Maastrichtian) soils, alkaline lakes or very shallow seas under semi-arid condition (Weaver 1989). Kaolinite normally forms in surficial condition through pedogenic processes (Chamley 1989). Its presence indicates semi-arid and humid climatic conditions (Velde 1985; Gertsch *et al.* 2011). Illite is one of the early products due to weathering of feldspathic and micaceous rocks and is stable under temperate climatic condition (Chamley 1989; Adatte and Keller 1998).

Salil *et al.* (1994, 1997) and Salil and Shrivastava (1996) made detailed study of clay minerals and their geochemistry including rare earth and trace elements of the type area succession of Lameta at Jabalpur. Salil *et al.* (1994) observed that the clay mineral fractions of the type area succession consist dominantly of montmorillonite along with minor fractions of chlorite, illite and kaolinite that depicts Deccan basalt as the source rock. Geochemical signature of the clay minerals also supports the same conclusion (Salil and Shrivastava 1996). Salil *et al.* (1997) noticed the dominance of smectite, illite and kaolinite in both Lameta sediments and weathered basalt of the Deccan Trap at Jabalpur area and interpreted weathered Deccan basalt as the major provenance rock for the Lameta sediments. Similarly, occurrence of montmorillonite, celadonite, illite and kaolinite are also reported from the Green Sandstone lithounit of the type area succession of Lameta, of which, montmorillonite and celadonite indicate degradation of parent basaltic material (Tandon 2002; Singh and Tandon 2004).

Comparing, the clay mineral assemblage of the studied locality with the type area clearly shows their different nature. The assemblage under investigation is dominated by palygorskite whereas, montmorillonite dominates in the type area succession (Salil *et al.* 1994, 1997; Salil and Shrivastava 1996). This may be due to change in climatic and depositional conditions in the basinal area. Similar conditions are reported from non-marine and marine sediments of Intertrappeans which occupy the gaps in volcanic eruption, represented together by regionally exposed Deccan Trap province in central and western India. Clay minerals from these Intertrappeans, exposed in central and western India, have also been studied by various researchers because of its significant role in reconstructions of palaeoclimatic and palaeoenvironmental conditions. High percentage of palygorskite as of the clay mineral assemblage has been reported from ca. 70 cm thick, reddish, pinkish and yellowish coloured laminated clay-marl unit of Jhilmili Intertrappean, a deposit of marine incursion, that indicates dry condition in the area during the deposition (Keller *et al.* 2009; Pal *et al.* 2013). Similarly, palygorskite dominated clay assemblage has also been reported from Anjar Intertrappean indicating their deposition in lacustrine or perimarine environment of high alkalinity reflecting increase in aridity induced by volcanism (Shrivastava *et al.* 2000; Shrivastava and Ahmad 2005, 2008). Palygorskite and kaolinite are also reported from different stratigraphic levels of the Sylhet Trap, in which, the previous depicts weathering in perimarine or, a saline lake setting while kaolinite indicates its derivation due to wet, humid and heavy rainfall weathering condition (Shrivastava *et al.* 2012). Occurrence of mixed layer clays with palygorskite and kaolinite at various sections in late Maastrichtian–early Paleocene marine sediment column of the Ariyalur Formation, Cauvery basin indicates alternations of warm and wet, warm and dry climatic condition (Madhavaraju *et al.* 2002). Prevalence of arid climate in western India is also interpreted on the basis of clay minerals and palynological studies of estuarine to near marine Ninama Intertrappean sediments of Saurashtra (Samant *et al.* 2014).

The dominance of illite in certain part of the column also makes the present assemblage different from the type area succession of Lametas (Salil *et al.* 1994, 1997; Salil and Shrivastava 1996). Occurrence of abundant illite has been reported from upper part of Jhilmili Intertrappean which is interpreted to be formed in semi-arid climate (Keller *et al.* 2009). Selective occurrence of illite at various stratigraphic levels in late Maastrichtian–early Paleocene marine sediment column of the Ariyalur Formation, Cauvery basin indicates strong physical weathering just before the K/T boundary (Madhavaraju *et al.* 2002). Its high content in the various sections of the Cauvery basin is interpreted due to the change in weathering pattern and also break in supply of clastic sediments (Madhavaraju *et al.* 2002). Dominance of palygorskite in the studied lithocolumn and illite in selected parts of the succession are justifiable by comparing climatic and depositional environment conditions of various Intertrappean sediments discussed earlier showing broadly arid to semi-arid climatic condition and near marine set-up of deposition. It may be mentioned that certain reports in the past have already advocated regarding evidences of marginal marine environment during the deposition of Lameta sediments in central and western India, i.e., presence of algal structure and glauconitic mineral (Chanda 1967), coastal complex depositional setup including preservation of burrows (Singh 1981; Kumar and Tandon 1979). In recent years, the same has been strengthened by reporting lizard eggs and trace fossils of marine affinity from the type area (Shukla and Srivastava 2008; Saha *et al.* 2010). Bansal *et al.* (2018) reported authigenic glauconite from the Green Sandstone of the Lameta Formation exposed at Phutlibaori area of Madhya Pradesh. Authigenic nature of the glauconite is interpreted due to its formation by the replacement of K-feldspar in the cleavages and fractures of feldspar, along peripheries of feldspar which later evolved as pellets in due course of time. Based on advanced geochemical and structural analysis including EPMA, Mössbauer spectroscopy and field emission gun-scanning electron microscopy of glauconite, Bansal *et al.* (2018) further interpreted existence of estuarine environment, in which, formation of glauconite with high concentrations of K, Si, Mg, Al and moderate Fe has taken place due to pseudomorphic replacement of K-feldspar. Srivastava *et al.* (2018) studied the same argillaceous succession from which, the clay assemblage is under investigation and reported short term marine intrusion on the basis of rich preservation of calcareous algae, viz., *Clypeina* sp., *Acroporella* sp., *Trinocladus radoicicae, Trinocladus* sp., *Dissocladella undulata, Dissocladella* sp., *Halimeda cylindracea, Halimeda* sp., *Ovulites* sp. (Chlorophyta); *Microchara* sp. (Charophyta); *Lithoporella* sp. and *Sporolithon* sp. (Rhodophyta) in a thin, discontinued bed of light gray, micritic limestone.

5. Conclusion

Five clay minerals, viz., palygorskite, illite, sepiolite, kaolinite and trace montmorillonite have been identified from argillaceous lithounit of Lameta succession. Palygorskite is the dominant mineral and present in entire column except lower and top of the lithounit, in which, illite is dominant. The selective dominance of minerals in the succession shows warm and humid, arid to semi-arid climatic condition and also the influence of short term marine incursion during the deposition of argillaceous sediments constituting lower part of Lameta succession. Short term marine intrusion is also supported by the preservation of diversified calcareous algae in a thin micritic bed.

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