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Review of Fossil Tick Interactions with Other Organisms

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Abstract

The characterization of fossils is important for the study of the origin, environment and evolution of ticks (Arthropoda: Chelicerata: Arachnida: Parasitiformes: Ixodida: Ixodidae hard ticks and Argasidae soft ticks). Tick inclusions are less common than other arthropods and have been described in fossil amber and remains. In this study, the record of tick interactions with other organisms was used to review parasite environment and evolution. Fossils provide evidence of tick parasite-host, prey-predator and tick vector-pathogen interactions to advance in the study of the evolution of tick-host-pathogen interactions.

Keywords: Amber; Environment; Evolution; Fossil; Pathogen; Tick

Introduction

The origin of ticks is estimated during the Cretaceous period (66-145 Mya) with both the Argasidae and Ixodidae being established in the middle Cretaceous with putative primeval host reptiles (e.g., dinosaurs and lizards) and amphibians as described in Burmese Cretaceous amber (ca. 99 Mya) [1-3].

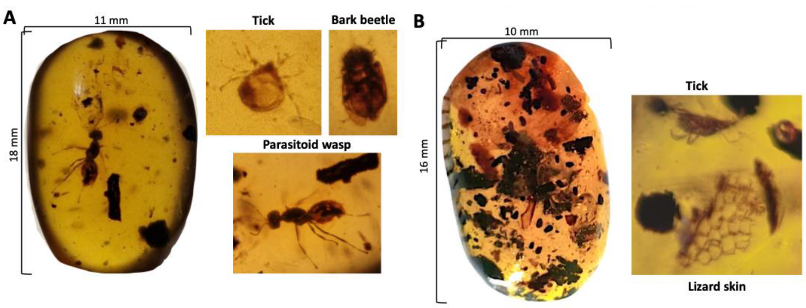

Figure 1: Representation of fossil ticks with syninclusions in Burmese amber. (A) Tick with insect and plant syninclusions (Burmite, ca. 99 Mya, 18 x 11 x 6 mm). Tick (Arachnida: Ixodida: Ixodidae, C.L. Koch 1844) with bark beetle (Insecta: Scolytinae, Latreille 1804) and parasitoid wasp (Insecta: Hymenoptera). (B) Tick with lizard skin and plant syninclusions (Burmite, ca. 99 Mya, 16 x 10 x 5 mm). Tick larva (Arachnida: Ixodida: putative Argasidae, C.L. Koch 1844) with lizard (Reptilia: Squamata, Oppel 1811) skin showing a patch of overlapping polygonal scales. Plant remains are visible as represented close to the wasp in (A) and to the tick and lizard skin in (B). Additional information in Notes.

The analysis of fossil remains, and amber inclusions provides information of the fossil environment with the presence of multiple organisms including ticks (e.g., [4]; Figures 1A and 1B). Ticks are not common fossil animals and fossil tick syninclusions represent arthropod evolution and coexistence with other organisms [5,6].

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Amber syninclusions are mostly associated with the presence of different organisms in the fossil environment that got entrapped in amber by random processes in an ecological context. However, as approached in this study, in some very unique cases ticks have been identified with possible multiple type interactions.

Fossil Tick Interactions with Other Organisms

Cases of tick interactions in fossil amber

Case 1: Tick parasite-host interactions. Cretaceous Burmite (ca. 99 Mya). Ticks *Cornupalpatum burmanicum*† (Ixodida: Ixodidae: *Cornupalpatum*, Poinar & Brown 2003) and of the extinct family Deinocrotonidae† (Ixodida: Deinocrotonidae: *Deinocroton*) were found to parasitize and feed on blood from feathered dinosaurs [7].

Case 2: Tick prey-predator interactions. Cretaceous Burmite (ca. 99 Mya). Tick-spider interactions were identified with evidence associating ticks with predatory spiders [8,9]. Fossil hard ticks, putative *Compluriscutula vetulum* (Ixodida: Ixodidae: *Compluriscutula*, [10]), were found wrapped in or closely associated with spider silk web.

Case 3: Tick parasite-host interactions (Figure 1B). Cretaceous Burmite (ca. 99 Mya). The syninclusion of a **lizard skin and a tick (Figure 1B)** should be generally interpreted as a highly probable **paleoecological interaction** rather than a random process [11]. As shown here (Figure 1B), a soft tick (Arachnida: Ixodida: putative Argasidae, C.L. Koch 1844) larva with a lizard (Reptilia: Squamata, Oppel 1811) skin syninclusion was identified with possible parasite-host interactions [12,13]. Supporting this putative tick-lizard interaction, it has been proposed that ancestral tick families such as soft ticks *Argasidae* [3], were already specialized to feed on early reptiles like lizards identified in Burmese amber [14].

Case 4: Tick vector-pathogen interactions. Dominican amber (ca. 15-45 Mya). An engorged *Amblyomma* sp. (Ixodida: Ixodidae: *Amblyomma*, Koch, 1844) nymph was identified surrounded by mammalian host (putative primate) erythrocytes, both containing fossil piroplasms [15].

Case 5: Tick vector-pathogen interactions. Dominican amber (ca. 15-45 Mya). Spirochetes-like cells (Spirochaetales: Spirochaetaceae: *Palaeoborrelia dominicanan* gen., n. sp.) were found in the hemocoel and lumen of the alimentary tract of a larva tick, *Amblyomma* sp. (Ixodida: Ixodidae: *Amblyomma*, Koch, 1844) [16].

Case 6: Tick vector-pathogen interactions. Cretaceous Burmite (ca. 99 Mya). Gram-negative motile Enterobacteriaceae *Kluyvera* sp. (Enterobacteriales: Enterobacteriaceae: *Kluyvera*) typically found in soil, sewage and water were identified by paleoproteomics analysis of tick *Cornupalpatum* sp.† (Ixodida: Ixodidae: *Cornupalpatum*, Poinar & Brown 2003) fossil amber inclusion [4].

Cases of tick interactions in fossil remains

Case 7. Tick parasite-host interactions. Argentina, Las Máscaras Cave, Catamarca, late Holocene (ca. 990 ± 35 cal yr.) owl pellet. A hard tick, *Ixodes sigelos* (Ixodida: Ixodidae: *Ixodes*) [17] was described as putatively feeding on the rodent, *Eligmodontia* sp. (Rodentia: Cricetidae: *Eligmodontia*, Cuvier 1837) [18].

Case 8: Tick parasite-host interactions. United States northwest Arizona Antelope Cave human coprolite (1-1000 A.D.). A hard tick (Ixodida: Ixodidae: *Dermacentor* sp.) was identified in archaeological occupation of human origin coprolite suggesting that ectoparasites were consumed by ancient humans [19].

Case 9: Tick parasite-host interactions. Ancient Egypt (ca. 1st-4th century A.D.) archeological expedition in El Deir. Hard ticks, *Rhipicephalus sanguineus* (Ixodida: Ixodidae) were morphologically identified on a dog mummy [20]. These findings represent the oldest record of brown dog ticks on animals with record of ancient dog infestations in the Mediterranean region.

Discussion and Conclusions

Tick parasite-host interactions have been reported in both fossil amber (Cases 1 and 3) and remains (Cases 7-9).

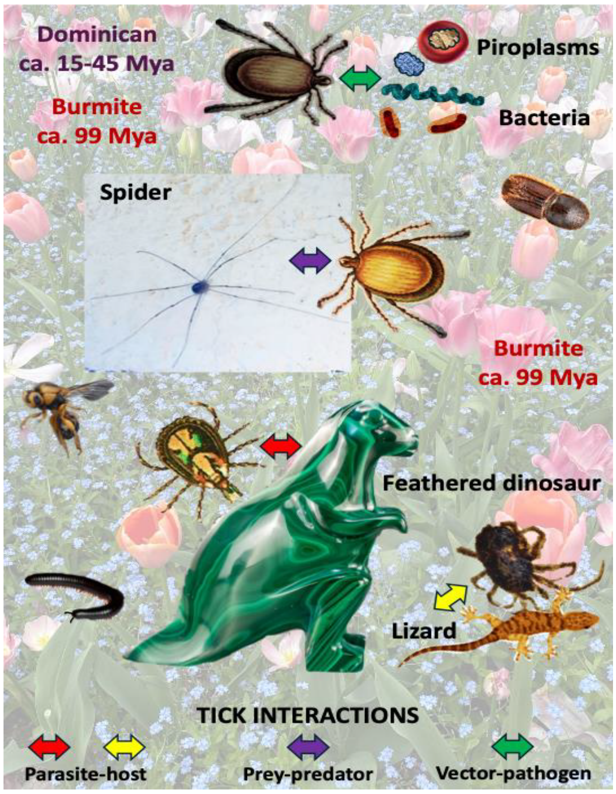

Figure 2: Tick interactions in fossil amber. Representations of the evidence of parasite-host, prey-predator and vector-pathogen interactions.

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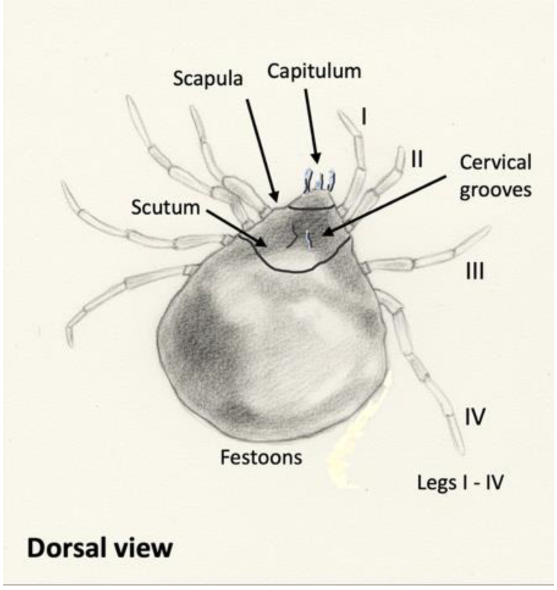
Focusing on the record of fossil inclusions in Burmese and Dominican amber (ca. 15-99 Mya), the results provide evidence of not only tick parasite-host (feathered dinosaur Case 1 and lizard Case 3) interactions, but also tick prey-predator (spider, Case 2) and tick vector-pathogen (piroplasms Case 4, spirochetes Case 5 and enterobacteria Case 6) interactions (Figure 2).

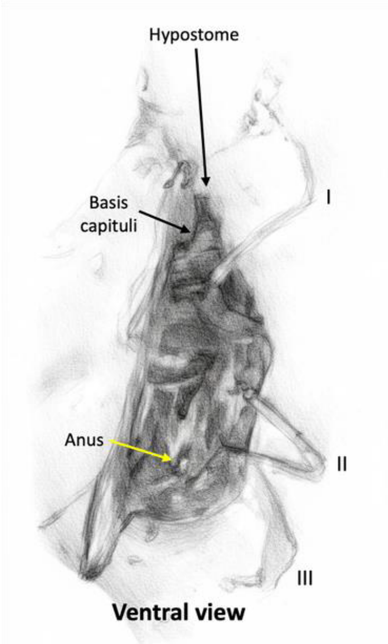
Evidence from the analysis of fossil inclusions support that interactions with vertebrate hosts, arthropods and microorganisms evolved since tick origins after End-Cretaceous extinction and continued to the present with evolutionary adaptations to different organisms and environments. These results are similar in other arthropods such as Arachnida spiders originating at least 380 Mya [21]. These studies advance our understanding of tick-host-pathogen interactions with evolutionary implications associated with arthropod holobiont conflict and cooperation and the growing impact of ticks and tick-borne pathogens on human and animal health worldwide [22-26]. Future studies with omics algorithms such as paleoproteomics will provide additional molecular evidence of fossil tick interactions with multiple organisms [4, 27].

Notes

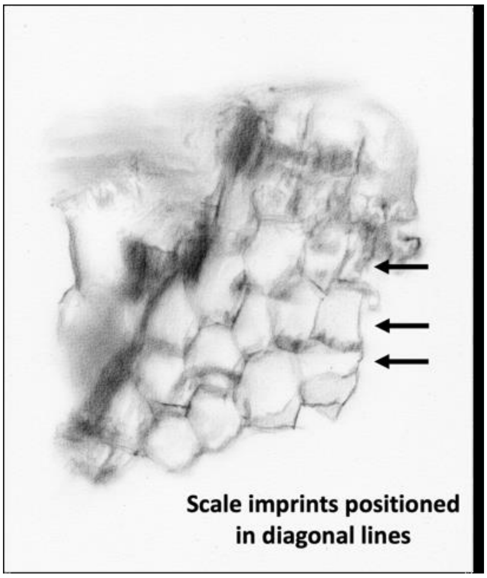
Amber fossils are authentic following reported considerations [4] and part of author´s KGJ Collection (Ciudad Real, Spain). Morphological classifications were based on preservation of inclusions and microscopic images captured as previously described [4] and camera drawings (https://colorifyai.art/photo-to-sketch/).



Morphological reference for hard tick (Arachnida: Ixodida: Ixodidae, C.L. Koch 1844) (Figure 1A) in Burmese amber [28].



Morphological reference for soft tick larva (Arachnida: Ixodida: putative Argasidae, C.L. Koch 1844) (Figure 1B) in Burmese amber [7]. The specimen is not well preserved and thus some body parts are difficult to identify properly.



Morphological reference for lizard (Reptilia: Squamata, Oppel 1811) skin scales (Figure 1B) in Burmese amber [29, 30].

Competing Interests

The author declares that no competing interests exist.

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