JOURNAL GEOLOGICAL SOCIETY OF INDIA
Vol.97, January 2021, pp.55-60

Hillichnus agrioensis and Associated Trace Fossils from Hettangian to Bajocian Thaiat Member of Lathi Formation, Jaisalmer Basin, Western Rajasthan

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ABSTRACT

The present paper describes the abundant and very well preserved ichnotaxon complex *Hillichnus agrioensis,* as established by four different morphological levels of exposures. Associated trace-fossils such as *Jamesonichnites heinbergi* and *Ancorichnus ancorichnus* are also being reported from the Hettangian to Bajocian Thaiat Member of Lathi Formation of Jaisalmer basin, western Rajasthan, India. The ichnospeices *Hillichnus agrioensis* is being documented for the first time in India. Morphologically, *Hillichnus agrioensis* includes straight to gently curved, branched or feather-like (almost flat) structures with a central tube. It is interpreted as a deep-burrowing bi-siphonate or tellinaceans bivalves. The ichnotaxon *Jamesonichnites heinbergi* is interpreted as a burrow made by an infaunal deposit-feeder (fodinichnion), while *Ancorichnus ancorichnus* is domichnion and may also solely be the result of locomotion (repichnion). This study suggests the presence of shallow or marginal-marine environment for the above-mentioned trace-fossil bearing horizons as trace-fossils characterized by such features have also been found from other parts of the world.

INTRODUCTION

Bromley et al., (2003) introduced a new ichnogenus namely *Hillichnus.* These were known as fossilized seaweed impressions until Hill, (1981) described them as of ichnological origin. Based on the occurrence of this ichnogenus in three different outcrops of Palaeocene turbidites sandstone and mudstone facies of the Carmelo Formation at Point Lobos, Northern California, Bromley et al., (2003), concluded that *Hillichnus* is a complex ichnogenus. The *Hillichnus* ichnogenus contains a type ichnospecies named *H. lobosensis.* It is a complex, three-dimensional trace-fossil commonly found in turbidite deposits but also in marginal-marine deposits and considered to be a very rare trace-fossil (Bromley et al., 2003; Pazos & Fernández, 2010 and Ekdale & Ekdale, 2018). The *Hillichnus* specimens have complex morphological patterns composed of several levels, compared to other feather-like trace-fossils such as *Polykampton* (Buatois et al., 2001) and chevron-shaped burrow systems like in *Jamesonichnites* (Dam, 1990). The *Hillichnus agrioensis* (Pazos & Fernandez, 2010) ichnospecies have shown multiple different morphological level of exposures i.e. deposit-feeding (fodinichnia), horizontal displacement (repichnia), respiration, and defaecation, where the defaecation is located in the deepest level (4) of exposures. All the morphological level of exposures shows the different behaviors of different body parts of a single organism (deep-burrowing of a bi-siphonate bivalve) in the sediment according to Pazos and Fernandez, (2010). Morphologically, *Hillichnus agrioensis* differs from *Hillichnus lobosensis* in having more meandering pattern, more regular shape of each branch, and a greater length in level 2 of exposures. *Jamesonichnites heinbergi* is a cylindrical meniscus filled tunnel with distinct mantle showing chevron-shaped burrow system morphology (Dam, 1990) whereas *Hillichnus* is feather/branch shaped with lateral spreiten and a central tube structure (Bromely et al., 2003). It is formed by an infaunal soft-bodied organism moving through the sediment for food (fodinichnion) according to Dam, (1990), while *Ancorichnus ancorichnus* is a domichnion burrow and may also be repichnion (Dam, 1990). The present study discuss the systematic ichnology, palaeoecology and palaeoenvironment of *Hillichnus agrioensis* and associated ichnogenera *Jamesonichnites heinbergi* and *Ancorichnus ancorichnus* recovered from the Thaiat Member of Lathi Formation of the Jaisalmer basin, western Rajasthan, India (Fig. 1).

GEOLOGICAL SETTING

The Lathi Formation is the lowermost lithostratigraphic unit, unconformably resting over the rocks of the Bhuana Formation (Lukose & Misra, 1980 and Misra et al., 1996) and underlain by lower Hamira Member of Jaisalmer Formation in the Jaisalmer Basin (Pareek,1984 and Roy & Jakhar, 2002). The Lathi Formation was earlier known as "Lathi beds" (Oldham, 1886) as it is well exposed in the vicinity of Lathi village. Other exposures are around Odania, Thaiat, Akal and near Devikote areas of Jaisalmer district. The Lathi Formation is about

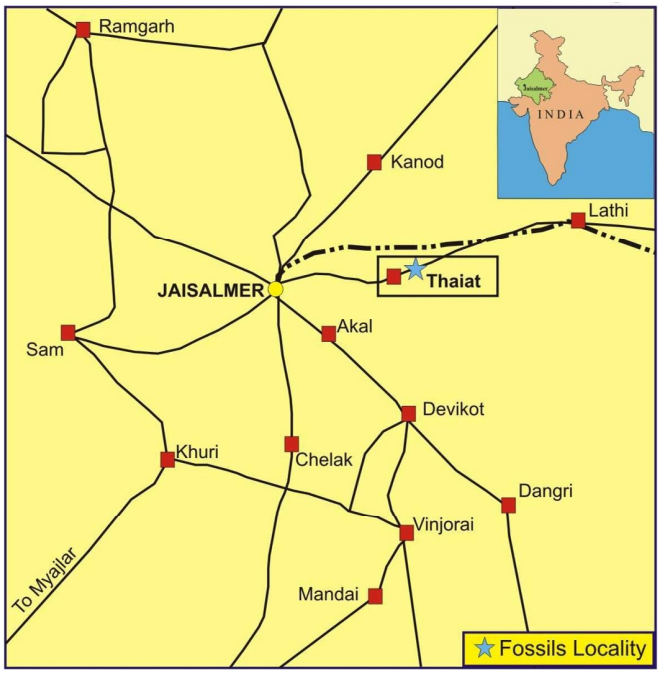

Fig. 1. Location map of the Thaiat Section of Lathi Formation of Jaisalmer Basin showing trace fossils locality.

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350m thick and its thickness increases towards northwest direction (Roy & Jakhar, 2002). In stratigraphic order, the Lathi Formation is divided into Lower Odania Member and Upper Thaiat Member (Dasgupta, 1975). The Odania Member is further subdivided in to Lower Odania Member and Upper Odania Member. The Lower Odania Member is exposed mainly in Lathi -Odhania area comprises conglomerates, coarse-grained arkosic sandstone beds grading into whitish maroon sandy siltstone and cross-bedded coarse-grained sandstone beds at the top (Dasgupta, 1975 and Pandey et al., 2006b). The Upper Odania Member is well-exposed in and around Akal and Devikote area containing glauconitic, calcareous and dark brown ferruginous sandstones, petrified woods (gymnosperm wood-fragments and tree trunks), trace-fossils, cross beddings, box-works, and concretionary structures (Dasgupta, 1974; Roy & Jakhar, 2002; Pandey et al., 2006b and Parihar et al., 2017). Based on fossil assemblages, the Odania Member of the Lathi Formation is assigned to the Early Jurassic. The Upper Thaiat Member of Lathi Formation is best exposed in the scrap sections near Thaiat village and its adjacent area (Fig. 1). It is represented by mudstone/claystone beds, alternate arrangements of fine-grained silty sandstone beds and fine-grained ferruginous sandstone beds grading into fossiliferous limestones (Pandey et al., 2006a). Based on theropod dinosaur footprints from Thaiat Member (Pienkowski et al., 2015 and Parihar et al., 2016) and occurrences of the Bajocian corals in the lower part of overlying Jaisalmer Formation (Pandey et al., 2006b) a Hettangian (Early Jurassic) to Bajocian (Middle Jurassic) stratigraphic position is suggested for the Thaiat Member of the Lathi Formation. The present trace-fossils bearing Thaiat section is located about 16kms East of Jaisalmer on Jaisalmer –Jodhpur road (NH-15). It is about 18.5m thick section comprising of inter-bedded sequences of mudstone/claystone beds and fine-grained sandstone beds at the base. This is followed by about 12.5m alternate sequences of fine-grained silty sandstone beds and fine-grained ferruginous sandstone beds. The *Hillichnus agrioensis, Jamesonichnites heinbergi* and *Ancorichnus ancorichnus* ichnogenera have been documented in the pinkish yellow fine-grained silty sandstone beds and yellowish brown fine-grained ferruginous sandstone beds. The generalized lithostratigraphic section of Thaiat area of Lathi Formation is given in Fig. 2.

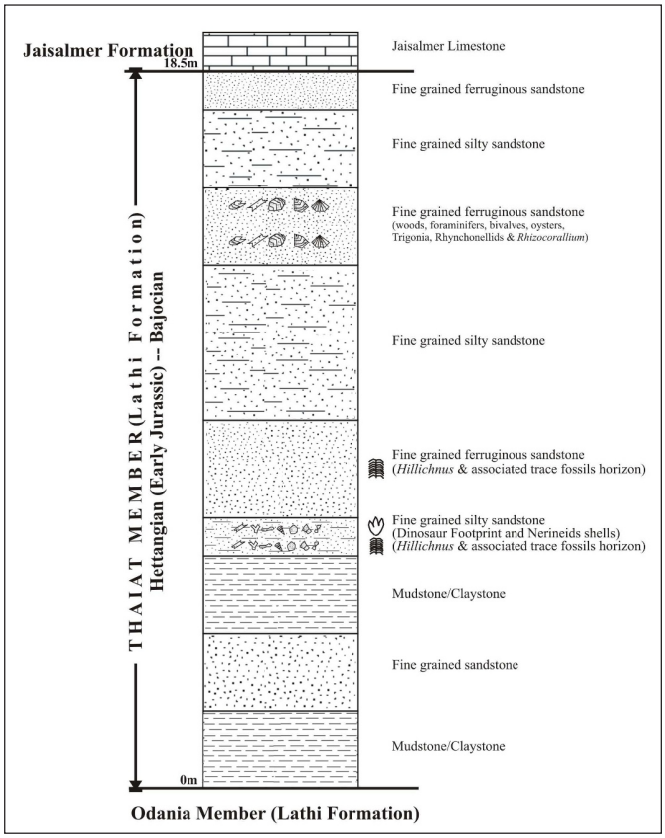

Fig. 2. Generalized lithostratigraphic section of Thaiat Member of Lathi Formation of Jaisalmer Basin near Prem Singh ki Dhani showing trace fossils bearing horizons (modified after Pandey et al., 2015).

MATERIALS AND METHODS

The trace-fossil pertaining to *Hillichnus agrioensis, Jamesonichnites heinbergi* and *Ancorichnus ancorichnus* are being reported from the Thaiat Section of Jaisalmer Basin. Here, several well preserved samples of *Hillichnus agrioensis* and *Jamesonichnites heinbergi* ichnogenra have been identified. These trace-fossils were systematically studied and several representative samples were collected from individual beds of the Thaiat Section. The collected representative samples of *Hillichnus agrioensis* (30 specimens in 8 slabs), *Jamesonichnites heinbergi* (9 specimens in 6 slabs) and *Ancorichnus ancorichnus* (2 specimens) have been reposited in Palaeontology Laboratory of Department of Geology, Jai Narain Vyas University, Jodhpur, western Rajasthan.

PALAEONTOLOGY

Systematic Ichnology

Ichnogenus: *Hillichnus* (Bromley et al., 2003).
Ichnospecies: *Hillichnus agrioensis* (Pazos & Fernandez, 2010), (Figure 3b, 4a, b, 5a, b, c, d e, f & 6a).

Material: DG/JNVU/TF/Thaiat Section of Lathi Formation/ Jaisalmer/08 Slabs and Field Photos.

***Derivation of Name*:** This species is named after the Agrio Formation of the Neuquen Basin, Argentina.

Diagnosis: Composed of 4 levels of exposures, feather/branch-like (almost flat) structures, with a central tube, generally visible in level 2 and level 3 of exposures, branches are variable and straight to gently curved or palmate.

Description: Epirelief or hyporelief and full relief, straight to gently curved, branched or feather-like (almost flat) structures with a central tube, preserved as usually more or less horizontal or parallel to bedding plane. The lateral branches are almost straight to gently curved or palmate and arranged at an angle to each side. The present *Hillichnus agrioensis* are the result of a three-dimensional reconstruction which in most of specimens belong to level 2 and some to level 3 exposures. The length of the branched or feather-like structure is about 12 cm-16 cm while its width is about 8 cm-10 cm. The width of each branch is about 0.8 cm-1.5 cm which is similar to the central tube of branched or feather-like structure. Structures in level 2 of exposures, with their repetitive displacement, staggered alternate symmetry, confirm that siphons were paired or bi-siphonate, as in typical tellinaceans lacking mantled siphons (Bromley et al., 2003). The level 1 is not necessarily present, but sometimes appears as isolated double rings exposed on surfaces. Level 4 may be due to the release of fecal material by downward movement of bivalve tentacles.

Remarks: The ichnognus *Hillichnus* is a three-dimensionally integrated trace-fossil commonly found in turbidite deposits (Bromley et al., 2003) or in marginal-marine deposits (Pazos and Fernandez 2010). The *Hillichnus agrioensis* trace-fossils show 4 different morphological levels of exposures i.e. deposit-feeding (fodinichnia), horizontal displacement (repichnia), respiration and defaecation where the defaecation occurs in the deepest level (4) of exposures. It indicates

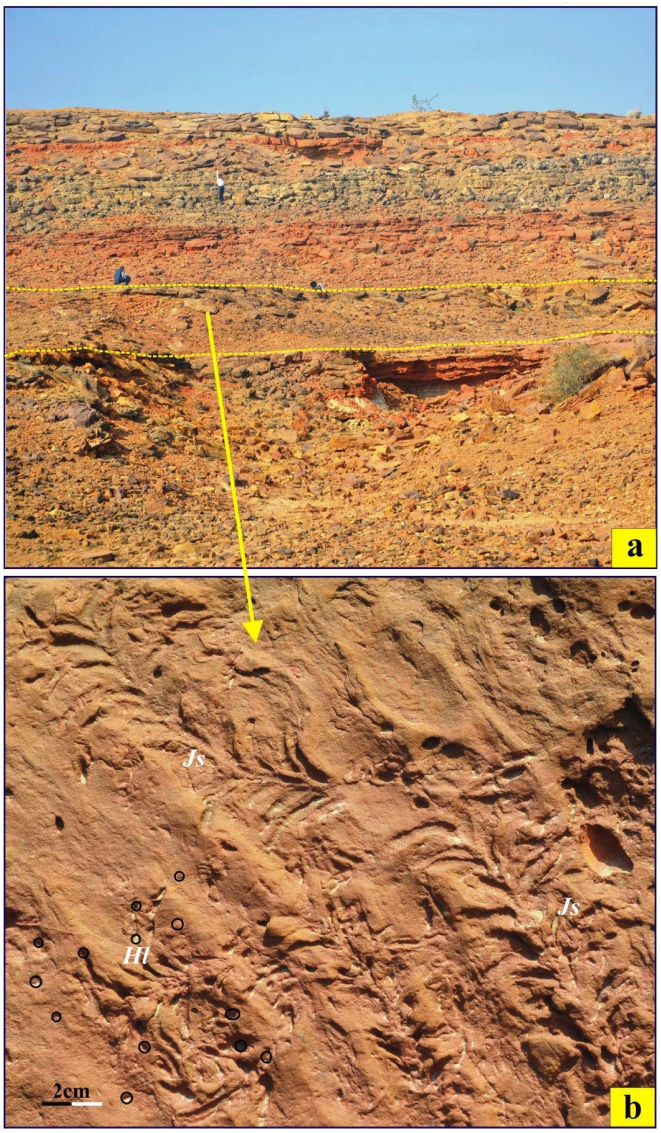

Fig. 3. (a) Field photograph showing trace fossils bearing horizon in Thaiat Section near Prem Singh ki Dhani, **(b)** Close–up view of Trace Fossils Horizon (***Hl***– *Hillichnus agrioensis* and ***Js*** *-Jamesonichnites heinbergi* trace fossils).

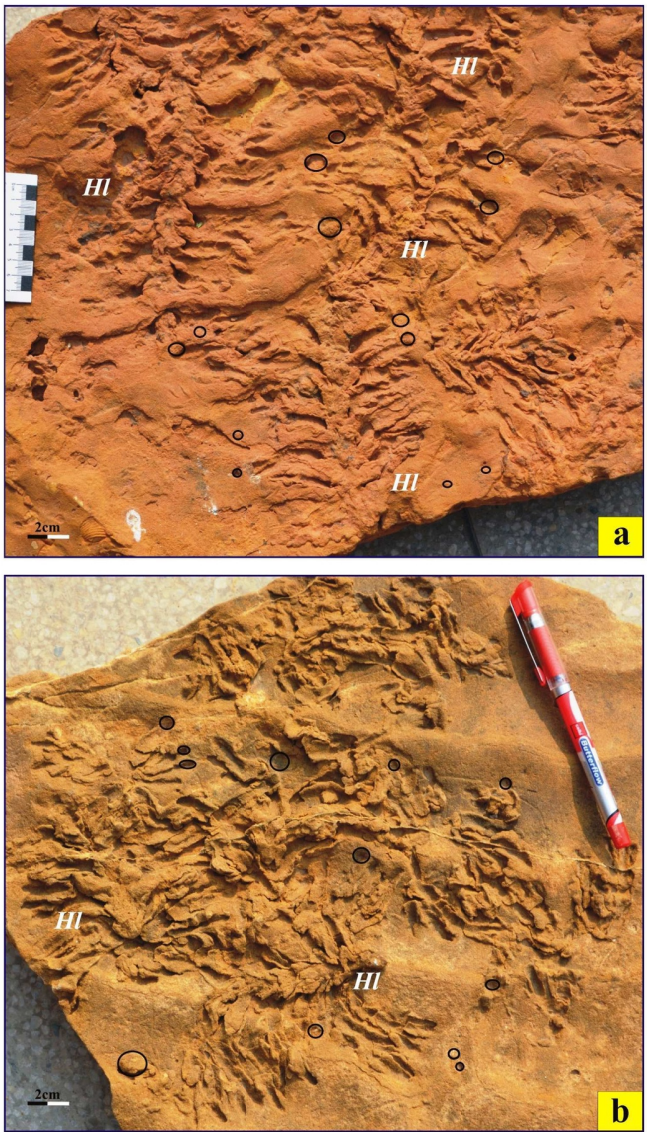

Fig. 4. (a). *Hillichnus agrioensis* ***(Hl)*** trace fossils preserved as epirelief or full relief, shows branched or feather-like (almost flat) structures with a central tube occurring in pinkish yellow fine grained silty sandstone in level 2 of exposures, **(b).** *Hillichnus agrioensis* ***(Hl)*** trace fossils occurred as hyporelief in level 2 and level 3 of exposures in yellowish brown fine grained ferruginous sandstone. Scale –The length of the pen is equal to 14 cm.

the different behaviors of different body parts of a single organism (a deep-burrowing bi-siphonate bivalve or tellinaceans bivalves) in the sediment (Pazos & Fernandez, 2010). The branched or feather-like structure (level 2) is the most characteristic features of *Hillichnus agrioensis* ichnospecies (Pazos & Fernandez, 2010). These branched or feather-like structures (level 2 of exposures) are well developed and some in level 3 of exposures are also present in the specimens. The present structures are much similar to the morphology of *Hillichnus agrioensis* (Pazos & Fernandez, 2010) and differ from the *Hillichnus lobosensis* in having more meandering pattern, more regular shape of each branch and a greater length in level 2 of exposures and therefore, are assigned to *Hillichnus agrioensis* trace-fossils. It has also been compared with other feather-like structures such as *Polykampton* (Buatois et al., 2001) and chevron-shaped burrow system like *Jamesonichnites* (Dam, 1990). This ichnospecies has also been compared with *Hillichnus* trace-fossils from the Callovian-Oxfordian Tuwaiq Mountain and Hanifa Formations, Central Saudi Arabia (Hedeny et al., 2012) and Palaeogene deposits of Southern California, USA (Ekdale & Ekdale, 2018).

Occurrences: Pinkish yellow fine-grained silty sandstone and yellowish brown fine-grained ferruginous sandstone beds, shallow or marginal-marine settings of Thaiat Member of Lathi Formation of Jaisalmer basin, Thaiat area, Jaisalmer, western Rajasthan.

Ichnogenus: *Jamesonichnites* (Dam, 1990).
***Derivation of Ichnogenus Name*:** Named after Jameson Land.
Ichnospecies: *Jamesonichnites heinbergi* (Dam, 1990), (Figure 3a & 6a, b, c, d, e & f).

***Derivation of Ichnospecies Name*:** Named after Claus Heinberg, a veteran in the study of Jurassic trace fossils from East Greenland by Dam (1990a).

Material: DG/JNVU/TF/Thaiat section of Lathi Formation/ Jaisalmer/06 slabs and field photos.

Diagnosis: Cylindrical meniscus filled tunnels with a distinct

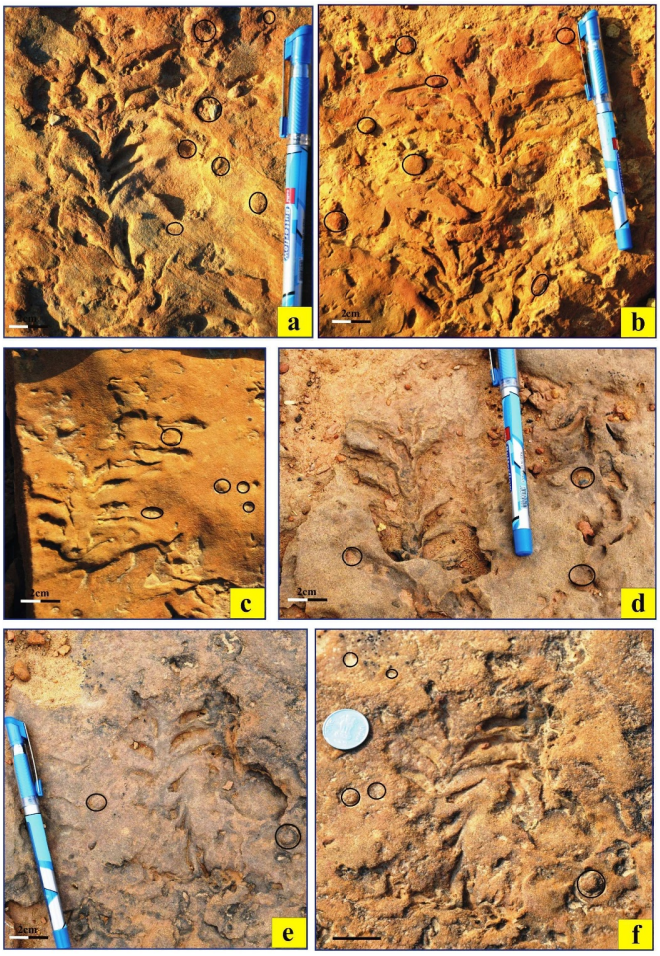

Fig. 5. (a) & (b). Close-up view of excellent –preservations of *Hillichnus agrioensis* trace fossils showing straight to gently curved, branched or feather-like flat structures with a central tube occurring in pinkish yellow fine grained silty sandstone shows level 2 and level 3 of exposures, **(c), (d), (e) & (f).** Close-up view of *Hillichnus agrioensis* trace fossils shows level 2 of exposures with branched or feather-like structures occurred in yellowish brown fine grained ferruginous sandstone. **Scale** –The length of the pen is equal to 14 cm and coin diameter 2.5 cm.

mantle, arranged in a horizontal to sub-horizontal chevron -shaped burrow system.

Description: Preserved as concave epirelief or full relief, cylindrical meniscus filled tunnels with a distinct mantle, normally arranged in more or less horizontal or parallel chevron-shaped burrow tube systems. These tunnels are separated from the surrounding host rock sediments. The tunnels divide alternatively from each side of burrow system and mantle of burrow tubes have formed chevron-shaped patterns. The length of the *Jamesonichnites heinbergi* burrow system ranges from 8 cm-16 cm and width from 6 cm-8 cm with chevron-shaped patterns. The width of each tunnel is 1 cm-1.5 cm, while the thickness of the mantle is 2 mm-3 mm and 5 cm-9 cm in length. In our most of specimens, the central meniscus filled tunnels are often weathered out and only marked as transverse furrows. The spacing of furrows is 2 mm-3 mm inside of the mantle. Some *Jamesonichnites heinbergi* specimens also occurred in close association with *Ancorichnus ancorichnus* ichnospecies in Thaiat area (Fig. 6b, e & f).

Remarks: The internal meniscus filled tunnels of *Jamesonichnites heinbergi* burrows is the same as in *Ancorichnus ancorichnus,* described by Heinberg (1974), but it is clearly different in chevron-shaped branching morphology. The *Jamesonichnites heinbergi* ichnogenera is considered as a burrow made by an infaunal soft-bodied organism moving through the sediment or systematically mining the sediments for food (fodinichnia) (Dam, 1990). The present burrows are much similar to the chevron-shaped burrow system morphology of *Jamesonichnites heinbergi,* (Dam, 1990). They differs from ichnogenus *Hillichnus* which is feather-like/branched with lateral spreiten structures, central tube structures and vertical rising tubes (Bromely et al., 2003). This ichnospecies also occurs in close association with the *Ancorichnus ancorichnus* bearing sediments and might represent variations in preservation of the *Ancorichnus* same as reported Jurassic sediments of Greenland (Dam, 1990). It also compares well with *Jamesonichnites heinbergi* from Bhadesar Formation of Jaisalmer (Desai & Saklani, 2014).

Occurrences: Pinkish yellow fine-grained silty sandstone and light brown fine-grained ferruginous sandstone beds, shallow or marginal-marine settings of Thaiat Member of Lathi Formation of Jaisalmer basin, Thaiat area, Jaisalmer, western Rajasthan.

Ichnogenus: *Ancorichnus,* (Heinberg, 1974).

Ichnospecies: *Ancorichnus ancorichnus,* (Heinberg, 1974), (Figure 6b, e, f & g).

Material: DG/JNVU/TF/Thaiat Section of Lathi Formation/ Jaisalmer/02 samples and field photos.

Diagnosis: Straight to slightly curved, cylindrical meniscus filled burrow with tube-shaped mantle.

Description: Preserved as epirelief, unbranched, straight to slightly curved, usually more or less parallel to bedding plane, concave and convex cylindrical meniscus filled burrow with a structure-less tube-shaped mantle. The mantle separated from the host rock and central tunnel by thick sediments lining. The thickness of the mantle is 2 mm-3 mm and width of burrow is about 0.8 cm-1 cm. The length of the burrow systems are in the range of 8 cm-10 cm. The *Ancorichnus ancorichnus* burrow structures filled with surrounding rock sediments and mantle generally formed with fine grained particles. In the present studied area, the *Ancorichnus ancorichnus* also occur in close association with *Jamesonichnites heinbergi* in Thaiat area (Fig. 6b, e & f).

Remarks: *Ancorichnus ancorichnus* has been earlier recorded from the Middle and Upper Jurassic of East Greenland (Heinberg 1974; Fursich & Heinberg 1983 and Heinberg & Birkelund 1984). It is interpreted as activity or behavior of an infaunal soft-bodied organism (Heinberg, 1974) and monospecific after its revisions (Keighley & Pickerill, 1994). Here the *Ancorichnus ancorichnus* suggest that the two burrow patterns represent two different patterns of behavior of the same organism as they occur in close association with some *Jamesonichnites heinbergi* specimens in Thaiat Member. The *Jamesonichnites heinbergi* ichnospecies is interpreted as a burrow made by an infaunal deposit-feeder (fodinichnion), while *Ancorichnus ancorichnus* is domichnion and may also solely be the result of locomotion (repichnion). The present burrows are much similar to the morphology of *Ancorichnus ancorichnus* (Heinberg, 1974), therefore, they are assigned here to *Ancorichnus ancorichnus* trace-fossils. Globally, this ichnospecies is compared with *Ancorichnus ancorichnus* recorded from the Middle and Upper Jurassic of East Greenland (Heinberg 1974; Fursich & Heinberg 1983 and Heinberg & Birkelund 1984). Regionally, it is also compared with *Ancorichnus ancorichnus* recorded from Middle Jurassic Kaladongar Formation (Fursich, 1998), Callovian of Habo-dome Formation of Kachchh (Patel et al.,

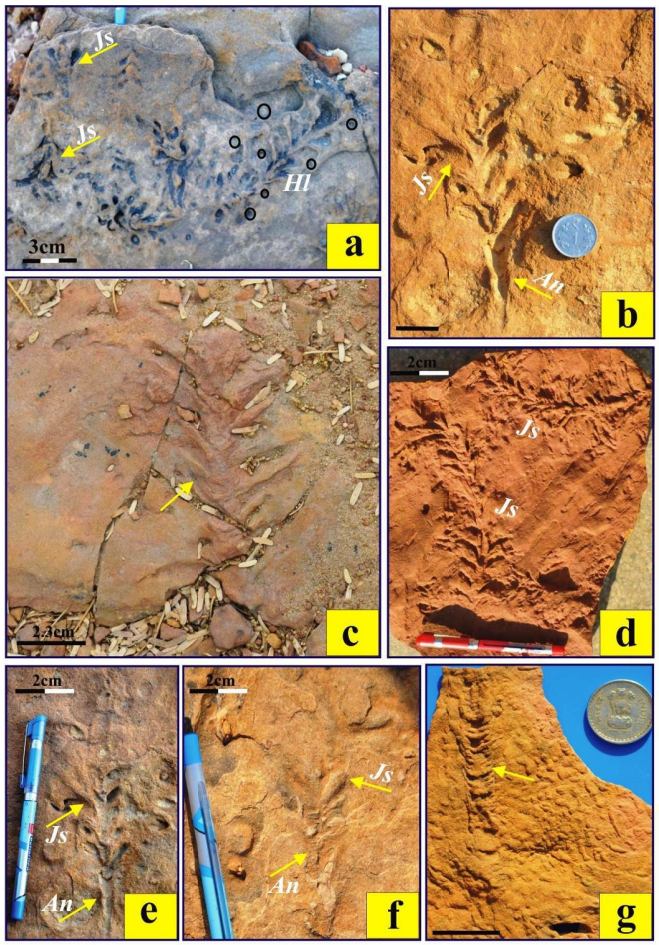

Fig. 6. (a). *Hillichnus agrioensis* **(*Hl*)** and *Jamesonichnites heinbergi* ***(Js)*** trace fossils occurred in light brown fine grained ferruginous sandstone, **(b), (e) & (f).** *Jamesonichnites heinbergi* ***(Js)*** trace fossils showing cylindrical meniscus filled tunnels with a distinct mantle, chevron-shaped burrow systems, in association with *Ancorichnus ancorichnus* ***(An)*** trace fossils, **(c) & (d).** *Jamesonichnites heinbergi* ***(Js)*** trace fossils showing chevron-shaped burrow tubes with well - preserved cylindrical meniscus filled tunnel occurred in pinkish yellow fine grained silty sandstone, **(g).** Well preserved *Ancorichnus ancorichnus* trace fossils shows straight, cylindrical meniscus filled burrow with tube-shaped mantle. Scale –The length of the pen is equal to 14 cm and coin diameter 2 cm.

2008) and Oligocene Bokabil Formation of Manipur (Singh et al., 2010).

Occurrences: Yellowish brown fine-grained ferruginous sandstone beds, shallow or marginal-marine settings of Thaiat Member of Lathi Formation of Jaisalmer Basin, Thaiat area, Jaisalmer, Western Rajasthan.

DISCUSSION

Palaeoecology

Stratigraphically, The Thaiat Member is upper member of Lathi Formation and well-exposed in and around Thaiat village (Dasgupta, 1975, Roy & Jakhar, 2002 and Pandey et al., 2006b). The sediments of the Thaiat Member have been studied for paleoecological aspect based on the presence of *Hillichnus agrioensis*, *Jamesonichnites heinbergi* and *Ancorichnus ancorichnus* ichnogenera. They occur in association with highly well preserved body fossil assemblages such as nerineid gastropods, heterodont bivalves, bakevelliid bivalves, bivalves, oysters, Trigonia, Eomiodon, rhynchonellid, brachiopods, crinoids fauna, *Teichichnus*, *Gyrochorte*, *Rhizocorallium* and *Thalassinoides* trace-fossils (Pandey et al., 2006a) which are diverse and common in benthic communities. The *Hillichnus agrioensis* ichnospecies shows multiple different patterns of feeding and records the defaecation downward in the deepest preservation in level 4 (Pazos & Fernández, 2010). It suggest vertical movement of siphons not only for respiration but also for defaecation or deposit-feeding exhibiting different behaviors of different body parts of a single organism (a deep-burrowing bi-siphonate or tellinaceans bivalves) in the sediment (Pazos & Fernandez, 2010). In Thaiat area, the presence of heterodonts, bakevelliid and other types of bivalve body fossils (Pandey et al., 2006a and 2012) also supports and suggests that bi-siphonate or tellinaceans bivalves are the main producers of *Hillichnus agrioensis*. The *Jamesonichnites heinbergi* is considered as a burrow made by infaunal deposit-feeders (fodinichnion), while *Ancorichnus ancorichnus* is interpreted as domichnion (deposit-feeders burrows) and may also indicate result of locomotion (repichnion) (Heinberg, 1974 and Dam, 1990). The fossil woods (remains of stems of gymnosperm) have been found commonly in lower part of Thaiat Section (Pareek, 1978 and Pandey et al., 2006a). The presence of remains of several epifaunal and infaunal organisms, trace-fossils, body fossils and plant fossils are showing existence of a wide variety of herbivores, carnivores and detritivores habitat which might have contributed to an ecological system in shallow or marginal-marine environments in Thaiat Member of Lathi Formation. We agreed to Pazos & Fernandez, (2010) which proposed same palaeoenvironment for the *Hillichnus agrioensis* trace-fossils in Agrio Formation of Neuquen basin, Argentina.

Paleoenvrionment

The lower part of the Thaiat succession is mainly composed of siliciclastic sedimentary rocks with low CaO and MgO contents whereas the upper part is more calcareous with more diversified fauna indicating a fully-marine environment (Pandey et al., 2006b and Pienkowski et al., 2015). Previously, the *Hillichnus* ichnogenus was recovered from three different outcrops of Palaeocene turbidite deposits of the Carmelo Formation at Point Lobos, Northern California by Bromley et al., (2003). In Scripps Formation of San Diego County, Southern California, *Hillichnus lobosensis* has been recorded from the middle Eocene shallower depths settings (Ekdale & Ekdale, 2018). The paleoenvironmental range of *Hillichnus lobosensis* is from deep-water turbidites to shallow-marine near-shore settings (Bromely et al., 2003; Ekdale & Ekdale, 2018). The *Hillichnus agrioensis* ichnospecies also indicates shallow or marginal-marine environments recorded from the Lower Cretaceous Agrio Formation of Neuquen Basin, Argentina (Pazos & Fernandez, 2010). The *Jamesonichnites heinbergi* and *Ancorichnus ancorichnus* trace-fossils recovered from the Lower Jurassic Neill Klinter Formation, East Greenland also suggest shallow-marine depositional environment (Dam, 1990). The recorded fauna like nerineid gastropods, heterodont bivalves, bakevelliid bivalves, oysters, *Trigonia, Eomodion*, rhynchonellid brachiopods, crinoids and trace-fossils (*Teichichnus*, *Gyrochorte*, *Rhizocorallium*, *Thalassinoides*, and *Skolithos*) (Pandey et al., 2006a) from Thaiat member indicated the presence of highly diverse shallow-marine communities. Based on the presence of *Hillichnus agrioensis, Jamesonichnites heinbergi* and *Ancorichnus ancorichnus* ichnogenera with associated fauna and trace-fossils (Pandey et al., 2006a & 2012) we propose a shallow or marginal-marine environment for the Thaiat Member of Lathi Formation.

CONCLUSIONS

(i) *Hillichnus agrioensis* trace-fossils has been reported for the first time from India. Incidentally, this occurrence of *Hillichnus*

agrioensis from Hettangian to Bajocian age sediments is the oldest so far from anywhere in the world. In Thaiat area, the trace-fossils of *Hillichnus agrioensis* quite common compared to the *Jamesonichnites heinbergi*. All these ichnogenera are preserved in ideal and bookish forms and several samples of *Hillichnus agrioensis* (complex or compound) trace-fossils are collectable.

(ii) A Hettangian (early Jurassic) to Bajocian (middle Jurassic) age has been suggested for the Thaiat Member of the Lathi Formation based on the presence of theropod dinosaur footprints (Pienkowski et al., 2015 and Parihar et al., 2016) and the Bajocian coral remains in the overlying Jaisalmer Formation (Pandey et al., 2006b).

Acknowledgements: Author's have deep gratitude to Prof. S. R. Jakhar, Head, Department of Geology, Jai Narain Vyas University, Jodhpur for laboratory facilities. We are also thankful to Abhimanyu Singh, Anshul Harsh and Pawan Kumar, Research Scholar, for technical and field assistance.

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(Received: 13 January 2020; Revised form accepted: 8 September 2020)