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A new genus and species of fossil pseudoscorpion (Arachnida: Pseudoscorpiones) from the Eocene amber of Western India

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ABSTRACT

A new genus and species of fossil pseudoscorpion, *Geogaranya valiyaensis* gen. nov. sp. nov., is described from the Valia Lignite Mine, Cambay Basin, Gujarat. The new fossil taxon is exceptionally preserved in the early Eocene Cambay amber and is a member of the family Geogarypidae, with similar affinities to the modern genus *Geogarypus* (Chamberlin, 1930) recorded from Sri Lanka, India and New Guinea. The taxon is one of the smallest known adult fossils of pseudoscorpion in amber from the Cambay Basin and adds to the bark-dwelling arthropod biodiversity identified in the Eocene amber from Western India.

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INTRODUCTION

Unique fossil resources have been found in the Cenozoic amber deposits recovered from India and many sections of the Asian Lignite Mines over recent years. The Indian amber deposits from the Cambay Basin are linked to the resinous trees of Dipterocarpaceae, classified as a class II (dammar) resin (Dutta et al., 2009, 2011; Rust et al., 2010; Shi et al., 2014; Dutta and Mallick 2017; Bansal, 2022). Unlike compression fossils, biotic inclusions in amber have resulted in an array of exceptionally preserved floral and faunal species. The Cambay Basin has been a rich palaeontological hotspot for terrestrial mammals (Rana et al., 2005, 2008; Smith et al., 2007; Rose et al., 2009; Mayr and Smith, 2019) and amber inclusions (Alimohammadian et al., 2005; Rust et al., 2010). Resinous trees, such as the Dipterocarpaceae, originated from the warm period of the Ypresian, indicating the presence of early angiosperm-based megathermal forests (Heinrichs et al., 2016; Khan et al., 2020). Cambay amber holds records of primitive flower and pollen species (Singh H. et al., 2021), arthropods including social insects (Grimaldi and Singh, 2012; Kania et al., 2015; Stebner et al., 2016, 2017), such as termites (Engel et al., 2011), beetles (Ortega-Blanco et al., 2013) and freshwater crustaceans.

Here, we describe a new genus and species of fossil pseudoscorpion (Family Geogarypidae) (Figure 1) in Cambay amber from the Valia Lignite Mine, Gujarat. Pseudoscorpions are an ancient lineage of terrestrial arachnids (Shear et al., 1989), which are morphologically similar to true scorpions but lack a tail and stinger. Certain families possess a distinct venom apparatus in the chelal fingers of the pedipalps, which evolved independently from that of scorpions and spiders (Kramer et al., 2019). Recent studies have also supported the inclusion of pseudoscorpions as the sister group of scorpions (Ontano et al., 2021). The term Panscorpiones has been proposed for the clade uniting scorpions and pseudoscorpions, based on the data of taxonomic sampling while studying the phylogenetic placement of pseudoscorpions. The presence of venom glands on both chelal fingersis presumed to be a plesiomorphic trait, and later lost in one of the fingers (Murienne et al., 2008). A few species have a capacity to use phoresy for dispersion, while others act as commensals, living in mammal or bird nests (Turienzo et al., 2010). In comparison to other more widely preserved arachnid groups of spiders and mites, they have a limited fossil record with significant biogeographical implications. Because of their delicate bodies and small size, these fossils are mostly discovered in amber deposits across the world, rather than in sedimentary deposits. Forty-nine pseudoscorpion species have been documented from the Baltic and Rovno amber which is of Eocene in age (Harvey, 2013; Harms and Dunlop, 2017; Schwarze et al., 2021). Based on the International Chronostratigraphic Chart (Cohen et al., 2013), new pseudoscorpion taxa were listed from Cenozoic and Cretaceous ambers, including *Progonatemnus* (Atemnidae), *Roncus* and *Neobisium* (Neobisiidae), *Electrochelifer* (Cheliferidae), *Cheiridium* (Cheiridiidae) and *Geogarypus* (Geogarypidae). Quality preservations have also been mentioned from the Bitterfeld (Ahrens et al., 2019) and Burmese (Harvey et al., 2018) amber, with data of unique genera *Allochthonius, Centrochthonius* and *Weygoldtiella* respectively. From the Cenomanian Burmese deposits of Myanmar, the genera *Electrobisium, Amblyolpium* and *Protofeaella* have also been mentioned. Baltic amber preserves Eocene genera *Pseudogarypus, Pychnochelifer, Cheiridium* and extinct genus *Chelignathus*. Major Baltic contribution was by Max Beier, who described seventeen pseudoscorpion species in his articles (Beier, 1937, 1947, 1955) and by Harvey (1992), who proposed the first objective phylogeny based on morphological traits, differentiating two lineages, Epiocheirata and Iocheirata. Schawaller (1978) and Judson (2003) later added three more genera *Chthonius, Microcreagrus* and *Neobisium* to the list. Pseudoscorpion families in Dominican amber from the Neotropicalregions of the State of Chiapas and Island of Hispaniola yield significant species of *Pachychernes, Pseudochthonius, Lechytia, Cryptocheiridium,* extant species *Idiogaryops, Pseudochiridium* and other recent records listed by Penney and co-workers (2008). Pseudoscorpion researches from the Indian subcontinent and Sri Lanka have also looked into indigenous families Chernetidae (genus *Meghachernes*), Withiidae (genus *Metawithius*) and Hyidae (genus *Indohya*) of both contemporary and Gondwanan origin (Harvey and Volschenk, 2007; Batuwita and Benjamin, 2014; Novak and Harvey, 2018; Johnson et al., 2019). However, there are no previously published records of fossil pseudoscorpions from India.

Family Geogarypidae is amongst those groups of bark-dwelling and litter-dwelling species which are similar to family Garypidae in having a characteristic subtriangular carapace and eyes near the anterior margin. The family contains more than seventy species with habitat preferences suit-

FIGURE 1. *Geogaranya valiyaensis* n. gen., n. sp. ♂ (dorsal view), BSIP Museum Number- 41982.

able in tropical and subtropical regions with a few reported from temperate biomes (Harvey, 2013; Nassirkhani, 2014; Neethling and Haddad, 2017). Geogarypidae are more common in the Baltic and Rovno amber with a few records from the Cretaceous Burmese amber (Table 1). Unlike their scarce records in fossils, their modern counterparts have been recorded from all major biogeographical regions, including Europe, Central Asia, North America and North Africa (Harvey, 2013). Their fossil records serve as a source to understand palaeoenvironment and climatic conditions during the Early Eocene Climatic Optimum (EECO) (Cramer et al., 2003; Nicolo et al., 2007; Rust et al., 2010; Zachos et al., 2010).

LOCALITY AND AGE

The open-cast Valia Lignite Mine (latitude 21° 30' 52' N, longitude 73° 12' 20" E) is located in the Cambay Basin, with a well-established biostratigraphic framework (Biswas, 1993; Bhandari et al., 2005; Sahni et al., 2006; Punekar and Saraswati, 2010; Rust et al., 2010; Prasad et al.,2013; Rao et al., 2013; Singh H. et al., 2015, 2021). The Cambay Shale Formation overlies the Deccan traps and is underlain by the Paleocene-lower Eocene Vagadkhol Formation (Sudhakar and Basu, 1973; Singh H. et al., 2011). It is assigned a Ypresian age with context to dinoflagellate cysts (Garg et al., 2008) and benthic foraminiferal data of *Nummulites burdigalensis* from the adjacent Vastan Lignite mine (Punekar and Saraswati, 2010). The rock type of the studied mine exposure comprises of carbonaceous and grey shales of varied thickness. The stratigraphic section consists of 3 lignite seams, and the upper and basal seams are thicker (4.5 m and 3 m) than the middle seam of 0.3 m (Figure 2). Amber nodules are collected from lignite seams I and III. Of significant findings, *Gynocardia* fossil wood (Shukla et al., 2015) and vertebrate remains and pollens (Singh V. P. et al., 2021) were documented from the respective lignite and shale beds. Geochemical data (bulk rock XRD and clay mineralogy) carried on rock samples infer the presence of kaolonite, siderite, quartz, smectite and chlorite. Kaolonite abundance indicates high degree of chemical weathering and high erosion (Singh V. P. et al., 2021).

MATERIAL AND METHODS

Amber nodules incorporating fossils were recovered from the open-cast Valia Lignite Mine, 30 km South East from Bharuch district, Gujarat. On a Buehler flat lap wheel, the amber slab containing the pseudoscorpion fossil was ground and polished using emery sheets. The specimen was observed and photographed under Leica stereoscope M205A. For scanning electron microscopy imaging (Figure 3), the amber slab was completely dissolved in toluene and left for the resin to totally evaporate. The fossil was then placed on a stub and scanned using a scanning electron micro-

TABLE 1. *Pseudoscorpion* taxa in amber.

GEOLOGICAL TIME	FAMILY	TAXA	AMBER TYPE	REFERENCES
Mesozoic	Cheliferidae	*Chelifer fossilis*	Lebanese amber	Whalley, 1980; Grimaldi, 1996
	Chernetidae Chthoniidae Cheiridiidae Garypidae Pseudochiridiidae	*Pachychernes* *Pseudochthonius* *Cryptocheiridium* *Idiogarypus* *Pseudochiridium*	Dominican amber	Hoff, 1963; Schawaller, 1980, 1981;Judson, 2007; Penney, 2008
	Cheliferidae	*Heurtaultia*	Archingeayamber	Perrichot, 2004
	Geogarypidae Cheiridiidae Pseudogarypidae Feaellidae	*Electrobisium* *Amblyolpium* *Protofeaella*	Burmese amber	Cockerelll, 1917, 1920; Henderickx and Boone, 2016; Xing et al., 2018
Cenozoic	Geogarypidae Pseudogarypidae Cheliferidae Cheliferidae Tridenchthoniidae Cheiridiidae Chernetidae Chthoniidae	*Geogarypus* *Pseudogeogarypus* *Trachychelifer* *Pycnochelifer, Obisium* *Chelifer ehrenbergii* *Chelignathus, Cheiridium* *Chthonius, Oligochernes* *Microcreagris, Neobisium*	Rovno amber and Baltic amber Fushun amber Baltic and Bitterfeld amber	Henderickx, 2005; Henderickx and Perkovsky, 2012; Henderickx et al., 2013; Harms and Dunlop, 2017 Hong, 1983 Koch and Berendt, 1854; Beier, 1937, 1947, 1955; Harvey, 2011; Judson, 2003

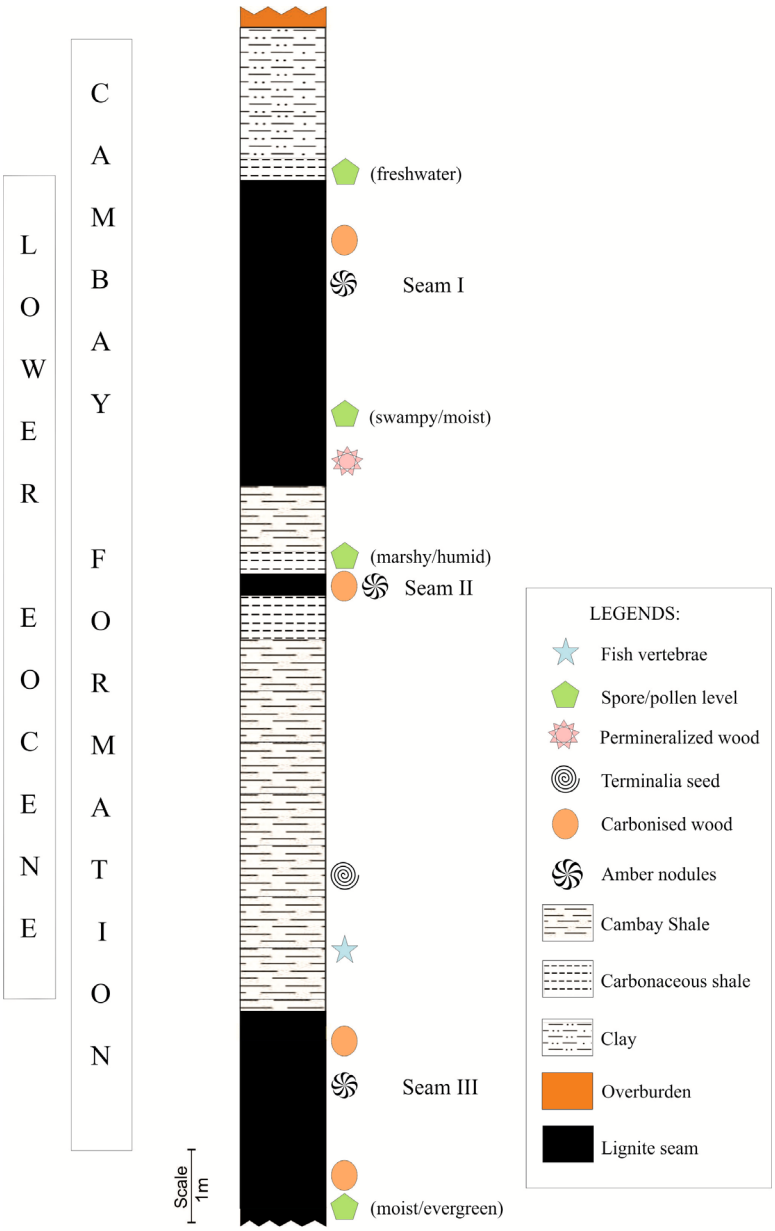

FIGURE 2. Lithological section of Valia Lignite Mine, Cambay Basin, Gujarat (latitude 21° 30' 52' N, longitude 73° 12' 20" E).

scope Leo 430. The holotype is deposited at the Birbal Sahni Institute of Palaeosciences, Lucknow repository, with museum number as 41982. This specimen is also included in Singh V.P. et al. (2021). Systematic terminologies follow that of Chamberlin (1931).

SYSTEMATIC PALAEONTOLOGY

GEOGARYPIDAE (Chamberlin, 1930)
GEOGARANYA gen. nov.

G. valiyaensis sp. nov. ♂
Figures 1, 3, 4

zoobank.org/53588E48-742C-485E-9CE3-7B23C3B93E1B

Type material. BSIP museum no. 41982; a geogarypid adult pseudoscorpion, well-preserved in amber resin.

Locality. Valia Lignite Mine, Cambay Basin, Gujarat.

Age. early Eocene

Etymology. Genus name derived from the Indian *Geogarypus* and Aranya, meaning "wilderness" '

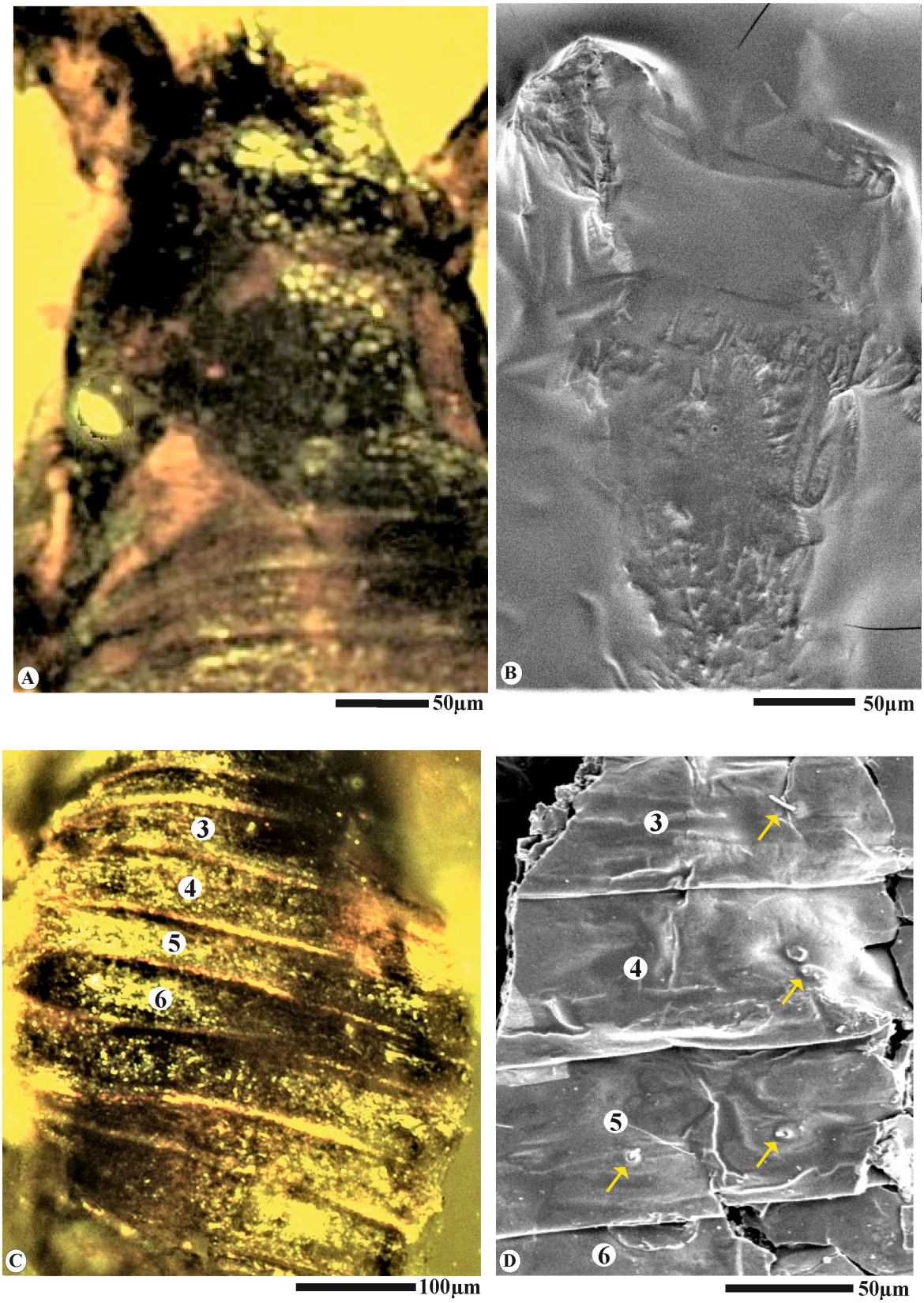

FIGURE 3. High resolution images (A and C- under stereoscope M205A, B and D- SEM images) of characteristic details of *Geogaranya valiyaensis*. (A) and (B) granular projections on cephalothorax (dorsal view), (C) and (D) tergites III to VI with lyrifissures (magnified dorsal view).

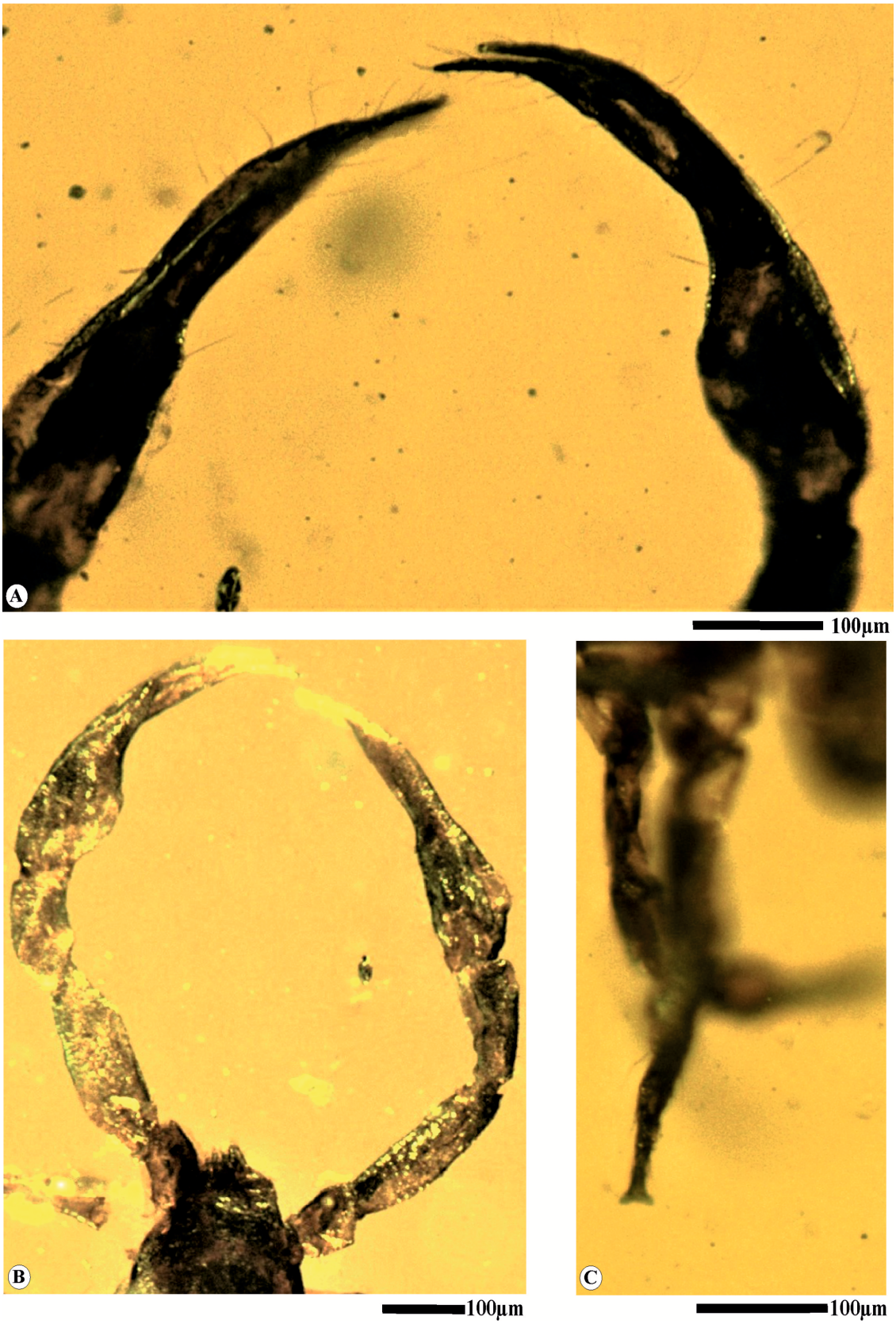

FIGURE 4. High resolution images of details of *Geogaranya valiyaensis*. (A) Chelal fingers (L and R) with long setae (magnified view), (B) pedipalps (L and R), (dorsal view), (C) fair preservation of tarsi on fore- and midleg (L).

in sanskrit; the specific epithet named after Valia Lignite Mine.

Diagnosis. *G. valiyaensis* gen. nov. sp. nov. differs from the other genera of family Geogarypidae in possessing carapaceal alae, smallest size, triangular carapace, eyes on ocular tubercles, exceptionally long chelal fingers, non-clavate bristles, distinctly granulated prosoma, and articulation differences between appendages.

Genus description. Prosoma-chelal fingers with 5-6 pair of setae, no teeth on movable fingers, tarsal claws absent, prosoma coarsely granulated, flagellum with minute bristles, ovate chelicerae, no tubercles lining the thorax, non-clavate bristles unlike other genera; opisthosoma- male sternites without margins, pitted surface lining the Ist tergite, tergites II-VI with prominent keels, spiracles and tarsal setae absent; appendages-articulation difference between front, mid and hind legs unlike the heterofemorate articulation found in other genera of Family Geogarypidae.

Species description. Smallest known adult (Figure 1), well preserved in Cambay amber, length from chelicerae to abdomen 0.60 mm, flattened, pear-shaped body, chelicerae rather short, distal blades with serrations, prosoma 0.16 mm, longer than broad, sub-rectangular, granular pattern over the carapace, antero-marginal position of eyes, pedipalps 0.8 mm (L and R each), twice the length as the abdomen, smooth chelae including movable fingers, no teeth overmovable fingers, numerous setae on the dorsal chelal surface (Figure 4A), trochanter 0.06 mm (L and R each), femur 0.20 mm (L), 0.23 mm (R), elongate, patella 0.10 mm (L), 0.16 mm (R), chela without pedicel, 0.40 mm (L), 0.41 mm (R), swollen, trichobothria indistinguishable, carapace granular with minute setae, opisthosma 0.36 mm, ovate, marked segmentation (Figure 3C, D), twelve opisthosomal segments visible, I-XII tergites visible, median suture lines dividing each tergite longitudinally, numerous lyrifissures, no terminal stinger, spiracles absent, legs poorly preserved (Figure 4C), broken, leg 1 (L) detached from the body, coxae attached with the thorax of leg I (R), II (L, R), III (L, R) and IV (L, R).

Remarks. *G. valiyaensis* gen nov. sp. nov. in amber adds major insights into the evolution of the pseudoscorpion taxa and contributes to the diverse amber arthropod community found in the Cambay Basin of Gujarat. The fossil implies a much warmer temperature, with its assimilation of distinct characteristics, akin to fauna in a warm-temperate biome. We also find similar affinities of the fossil with those recorded from the Baltic and Bitterfeld, in support of a strong tilt towards bark-dwelling taxa (Harms and Dunlop, 2017).

DISCUSSION

Pseudoscorpions represent a group of ancient lineage of the earliest arthropods which colonized the landmass of the Earth during early Devonian based on fossil evidence (Shear et al., 1989). The diversified order occupies more than three percent of the total known arachnid species (Harvey, 2007). Unlike pseudoscorpions, other arachnid taxa occur at a much younger age, with fossil records including spiders and scorpions previously recorded from the late Carboniferous and potentially originating later. Flying insects radiated much later during the Carboniferous (Dunlop, 2010; Dunlop and Penney, 2012). In addition, pseudoscorpions adapt themselves to cryptic habitats including litter and tree barks, and hence, their evidence in amber fossil record strongly supports that they also share some similarities with several clades of acariform mitesfrom the Palaeozoic and Cretaceous (Dunlop and Penney, 2012). Due to its similarities in morphology and habitats through fossil records, it is believed that the biology and behavioral features could have been maintained between both taxa (Shear et al., 1989; Poinar et al., 1998).

With respect to the Eocene palaeoenvironment, amber-preserved biota documents an exceptional preservation of taxa living close to the amber source which are more likely to be trapped in the amber resin. In case of pseudoscorpions, the record of a bark dwelling *G. valiyaensis* preserved in the Cambay amber adds valuable insights into the arthropod biodiversitythat survived near the resin source in a broad-leaved angiosperm dominated tropical rainforest during the early Eocene. Molecular affinities of Cambay amber are more connected to the present-day forest on peat bogs from Borneo and Sumatra, Indonesia (Naglik et al., 2018; Simoneit et al., 2020). Both show properties that are comparable to those seen in angiosperms. *Shorea* is the most common resin-producing genus in both regions with similar chemical composition.

The systematic description of *G. valiyaensis* in amber indicates a biota belonging to a much warmer temperature during the Eocene. We also state record similar affinities of the fossil with those recorded from the Baltic and Rovno, in support of a strong tilt towards bark-dwelling taxa. The occurrence of this early Eocene pseudoscorpion taxon in Cambay amber provide evidence for the presence of arachnid species inthe vicinity of a warm Eocene

forest, with similar diversification pattern to the Eocene spiders (Dunlop et al., 2018). Dimension of pedipalps and the structure of chelae aid in handling larger fauna, both for predation and transportation. In accordance with Judson's (2012) theory, we have observed plesiomorphic and derived traits by interpreting *Dracochela* as a stem-group pseudoscorpion, clearly indicated by pedipalps (Figure 4), trichobothria and a cuticle texture implying living in moist environments like leaf litter. The ancestral forms which belong to the Geogarypidae already possessed trichobothria, pedipalps, chelicerae and galea. Presence of unusually larger pedipalps does create the possibility of phoresy, and that species from non-arboreal habitats may unintentionally be conveyed into amber, linked to their flying hosts. None of the evidences suggest that the present species had any ecological difference from other geogarypids and that it belongs to a bark-dwelling arachnid group. The fossil belongs to a clade that is not well known from the Indian Eocene amber fauna and differs from other arthropod species known from Southeast Asia. The terrestrial environment that fostered the formation of this fossil species preserved in Cambay amber, qualifies as a possible Gondwanan relict, when there was a significant transition from a temperate to tropical zone across the equator. However, based on Devonian fossils, it is possible to state that pseudoscorpions diverged into main clades earlier than certain other arachnid taxa, such as the spiders (Harms and Dunlop, 2017). Also, findings of freshwater crustaceans (ostracods) in amber from similar locality suggests that open pool systems may have existed in the region, penetrating deep into the Eocene forest, with overhanging branches of resinous trees around these water bodies.

CONCLUSIONS

1. *Geogaranya valiyaensis* gen. nov. sp. nov. is the first ever record of pseudoscorpion, extracted from an amber nodule, recovered from the amber-bearing lignite deposits of the Valia Lignite Mine of Gujarat, western India.
2. The discovery of one of the smallest known pseudoscorpion adults in amber from the Cambay Basin provides insights into the bark-dwelling arthropod taxa, similar to fossil taxa recorded in Baltic and Bitterfeld amber, which survived during the early Eocene.
3. The fossil shows strong resemblance with the modern *Geogarypus* (Chamberlin, 1930). The scanning electron microscopic study reveals diagnostic traits of the fossil, such as exceptionally enlarged pedipalps, which increases the idea of phoresy and suggests that species from non-arboreal habitats may have mistakenly been transported into amber and related to their flying hosts.

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