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Significance of the trace fossil *Balanoglossites* Mägdefrau, 1932 from the Lower Cretaceous Guneri member (Bhuj formation) of the Guneri dome, Kachchh, India

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Abstract The Guneri dome, situated in the Western Kachchh, is famous for its prominent exposures of Lower Cretaceous sandstone-dominated Guneri member belonging to the Bhuj formation. The ichnogenus *Balanoglossites* Mägdefrau, 1932 is reported for the first time from the Indian subcontinent and is represented by *B. triadicus* and *B. ramosus*, occurring in association with the tear-shaped boring *Gastrochaeonolites*. These trace fossils occur as a part of two, laterally extensive *Glossifungites* ichnofacies surface, representing omission suite assemblage. The detailed analysis of the trace fossil *Balanoglossites* along with lithofacies analysis suggests that it belongs to the *Glossifungites* ichnofacies surface and this trace fossil bearing surface corresponds to the Lower Cretaceous regressive phase that marks the unconformity of other parts of the Kachchh basin.

Keywords Ichnogenus *Balanoglossites* · Guneri member · Bhuj formation · Kachchh

Introduction

Complex trace fossils often result from strong ecological interaction and complex behaviour of trace producing organisms. The ichnogenus *Balanoglossites* (Mägdefrau 1932) is one of such complex trace fossils. It contains predominantly U- or Y-shaped tunnels and shafts that records both burrowing and boring trace maker action (Knaust 2008). This trace fossil is characterized also by irregular tunnels of variable width and orientation, and by passive fill with contrasting sediments. Kazmierczak and Pszczólkowski (1969) demonstrated *Balanoglossites* to be made by annelids and enteropneusts and also dealt with its morphology. Recently, Knaust (2008) re-described *Balanoglossites* from its type area and also dealt with its detailed morphology, distinguishing a new ichnospecies. Patel and Desai (2009) reported grouped funnel burrows similar to *Balanoglossites* from recent lagoonal sediments of the Mandvi intertidal zone in Kachchh. In the present paper, *Balanoglossites* is recorded for the first time from Cretaceous sediments of the Indian subcontinent, i.e., in the Bhuj formation (Lower Cretaceous) exposed at Guneri dome in the western most part of the Kachchh basin. Moreover, its ichnofabric and stratigraphic significance is discussed.

Although several trace fossils have been reported from the Bhuj formation, their stratigraphic details are imprecise and generalized only for the entire formation. Kumar et al. (1982) listed *Arenicolites*, *Lockeia*, *Planolites*, *Thalassinoides* and Callianassids burrows from the Bhuj formation near Bhuj city. Casshyap et al. (1983) reported *Planolites*, *Skolithos* and *Thalassinoides*, indicating littoral marginal marine environment, but without stratigraphic details. Krishna (1987) reported *Thalassinoides*, *Skolithos*, *Chondrites*, *Ophiomorpha*, *Rhizocorallium*, *Aulichinites*, and *Cylindrichnus* from the Umia formation (top part equivalent to the Guneri member of the Bhuj formation). Howard and Singh (1985) described *Rhizocorallium*, *Ophiomorpha*, *Thalassinoides*, *Skolithos*, *Chondrites*, *Gyrochorte*, *Monocraterion*, *Teichichnus*, *Cylindrichnus* and *Medousichnus* from the shaly horizons of the Bhuj formation. Singh and Shukla (1991) reported highly bioturbated horizons along with *Rhizocorallium*, *Diplocraterion*, *Thalassinoides*, vertical burrows, inclined sand-filled burrows, and sand-filled burrows from the Rukhamavati

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section south of Bhuj. Patel et al. (2008) reported *Asteriacites quinquefolius*, a resting trace of starfish from the lower part of the Bhuj formation (=Guneri member) from the central mainland. Recently, Desai (2012) interpreted six asymmetrical bioturbational cycles of basinal scale, including the *Balanoglossites* horizons.

Geology and stratigraphy

The sedimentary basin of Kachchh is a peri-cratonic rift basin in the western part of the Indian Peninsula. It comprises Middle Jurassic to Middle Cretaceous rocks. It is subdivided into six disconnected uplifted areas in the extensive plains of Rann. These uplifts include Kachchh Mainland, Pachham Island, Khadir Island, Bela Island, Chorar Island and Wagad. The Kachchh mainland exposes a continuous Bajocian–Santonian succession (Biswas 1993). The lithostratigraphic sequence of Mainland comprises the Jhurio, Jumara, Jhuran and the Bhuj formations (Biswas 1977). The Bhuj formation is the youngest formation dominated with huge thickness of marine to non-marine sandstones. The formation occupies about three-fourths of the Mesozoic outcrops in the mainland and extends from Bhachau in the east to Guneri in the west (Biswas 1977). The formation was subdivided by Biswas (1977) into Guneri, Ukra, and the Upper members. The lowermost Guneri member is characterized by highly bioturbated; ferruginous, medium- to coarse-grained cross-bedded sandstones, alternating with ferruginous, micaceous, laminated, fine-grained sandstone with minor shales. The Guneri dome (Fig. 1) is situated in the westernmost part of the Kachchh and is designated as the type section for the Guneri member. Wynne (1872) described in detail the succession of the rocks at Guneri village. Rajnath (1932) described in detail faunal assemblages of the Guneri dome. Subsequently, Biswas (1978) discussed in detail the stratigraphic position of the Trigonia beds, occurring at the core of the dome and placing them in the Katesar member. Bose et al. (1986) described in detail the sedimentary facies occurring in the Guneri dome. Fürsich and Pandey (2003) have described the genesis of the Guneri Trigonia beds exposed at the Guneri dome in the sequence stratigraphic context. Biswas (1977) has recognized a rhythmic sequence of ferruginous or lateritic bands in the Guneri member and has correlated them with fluctuations of sea level.

The Guneri dome (Fig. 1) is a kidney-shaped dome located in the western most part of Kachchh. The lithological succession starts with shales-marls and gypsiferous shales of the Katesar member (Jhuran formation). These are exposed in the core of the dome on both sides of the road leading to Guneri village. The overlying sediments are coarse- to medium-grained ferruginous, bioturbated sandstones of the Guneri member (Bhuj formation). The Bhuj sandstone is differentiated from the underlying Katesar member by the presence of ferruginous hard bands (Biswas 1977). The section studied in detail (Figs. 1, 2) is exposed along the centre of the dome near the check dam. The shales and marls of the Katesar member are overlain by thick, medium- to fine-grained, ferruginous sandstones with cross lamination. The sandstone is overlain by the distinct Trigonia-rich shell bed (Fig. 3a, b). This is referred to as the Guneri Trigonia band and is interpreted to as deposit of a transgressive system tract (Fürsich and Pandey 2003). The Guneri member is characterized by cyclic repetition of ferruginous bands (highly bioturbated), shales and sandstones (Biswas 1977; Desai 2012). The studied section contains four prominent lithofacies (Fig. 2). These are briefly described as follows.

Bioturbated marl lithofacies is common in the core of the dome, specifically in the top part of the Katesar member (Figs. 2, 3e). It is finely laminated glauconitic marl, which is moderately bioturbated (BI = 3–4) and comprises dominantly trace fossils of deposit feeders, which include *Gyrochorte robusta*, *Lanicoidichna* isp., *Teichichnus rectus*, and *Zoophycos brianteus*. These trace fossils and fine-grained sediments point to deposition between fair weather and storm wave base in the shelf region.

Bioturbated siltstone/sandstone lithofacies is represented throughout the studied sequence. It alternates with shales and is subdivided into bioturbated siltstones and medium-grained sandstones. The bioturbated siltstones (Figs. 2, 3c, f) contain well sorted silt quartz grains and ferruginous cement. Index bioturbation is high (BI = 5). In result, primary sedimentary structures are obliterated. *Thalassinoides suevicus*, *Polykladichnus* isp., *Ophiomorpha nodosa*, *Skolithos linearis*, and *Monocraterion* isp. are common and abundant.

The *Balanoglossites* horizons (Figs. 1, 2, 4) also occur in siltstone facies, but these horizons are moderately bioturbated (BI = 4). They show several evidences of erosion and subsequent ferruginization of the exposed surfaces. The medium-grained sandstones (Figs. 2, 3d, g) repeat at several places. They contain moderate to well sorted medium grains of mostly quartz and less feldspar. Sedimentary structures include cross stratification, although massive sediments occur locally. *Thalassinoides suevicus* and *Skolithos linearis* are common. The bioturbation index is comparatively low (BI = 2–3). These sandstones passively fill the underlying burrow of *Balanoglossites* occurring in siltstone. The sandstones are referred to high-energy conditions in near shore environment.

Locality Section near Guneri Check Dam, N23°46′58″; E68°51′12″.

Horizon Bhuj formation (Guneri member), 10.5 m above the Guneri *Trigonia* band.

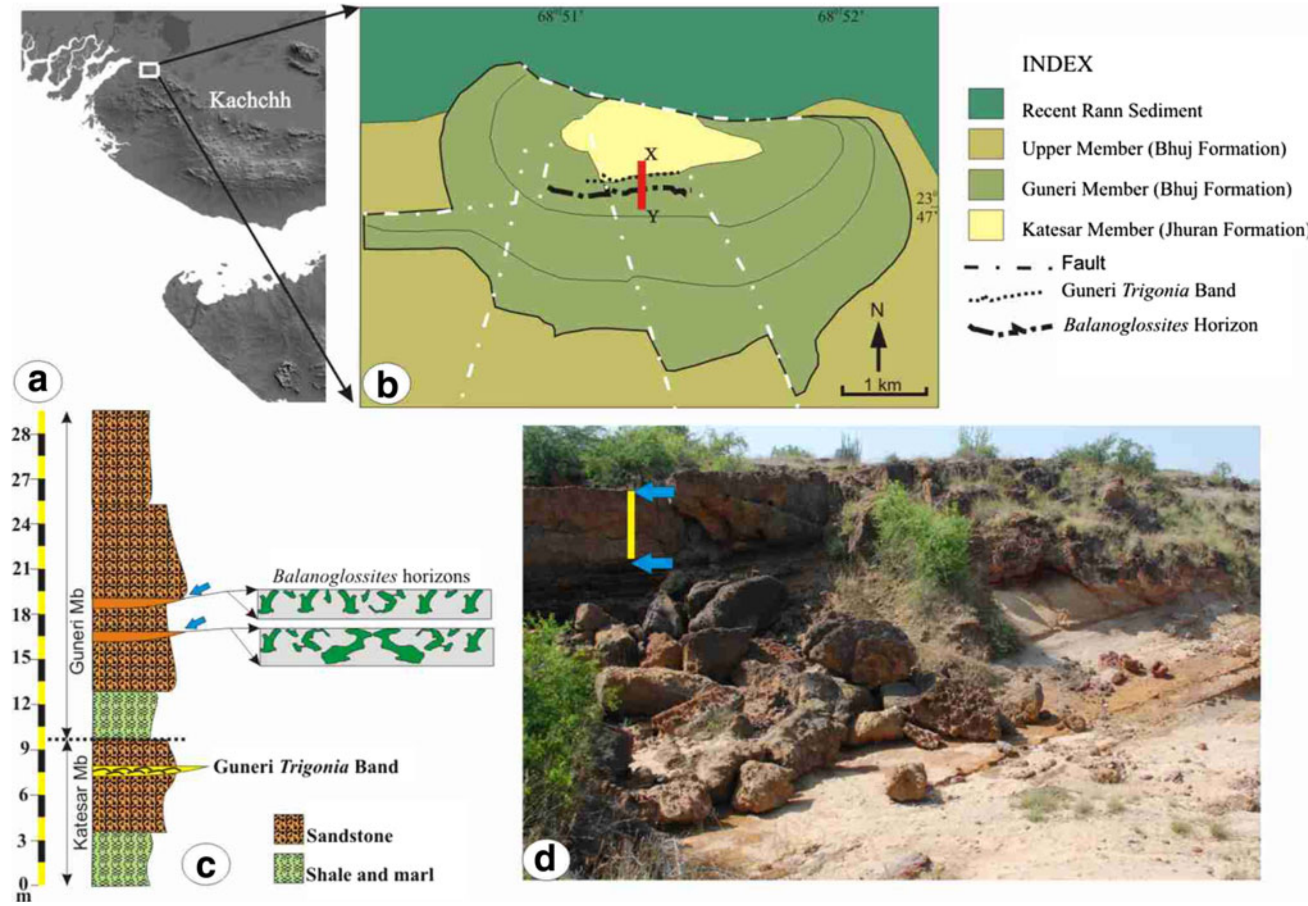


Fig. 1 Location and general geology of study area. **a**, **b** Location and geological and tectonic map of the Guneri dome showing the mapped Guneri *Trigonia* band and the *Balanoglossites* horizons. *X* and *Y* indicates section studied. **c** Lithostratigraphic column of the studied section showing stratigraphic location of the Guneri *Trigonia* band and the two horizons of *Balanoglossites*. **d** Field photograph of the studied section, *arrows* indicate position of the two *Balanoglossites* horizons. *Vertical band* represents 1.2 m

The shale facies occurs in the middle part of the sequence. Especially in the Katesar formation the shales are characterized by small- to medium-sized gypsum crystals of secondary in origin. The shales also contain silt grains of quartz and glauconite. Common trace fossils include *Gyrochorte robusta*, *Skolithos* isp. and *Thalassinoides* isp. The facies is interpreted to be deposited in shallow, quiet marine environment.

Systematic ichnology

Ichnogenus Balanoglossites Mägdefrau 1932

Type ichnospecies Balanoglossites triadicus Mägdefrau 1932.

Fig. 4

Diagnosis Branched galleries with several openings and acorn-, bulb- or lance-shaped side branches. Tunnels are elliptical or circular in cross-section, margin is unlined and locally striated; tunnel size varies in the order of several magnitudes within a single gallery system (after Knaust 2008).

Remarks See Kazmierczak and Pszczólkowski (1969); recently Knaust (2008) re-described this ichnogenus from the type area and re-evaluated the ichnospecies. Stratigraphically, the trace fossils ranges from Ordovician (Knaust 2008 and reference therein; Dronov 2011) to Holocene and recent deposits (Patel and Desai 2009). However, they are more abundant and widely reported from the Triassic carbonate successions of the Muschelkalk Basin (Kazmierczak and Pszczólkowski 1969; Knaust 2008). Paleoenvironmentally, *Balanoglossites* is reported from omission surface of shallow marine condition (Knaust 2008), lower intertidal zone (Kazmierczak and Pszczólkowski 1969), storm dominated shallow marine environment (Dronov 2011), intertidal lagoon (Patel and Desai 2009), shallow marine—Skolithos ichnofacies (Chamberlain

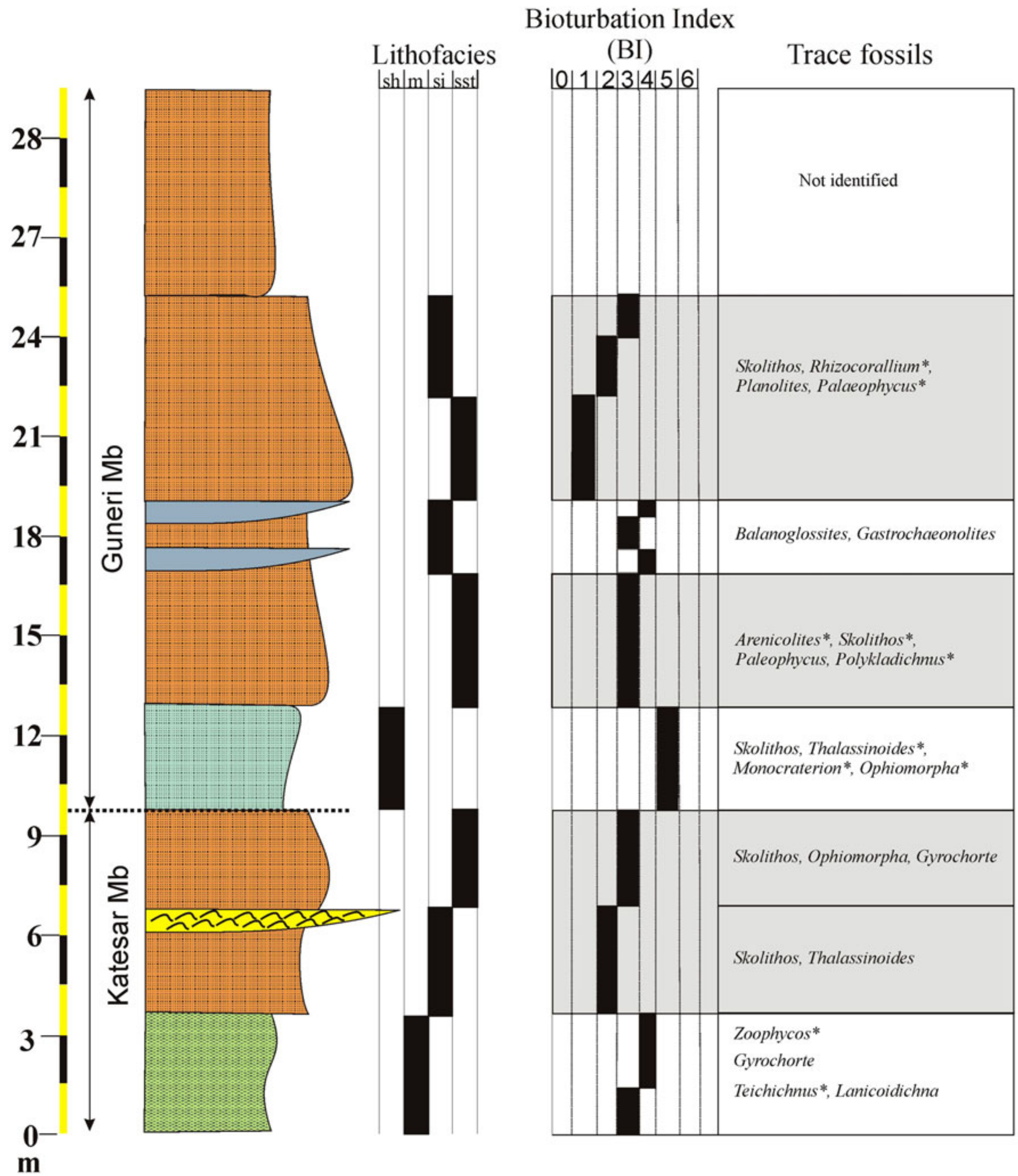


Fig. 2 Detailed lithostratigraphic column of the studied section showing variation in lithofacies (*sh* shales, *m* marl, *si* siltstone, *sst* sandstone), corresponding bioturbation index (BI) and different identifiable ichnogenera in various beds. *Asterisk* mark indicates trace fossils depicted in Fig. 3

1977) and firmground surface of lower shoreface environment (Carmona et al. 2008).

Repository All specimens are housed in the Ichnological Research Lab of the Pandit Deendayal Petroleum University.

Balanoglossites triadicus Mägdefrau 1932

Fig. 4a–c, f, i

Material Three specimens- (PDPU/BGD/IL/GUN/30–09; 45–09; 48–09)

Description Irregularly oriented, branched tunnels forming three-dimensional complex networks, resembling U, J, Y or I shape in a vertical section. All burrows are unlined with sharp margins, 10–28 mm in diameter. In the lower part of the burrows, cross-section of the tunnels and galleries is circular to elliptical. Towards the top of the bed,

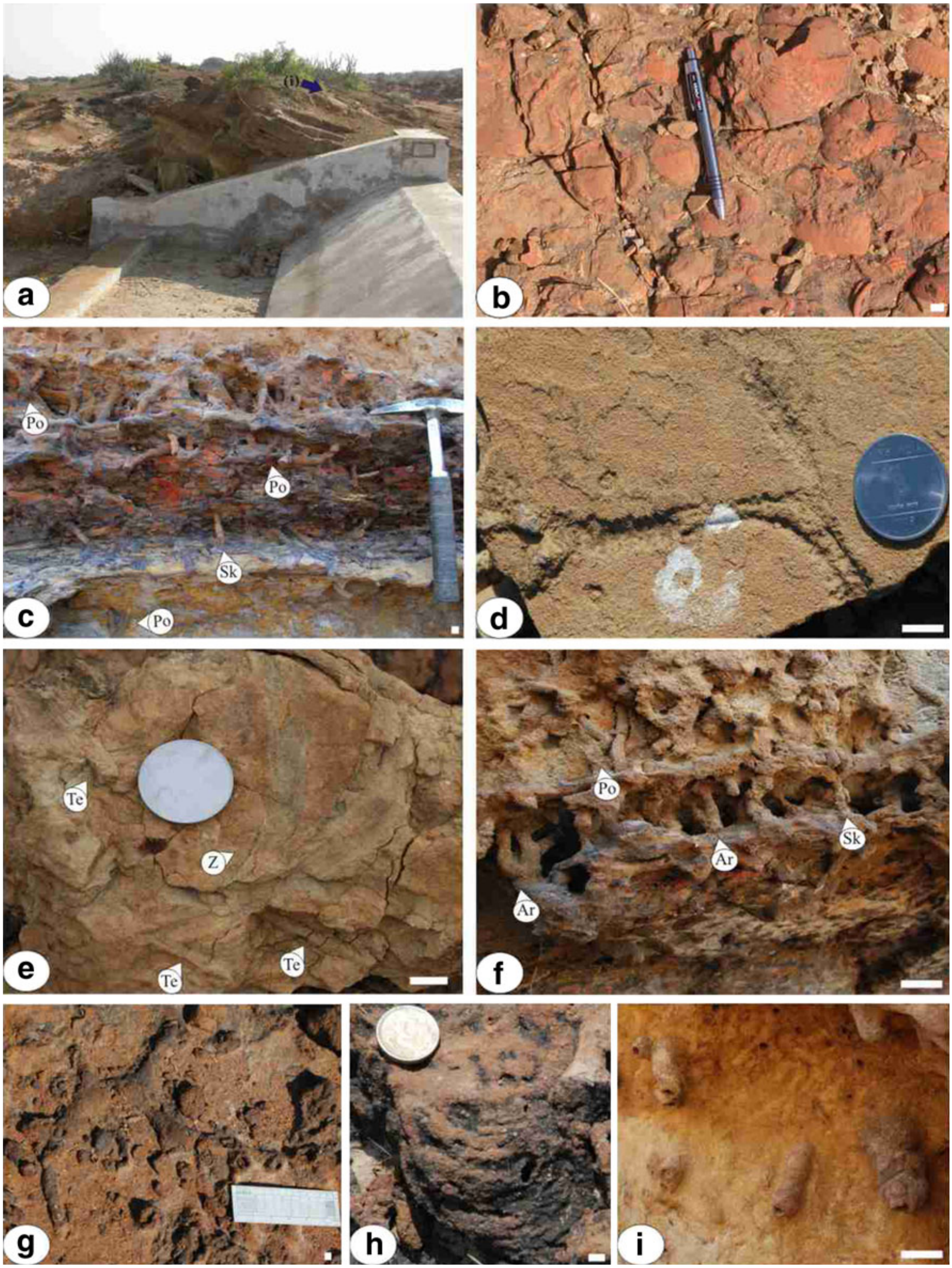


Fig. 3 Photograph showing section detail and various trace fossils identified from various beds. *White scale bar* on right bottom of photo = 1 cm. **a** Section near check dam showing gently dipping sandstone beds. *Arrow* indicates position of the Guneri *Trigonia* band. **b** *Bedding plan view* of the Guneri *Trigonia* band showing convex up disarticulated shells of *Trigonia*. **c** Heavily bioturbated siltstones (*Po Polykladichnus*, *Sk Skolithos*). Hammer length = 30 cm. **d** Epirelief preservation of *Ophiomorpha nodosa* in the bioturbated siltstone lithofacies. **e** *Bedding plan view* of trace fossils from the bioturbated marl lithofacies (*Te Teichichnus*, *Z Zoophycos*) note the cross-cutting relation of two trace fossils. **f** Ichnofabric as seen in vertical section, in medium-grained sandstone facies (*Ar Arenicolites*, *Po Polykladichnus*, *Sk Skolithos*), note all traces are vertically oriented. **g** Horizontal network (*bedding plan view*) of 3D burrows *Thalassinoides*; note that the burrow margins are ferruginised. **h** *Bedding plan view* of *Rhizocorallium* in medium-grained sandstone facies. **i** Inclined *Palaeophycus heberti* in bioturbated medium-grained sandstone

the burrow tends to widen in diameter forming funnels, which coalesce together forming wider irregular opening. The burrow fills are contrasting with the host rock and characterized by structureless medium- to coarse-grained sand grains, passively filled into the burrows. Locally, burrow fills are encircled by purple to reddish coloured ferruginous rims or halos.

Balanoglossites ramosus Knaust 2008

Fig. 4d, e, g, h

Material Four specimens- (PDPU/BGD/IL/GUN/38–09; 37–09; 20–09; 21–09).

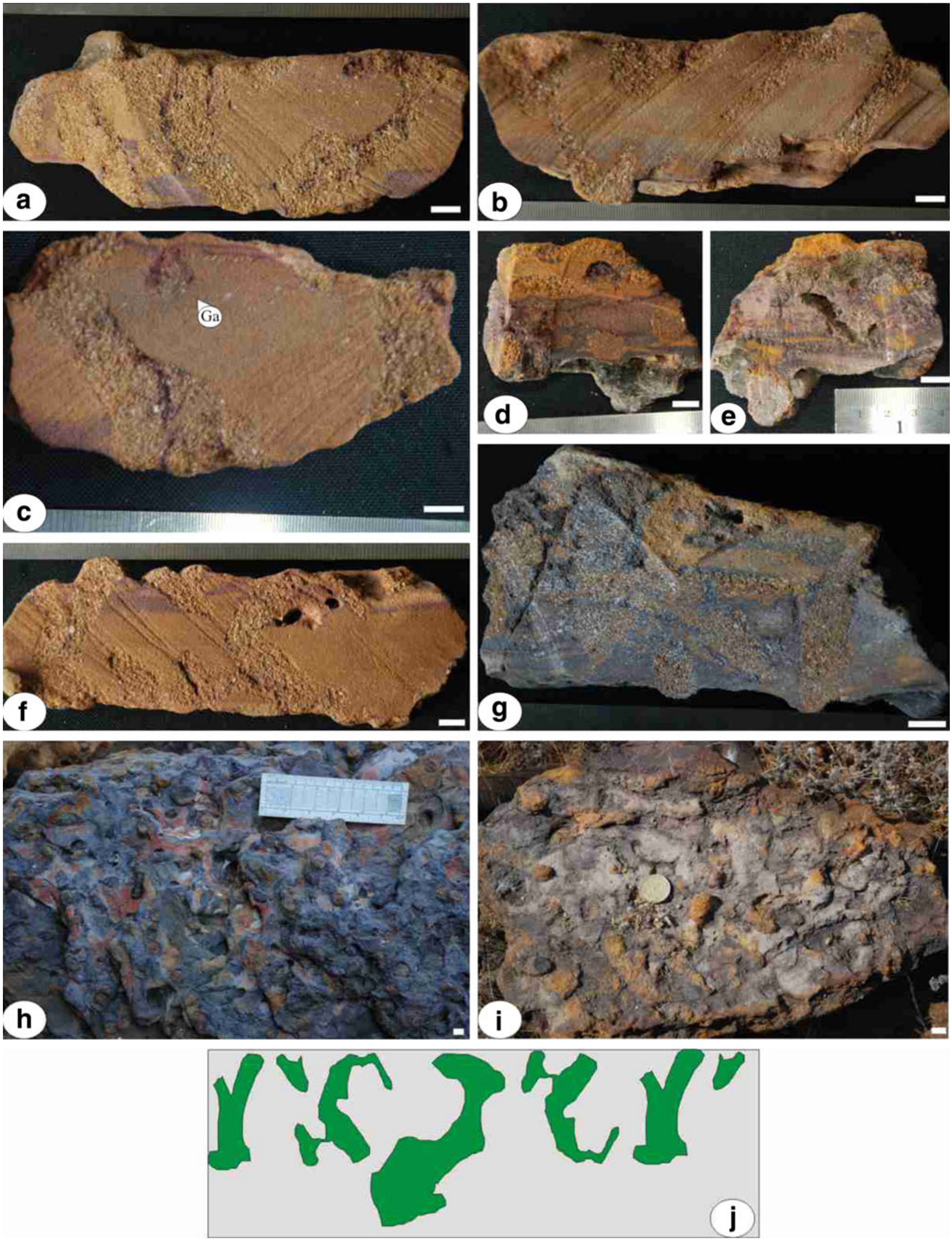
Description Complex burrow system in purple coloured, plane laminated, coarse-grained siltstone. The trace fossils consist of vertical to inclined shafts with horizontal tunnels. In the cross-section, the tunnels and shafts are circular to elliptical and in places irregular. Shafts are curved or straight and may bifurcate continuing as inclined or horizontal tunnels. The tunnels and shafts are unlined, with clean and sharp margins. Burrows are filled with medium-grained, structureless and the massive sandstone contrasting to the host sediment. Tunnels are locally blind ending and may show side branching.

Remarks For *B. triadicus and B. ramosus*: for a detailed synonymy of *B. triadicus and B. ramosus* refer to Knaust (2008). Kazmierczak and Pszczólkowski (1969) have described in detail the mode of burrowing along with substrate characteristics and bathymetry of the enteropneust burrows. Mägdefrau (1932) described two ichnospecies of *Balanoglossites*, i.e., B. *triadicus* and *B. eurystomus*, differentiating both on the basis of presence or absence of funnel at the top of the burrow. Knaust (2008) synonymized *B. eurystomus* considering it to be preservation variant of *B. triadicus* and introduced a new ichnospecies *B. ramosus*. *B. ramosus* is differentiated from *B. triadicus* in having (1) ramifications of tunnels and shaft, and (2) less conspicuous U and Y shape of shafts, and (3) circular tunnel cross-section (Knaust 2008). The Kachchh specimens differ from the German specimens in lacking faecal pellets. The Kachchh specimens of *B. triadicus* have prominent U- and Y-shaped shafts with bifurcations of the Y usually short. The unlined and sharp boundaries of the burrows suggest that they were made in firm sediment, which enabled the organism to maintain the burrow. Structureless sediment occurring as burrow fill suggests that the burrow was open and served as domichnia (dwelling traces). The complexity of the network of tunnels suggests that the animal was able to irrigate the burrow by sea water. Similar complex nature of burrows with tunnels and shafts with grouped funnel burrow was also reported by Patel and Desai (2009) from lagoonal sediments of the Mandvi intertidal zone Kachchh. In the Mandvi burrows were irrigated by the organism. Enteropneust burrows are also reported from the Ordovician and Devonian sediments of Nevada (Chamberlain 1977). *Balanoglossites* in the Lower Miocene of Chenque formation exposed in Patagonia, Argentina, represents firmground surface corresponding to a transgression (Carmona et al. 2008).

Fig. 4 The Ichnogenus *Balanoglossites. White Scale bar* on right ▶ bottom of the photograph = 1 cm. **a** *Section view* of *B. triadicus* showing irregular morphology of the burrow (sample No. BGD/IL/GUN/30). **b** Another view of the same sample, showing the distinct Y- and U- shaped burrows *B. triadicus*; note the massive nature of the host sediment. **c** *Sectional view* showing irregular burrow diameter of *B. triadicus* along with the boring *Gastrochaenolites* (Ga). Note the sharp unlined burrow margin. (sample No. BGD/IL/GUN/45). **d**, **e** Different *sectional view* of *B. ramosus* showing interconnected tunnels in plane laminated host sediment. (sample No. BGD/IL/GUN/38). **f** *B. triadicus* showing sharp unlined burrow margins along with a passively fill. (sample No. BGD/IL/GUN/48). **g** *B. ramosus* showing vertical components. **h**, **i** *Bedding plan view* of the both *Balanoglossites* horizons. **j** Line drawing of the ichnogenus *Balanoglossites* in *vertical section view* (not to scale). Note the irregularity of the diameter, blind ending and side branching

Balanoglossites ichnofabric

The ichnofabric of the bioturbated horizons is analyzed in detail in the field and discussed following the methodology of Taylor et al. (2003). The ichnofabric dominantly consists of discrete trace fossils consisting of abundant *B. triadicus* and *B. ramosus* in association with the tear-shaped boring *Gastrochaeonolites,* no other bioturbational structure is observed, except for *Balanoglossites* and *Gastrochaeonolites*. The trace fossil occurs in two distinct horizons separated by an about 1.2 m thick interval. The *Balanoglossites* ichnofabric is characterized by (1) simple colonization with tier replacement, (2) moderate bioturbation (BI = 4), and (3) low ichnotaxa diversity. According to Taylor et al. (2003), simple tier replacement, indicates that initial single colonization of opportunistic *Balanoglossites* making organisms were replaced by the boring *Gastrochaeonolites*, using different trace making strategies. According to Bromley (1975), the omission suites can be further subdivided into prelithification burrows and postlithification borings. Such types of contrasting trace fossils association suggest the *Glossifungites* ichnofacies representing omission suite. These omission suites are characterized by passively filled unlined burrows with sharp burrow margins (MacEachern et al. 1992). Thus, the *Balanoglossites* ichnofabric records firmground with, the opportunistic, trace fossil (*Balanoglossites*) belonging to omission suite along with by postlithification borings trace (*Gastrochaeonolites* borings).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Discussion

Several studies have successfully demonstrated the use and significance of omission surfaces as discontinuity surfaces (Goldring and Kaźmierczak 1974; Bromley 1975; Pemberton and Frey 1985; MacEachern et al. 1992; Savrda 1995; Asgaard et al. 1997) and for demarcating sequence boundary (MacEachern et al. 2007). Desai and Patel (2008), based on their studies on the *Glossifungites* ichnofacies surfaces developed in modern intertidal zone, have demonstrated the effect of tectonics or eustatic sea level changes on trace fossils assemblages developed within intertidal zone. According to the model of Desai and Patel (2008), in case of eustatic regression (forced regression), there would be gradual shifting of facies causing gradation of r-selected ichnotaxa over k-selected ichnotaxa. Such gradual shifting, in shallow marine conditions, would be reflected in overprinting of full spectrum of r-selective traces over the K-selected ichnotaxa, on account of prograding shorelines as a result of high rate of sedimentation. These would generate stacking pattern of prograding sequences depicted by seaward shift of facies, as well as a shallowing of the marine conditions near shoreline (Catuneanu 2002).

The trace fossils occurring in the Katesar member are k-selective in nature (*Zoophycos* ichnofacies) which gradually shifts to r-selective traces like *Skolithos*, *Ophiomorpha* (*Skolithos* ichnofacies). The r-selective traces further shows diversification with addition of trace fossils such as *Arenicolites*, *Balanoglossites*, *Gastrochaenolites*, *Rhizocorallium*, *Palaeophycus*, *Planolites*, *Polykladichnus*, *Monocraterion*.

Ichnologically, the uppermost part of the Katesar member, occurring in the core of the Guneri dome (Fig. 1), is represented by bioturbated marlstone consisting of abundant trace fossils, such as *Zoophycos*, *Teichichnus, Lanicoidichna*, which indicate sediments deposited in shelf, mostly below storm wave base. Bose et al. (1988), based on sedimentary structures, have also interpreted similar environments for the Katesar member (i.e., shelf between fair weather and the storm wave base). These shelf marlstone sediments are overlain by a 0.5 m thick *Trigonia* shell bed deposited under transgressive conditions influenced by storms (Fürsich and Pandey 2003). These transgressive deposits are again overlain by a 1.5 m thick unit of bioturbated sandstone containing two surfaces characterized by the *Glossifungites* ichnofacies. These bioturbated units were interpreted by Bose et al. (1986) as shallow marine shoal (barrier bar) facies.

In the palaeo-basinal context, the sediments of the Guneri dome are considered to be deposited in the distal part of the basin, i.e., near to the basin depocentre (Biswas 1981). The Guneri member is considered to be a delta front facies complex with shales of the underlying Jhuran formation forming within the pro-delta (Biswas 1977). The Katesar member in the study area is represented by an unconformity in remaining part of the basin, towards the east (Biswas 1991). The development of an unconformity in the proximal part of the basin, will lead to the cessation of marine sedimentation in the distal part, causing changes in the sediment characteristics from softground through firmground to hardground (Desai and Patel 2008).

The important development in the lower part of the Guneri dome includes:

1) Deposition of pre-omission silty sediments in intertidal-subtidal environment;
2) Exposure of the deposits leading to change in consistency of substrate from softground to firmground;
3) Development of omission surface and production of *Balanoglossites* by burrowing in firmground;
4) Erosion of the omission surface and change in substrate from firmground to hardground on account of regression;
5) Subsequent development of postlithification surface and production borings;
6) Repetition of similar sequence for the second *Balanoglossites* horizon.

Thus, the repetitive occurrences of the *Glossifungites* ichnofacies surfaces containing *Balanoglossites* and *Gastrochaeonolites* might be attributed to cyclic regressive phases caused by progradational delta front on account of high rate of sedimentation. The higher rate of sedimentation could have caused frequent filling of accommodation space, causing cyclic subaerial exposure and transition of firmground to hardground.

Conclusions

Balanoglossites occurs as an important element of the *Glossifungites* ichnofacies surface as well as ichnofacies developed in two horizons deposited in the intertidal-subtidal palaeoenvironment of Lower Cretaceous sediments of the Guneri member (Bhuj formation) in the Kachchh basin. Extensive colonization of opportunistic *Balanoglossites* indicates development of a firmground omission surface, followed by development of a hardground and an erosional phases. The development of two horizons of *Balanoglossites* indicates a regressive phase associated with high rate of sedimentation in the Kachchh basin during Lower Cretaceous times.

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