Part II - Parasite Remains Preserved in Various Materials and Techniques in Microscopy and Molecular Diagnosis

11. Mites, Ticks, and Paleoparasitology

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Mites, Ticks, and Paleoparasitology

Gino Chaves da Rocha • Nicolau Maués da Serra-Freire

The reconstitution of Earth's evolutionary history, of living and extinct beings, fundamentally involves three fields of study: geology, paleontology, and biology. In the late 20th century, biochemical and molecular techniques were increasingly applied to studies in evolutionary genetics, phylogenetic analyses, and molecular systematics (Navajas & Fenton, 2000). The study of geological layers, fossil records, and morphological and genetic characteristics to identify relations between organisms produces valuable knowledge on the history and diversity of planetary life or planetary biology, as suggested by Benner et al (2002).

Since the dawn of life on Earth, between 4.4 and 3.8 billion years ago (Chang, 1999), the various levels of competition for ecotopes (spatial niches) and the struggle for the establishment of trophic niches (food resources) have woven a complex web of biochemical relations among organisms (Forattini, 2004). The life and survival of species result from constant adaptation to the challenges raised by favorable or unfavorable conditions in the environment.

In this long history of irradiation and evolutionary adaptation, microorganisms, plants, and animals have developed mechanisms for absorbing and transferring energy (Chart 1) and “adopting” other organisms through an association of interspecific energy and biochemical dependence. Conceptually, parasitism thus exists when an organism finds its ecological niche in another life form. Parasitism is considered an ecological phenomenon (Zelmer, 1998; Rey, 2001; Ferreira, Reinhard & Araújo, 2008). Araújo et al. (2003) and Ferreira & Araújo (2005) present the arguments and foundations for host-parasite-environment relations, stating that “parasitism is inherent to life”.

The use of available energy in the troposphere became a condition for the survival of living species, including parasites and decomposers, with a key role in ecosystems.

Chart 1 – The energy cycle of living organisms on Earth: the energy pyramid in the modern age

Source and use of energy	Energy released (Kcal/m ³)	Used for respiration (Kcal/m ³)	Used for growth (Kcal/m ³)	% used for growth/released	Unused (Kcal/m ³)	Transferred (Kcal/m ³)	% transferred/total released
Produced by sun	1,700,000	–	–	–	–	–	100
Not absorbed by Earth	1,209,000	–	–	–	880,000 (68.22%)	410,00	24.118
Photosynthesis	410,000	389,190	20,810	5.08	12,977 (62.36%)	8,833	0.520
Plant respiration	20,810	11,997	8,833	42.45	5,463 (61.85%)	3,370	0.198
Herbivorous animals	3,370	1,890	1,480	43.92	1,500 (79.37%)	390	0.023
Carnivorous animals	390	316	74	18.97	53 (71.62%)	21	0/001
Omnivorous animals	21	13	8	38.10	7,999 (99.99%)	0.001	5 x 10 ⁻¹⁰
Decomposers	20,001	18,183	1,818	9.09	80 (4.40%)	1,738	0.102

This chapter discusses the ecological relations ruling the “parasitism phenomenon” and analyzes them according to paleoparasitological interpretations of paleontological and archaeological finds. We specifically present a line of research focusing on mites and ticks from the past. Didactically, but no less technically and scientifically, we describe these animals and their biological and anatomical similarities and differences between them and insects.

We also take an epidemiological approach to debate the importance of these invertebrates, emphasizing the complexity of ecological models for the transmission of infectious agents by Acari. In order to review and describe the records and reconstruct what may have occurred in the past, we conduct a systematic classification to establish the conditions for interpreting the importance of paleoacarological finds and their ecological context.

PARASITES OF ARTHROPODS

Of all parasites, fossil or living, those of phylum Arthropoda (the largest phylum in kingdom Animalia) definitely include the widest variety of forms, occupy the most different ecotopes, and display the widest range of biological and parasitic behavior (Giribet & Ribera, 2000; Hickman, Roberts & Larson, 2006; Serra-Freire & Mello, 2006). The group is highly heterogeneous, but with the following basic morphological characteristics: a segmented or metameric body, bilateral symmetry, jointed appendages (including for locomotion), and a chitinous or sclerotized exoskeleton (chitin is a stiff, resilient, and water-insoluble nitrogenated polysaccharide, and sclerotin is another nitrogenated polysaccharide, resilient yet pliable, but also water-insoluble). In geological time, the evolution of Arthropoda began in the Paleozoic, in the Cambrian period or even earlier (Pre-Cambrian), more than 600 million years ago (Weygoldt, 1998).

An in-depth analysis of the debate on the phylogenetic origins of arthropods is beyond the scope of this chapter (many authors defend a monophyletic origin, i.e., that all arthropods originated from a common ancestor on the evolutionary scale) (Weygoldt, 1998). Briefly, however, two major groups (subphyla) are recognized as having emerged from Arthropoda: the group of Mandibulata, which have mandibles as part of their mouthparts, and the group of Chelicerata, which have six pairs of jointed appendages, with one pair of chelicerae, a pair of leg-like appendages or pedipalps, and four pairs of walking legs (Hickman, Roberts & Larson, 2006).

The subphylum Mandibulata, which some authors classify as subphylum Uniramia, includes the following respective subgroups: Crustacea (with a hard “crust”-type carapace and two pairs of antennae), Myriapoda (“a thousand legs, feet”, or walking appendages), and Hexapoda (three pairs of legs). In subphylum Chelicerata, one of the largest classes is Arachnida (head fused to the thorax – cephalothorax and abdomen, no antennae or mandibles), which includes mites and ticks (Weygoldt, 1998; Wheeler & Hayashi, 1998; Giribet & Ribera, 2000; Hickman, Roberts & Larson, 2006). Among the mandibulates and chelicerates, two groups have great parasitological importance for both human and veterinary medicine: class Insecta (insects) and class Arachnida (which includes the mites and ticks).

EPIDEMIOLOGICAL IMPORTANCE, PRESENT AND PAST

Many of these arthropod species can serve as winged or wingless vectors in epidemiological transmission chains, as mechanical and biological transmitters of infectious agents (e.g., viruses, rickettsiae, bacteria, protozoa, fungi, and helminths). Through their bites and blood meals they inoculate and participate in the dissemination and dispersal of pathogenic bioagents to susceptible organisms, thus leading to diseases. Different processes can occur, depending on various other factors related to the time between emergence of cases and the characteristics of the geographic space in which they take place. Such processes can be epidemic (e.g., exanthematic typhus, Brazilian spotted fever, scabies), endemic (Lyme disease, babesiosis), or pandemic (rickettsiosis, ixodidiosis). Epidemiologically, they can also act as reservoirs and intermediate hosts of these same potentially pathogenic agents for humans and species of domestic and wild animals (Rey, 2001; Forattini, 2004; Coura, 2005).

Blood-feeding insects, mites, and ticks (adult ectoparasites and their larval and nymphal forms) are also responsible for debilitation through infestations such as botfly lesions, myiasis, and other dermatoses. Considering the serious social and economic impacts of these diseases in modern times, especially in developing countries, one can imagine their impact on human and animal populations in the past.

Importantly, the dynamics of infectious diseases involve complex ecoepidemiological chains, which combine with socioeconomic and cultural determinants of infectious processes to directly or indirectly affect humans; humans also help generate such processes (through anthropogenic actions). When these processes involve humans and other animals (zoonoses) and arthropod vectors, the biological and parasitic relations become highly intricate (Coura, 2005).

THE PALEOSCENARIO AND PALEOPATHOCENOSIS

Vectors transmit parasites to their vertebrate hosts during feeding (blood meals or hematophagy). The biological characteristics (anatomical, physiological, and behavioral) of Acari are different from those of Insecta. Distinct biological attributes, including adaptive responses to biotic and abiotic factors in the environment, determine differences between these groups in their epidemiological performance as vectors (Randolph, 1998). The latter

author thus proposes that systems of parasite transmission by vectors that are used for insects should not be applied to mites (and especially not to ticks).

Parasitic strategies display similarities between distant phylogenetic groups – strategies considered in studies of systematics and phylogenetics (Poulin, 1995). However, the spatial distribution (dispersal and diffusion), temporal distribution (seasonality), and density of vectors and susceptible individuals (among other factors) determine the survival and perpetuation of many vectors (during the non-parasitic phase) and thus their success in reaching a new host. The risks of infection to animal and human hosts were and are directly related to their parasitic and vector strategies. Importantly, the establishment of the parasite-host relationship depends on the entire complex ecological dynamics of these hosts (Poulin, 1995; Randolph, 1998; Coura, 2005).

ACAROLGY

Studies on mites and ticks were traditionally included within entomology (the field of biology/zoology that studies insects). However, mites and ticks do not fly. At most, tick larvae perform aeronautism (moving on the wind, i.e., by aeolian force), thus constituting a spatial strategy to guarantee their dissemination and long-distance dispersal. The fact that they are wingless is only one of many differences in relation to insects.

Acarology is thus the field of zoology that studies invertebrate organisms belonging to subclass Acari. These are chelicerates that have an undivided body (idiosoma) – the fusion of the cephalothorax and the abdomen – and the mouthparts forming another set, the gnathosoma or capitulum connected to the idiosoma. Signs of primary segmentation are present in the embryonic phase during metamerization (Oliveira & Serra-Freire, 1994), and can be seen in the post-embryonic phase in the sulci of the exoskeleton (Serra-Freire & Mello, 2006). Three major lineages are accepted: Opilioacariforms, Parasitiforms (the latter constituting the cohort of Parasitiforms Reuter, 1909), and Acariforms, forming the cohort of the same name. The first is considered the most primitive lineage of mites. At present, the members of the other two are important for human and veterinary medicine and are the most extensively studied.

The following are the main classical characteristics used and accepted by most acarologists for purposes of taxonomic identification, and which we find practical and didactic (Flechtmann, 1975; Hickman, Roberts & Larson, 2006; Wooley, 1988; Oliver, 1987 apud Serra-Freire & Mello, 2006; Dunlop & Alberti, 2007; Krantz & Walter, 2007):

- Parasitiform cohort: forms that present respiratory stigmata on the posterior tagma (hysterosoma) and sensory organs on the propodosoma. Ticks and mites are included. Another characteristic that served as the basis for classifying them as superorder Anactinotrichida is the nature of the cuticle, optically inactive, since it does not stain with iodine. This cohort includes the following orders: Opilioacarida Hammen, 1968, the most primitive Acari, which colonize semiarid spaces; Holothyrida Thon, 1909, which are lethal to birds and highly toxic to humans both by contact and when ingested; Ixodida Leach, 1815, which survive and reproduce on the blood they obtain from hosts; and Gamasida Hammen, 1968, which includes parasitic, predatory, and free-living decomposer species.
- Acariform cohort: forms that do not present respiratory stigmata on the hysterosoma, and in which the propodosomal sensory organs either do not exist, or when present, take the form of trichobothria, or more specialized structures such as rhabdomeres. This cohort constitutes the group of mites per se. Under the other systematic classificatory proposal, the group belongs to superorder Actinotrichida, since the cuticle is optically active – staining a yellowish color with iodine. This cohort includes the following orders: Astigmata Canestrini,

1891, which includes the majority of bioagents for scabies in animals and humans; Oribatida Hammen, 1968, including an extremely wide variety of decomposer mites that serve as intermediate hosts to helminth parasites of vertebrates; Actinedida Hammen, 1968, with the widest biological diversity among the Acari, with predatory species, parasites of vertebrates and invertebrates, and free-living species, including many decomposers. Decomposers are important in the energy pyramid because they reinsert energy (that would otherwise have been lost) to recirculate among living beings (Chart 1).

In the acarological literature, the most detailed textbook on Acari taxonomy is *A Manual of Acarology* (Krantz, 1978), which provides classification keys down to the family taxon, including information on their biology, behavior, evolutionary relations, and economic importance. This work has now been replaced by the latest edition, presenting the most recent concepts on the classification of mites (Krantz & Walter, 2009). According to this more recent systematic proposal, for example, the Acariforms are only divided into the orders Prostigmata (= Trombidiforms) and Sarcoptiforms.

Considering the geological time scale (Figure 1), the Acari are an ancient group belonging to the Upper Devonian (390 million years BP). These primitive mites were also considered terrestrial forms and classified as the single species *Protacarus crani* by Hirst in 1923 (Poinar & Poinar, 1998). Studies on the origin and formation of the current groups of Acari show that they probably had Euripterides as their ancestors in the Ordovician period (Serra-Freire 2003), and that ticks appeared on the evolutionary scale at a time that coincided with the evolution of primitive reptiles. Mites and ticks form the largest diversified known group among the Arachnida, with slightly more than 48 thousand species (Harvey, 2002 apud Dunlop & Alberti, 2007). Currently, a list of 889 valid names is proposed for tick genera and species (Barker & Murrell, 2004), although there is no consensus on acarological systematics, and other proposals exist for their taxonomic classification (Horak, Camicas & Keirans, 2002), especially when molecular, biochemical, and numerical systematics are considered, often disconnected from the classical morphological and morphometric taxonomy with biological considerations.

PALEOACAROLOGY

Parasitic infections and diseases that affected populations in the past can be diagnosed and studied by finding parasites, their evolutionary forms and their signs, in human and animal vestiges or remains found in archaeological and paleontological material, as well as in historical documents (Ferreira, Araújo & Confalonieri, 1988; Araújo & Ferreira, 1992). Paleoparasitology, a term proposed by Ferreira, Araújo & Confalonieri (1979), has emerged as a branch of paleopathology (biological and health sciences) and is defined as the study of the parasite finds and their meaning in material from the past (Araújo & Ferreira, 1997).

The specific study of the presence of parasite mites and ticks in ancient material is known as the branch of paleoacarology. By relating Acari finds in prehistoric or historical material to their parasitic biological characteristics and to the ecology of diseases caused by them or with bioagents for which they serve as vectors, one can infer the importance of these arthropods in the epidemiological scenario of the past. Such studies also make an important contribution to reconstruction of the paleofauna, possible ecological models, and the dynamics of existing infections.

Figure 1 – Chronology of animal life with evolution of the Arachnidae, Acari, Ixodida, and Ixodidae related to the evolution of the higher vertebrates

A BRIEF HISTORY

In the historical context, mites and ticks have been known (or at least suspected) since Antiquity. Aristotle (355 BC) coined the term *akari*. In the 16th century, the Latinized term *acari* began to be used, giving rise to the genus called *Acarus siro* by Linnaeus, in 1758, in his *Systema Naturae* (Dunlop & Alberti, 2007).

According to the historical review by Krantz (1978), the existence of parasites with ticks as vectors is suggested by records of a “tick fever” in Egyptian papyri (Ebers Papyrus), dated to 1550 BC (Krantz, 1978; Obenchain & Galum, 1982). This was most likely a rickettsiosis (an infection caused by microorganisms of genus *Rickettsia*), although the pathogen was only observed in tissue smears from ticks several millennia later, when ixodids were identified as the vector in the epidemiological transmission chain for that infectious agent.

One of the first references to ticks is attributed to Homer in 850 BC, when he cited the presence of these ectoparasites on Ulysses’ dog, Argus. Some 500 years later, Aristotle wrote about a mite of locusts (probably *Eutrombidium*), thrombiculid mite larvae, and mites colonizing old beehives in his treatise *De Animalibus Historia Libri*. He was also familiar with ticks of dogs, goats, sheep, and other domestic animals. He further claimed that ticks are generated from “couch grass”.

Other ancient references to Acari appeared in the writings of Hippocrates, Plutarch, Aristophanes, and Pliny. The latter, in 77 AD, in his treatise *Historia Naturalis*, cites an animal that lives off the blood of cattle and dogs, but never of asses. The tick attaches its head to those animals, then swells up and bursts, engorged with its blood meal.

This quote indicates the existence of ticks and characterizes both their feeding habits and possible hosts. Mites and ticks were frequently referred to as “lice”, “beesties”, or “little insects” during the Age of Darkness and Renaissance. The terms *akari* and “mite” appeared around 1650 AD. As mentioned above, Linnaeus used the generic name “Acarus” in the first edition of *Systema Naturae*, using the type *A. siro* in 1758 (Krantz, 1978).

Historically, after the formation of Ixodida on Earth, the evolutionary process maintained its course, and during the Triassic Period, in the Paleocene Age, a major differentiation must have occurred, giving rise to the diversity we know today, as illustrated in Figure 2.

The hypothesis presented in Figure 1 considers the absence of fossil evidence (so far) allowing a phylogenetic evaluation of Arachnida in general or particular. However, there are indications that arachnids were already well represented on Earth since the Middle Paleozoic – during the Devonian or Silurian period (Krantz, 1978). Furthermore, the oldest fossil record of mites, *Protacarus crani* Hirst, dates to this time (440–360 million years). The record further indicates that the greatest adaptive leap in Acari occurred during the Late Mesozoic (146 million years) (evolutionary synergism) and Recent Cenozoic (65 million).

Figure 2 – Evolution of Ixodida from the Paleocene to present, considering their primary origin in trilobites

FOSSIL MATERIAL

Fossil records of insects are found in large numbers, but there are few mite and tick finds in paleozoological studies. Fossils are defined as material remains of ancient living organisms or remains of their activities (ichnofossils or trace fossils, e.g., trails, tracks, coprolites, tubes, perforations). To be considered fossils, organic remains must date to more than 13,000 BP, corresponding to the last glaciation.

Fossilization (chemical and physical modifications that occur over a period of time) is a rare and complex event (less than 1% of situations) that allows the preservation of evidence (remains) of the remote existence of living organisms. The process consists of the substitution of dead organic compounds with other more stable ones like calcite, silica, pyrite, carbon, and others. Usually only the hard parts (trunks, shells, carapaces, bones, and teeth) undergo fossilization.

There are various modes of fossil transformation: unaltered preservation (inclusion in amber), recrystallization (growth of minerals or change in the crystalline structure), replacement or substitution (silicification), permineralization

(filling of pores and cavities with mineral), carbonization, incrustation (covering with a mineral film), molds (casts), or impressions (counter-molds and replicas) (De la Fuente, 2003; Oliveira & Serra-Freire, 2008). More specifically, in relation to unaltered preservation, amber is a fossil resin produced by conifer trees that existed around the Carboniferous Period (Paleozoic Age) – between 280 and 345 million years BP – with the increasing predominance of these plants during the Upper Permian – 250 to 280 million years BP. This fossil resin underwent limited chemical alterations in relation to the original plant resin, and those in the Americas with preserved arthropods vary in age from 15 to 150x10⁶ years. The process occurred over time as follows:

arthropod trapped inside plant resin → resin was buried
 with the arthropod inside → partial polymerization occurred
 in the resin (copal) → terpenes evaporated → amber was formed

The principal tree species that released resins was the group of legumes, especially locust tree (genus *Hymenaea*), which preserved many specimens in amber.

Mites and ticks can also be found in ancient material inside natural cavities (nasal fossae and diverticula, auditory canals), or even on the surface (skin, hairs) of naturally mummified bodies. They can also be found in both the stomach content of mummified animals and in coprolites. Unlike fossils, specimens can be recovered in these conditions in paleontological or archaeological material that dates more recently than the 13,000 years that characterizes fossilization.

PALEOACAROLOGICAL RECORDS

Concerning fossil Acari finds, we present the records in the scientific literature based on the review by Guerra (2002). To date, the latter is the first thesis on the subject in Brazil. The researcher's doctoral dissertation featured an ecological analysis of mites associated with coprolites recovered from an archaeological site in Northeast Brazil. We will also cite other reviews, in addition to more current records, in order to provide an overview of paleoacarology and the meaning of its findings. We opted to present them according to the systematic classification for Acari, i.e., first the paleoacarological records on members of the Parasitiform cohort, followed by the Acariform cohort.

The greatest adaptive advance in Acari occurred during the Late Mesozoic (146 x 10⁶ years) (evolutionary synergism) and Recent Cenozoic (65 x 10⁶ years) (Krantz, 1978). Among the Parasitiforms, various specimens from the orders Holothyrida, Gamasida, and Ixodida were found from the Mesozoic to the Cenozoic, beginning at 245 x 10⁶ years, according to a review article by Krivolutsky & Druk (1986), when dinosaurs, mammals, and modern groups of reptiles and amphibians appeared.

From order Ixodida (ticks), the following finds were recorded, in the reviews by Lane & Poinar Jr. (1986), Guerra (2002), and De la Fuente (2003), shown in Chart 2.

Chart 2 – Fossil tick finds according to taxa, host, stage, origin, and bibliographic reference for the genus

Genus and/or species	Current hosts for genus ^a	Stage/ Sex (Family)	Origin ^b (x 10 ⁶ years)	References
<i>Carios jerseyi</i>	Birds, mammals	Larva (Argasidae)	New Jersey amber (Cretaceous, 90-94)	Klompen & Grimaldi, 2001
<i>Ixodes succineus</i>	Birds, mammals	Female (Ixodidae)	Baltic amber (Tertiary, 35-50)	Weidner, 1964
<i>Ixodes</i> spp.	Birds, mammals	Larva (Ixodidae)	Baltic amber (Tertiary, 35-50)	De la Fuente, 2003
<i>Hyalomma</i> spp.	Mammals, reptiles, birds	Male (Ixodidae)	Baltic amber (Tertiary, 35-50)	De la Fuente, 2003
<i>Amblyomma</i> (<i>A. testudinis</i>)	Reptiles, birds, mammals	Male (Ixodidae)	Dominican amber (Tertiary, 35-50)	Lane & Poinar, 1986
<i>Amblyomma</i> spp.	Amphibians, reptiles, birds, mammals	Larva (Ixodidae)	Dominican amber (Tertiary, 15-40)	Poinar, 1992
<i>Amblyomma</i> spp.	Amphibians, reptiles, birds, mammals	Larva (Ixodidae)	Dominican amber (Tertiary, 15-40)	Amberdepot Inc.
Unknown	Unknown	28 1 st instar larvae (Ixodidae)	Dominican amber (Tertiary, 15-40)	Amberdepot Inc.
<i>Amblyomma</i> spp.	Amphibians, reptiles, birds, mammals	Adult (Ixodidae)	Dominican amber (Tertiary, 15-40)	Amberdepot Inc.
Unknown	Unknown	Adult (Argasidae)	Dominican amber (Tertiary, 15-40)	Amberdepot Inc.
<i>Ornithodoros antiquus</i>	Amphibians, reptiles, birds	Female (Argasidae)	Dominican amber (Tertiary, 15-40)	Poinar, 1995
<i>Ixodes terciarius</i>	Birds, mammals	Not reported (Ixodidae)	Not reported (Tertiary, Oligocene, 30)	De la Fuente, 2003
<i>Dermacentor reticulatus</i>	Mammals	Male (Ixodidae)	Auditory canal of wooly rhinoceros (Tertiary, Pliocene, 2-5)	De la Fuente, 2003
<i>Amblyomma</i> spp.	Amphibians, reptiles, birds, mammals	Larva (Ixodidae)	Felid coprolites (Holocene, 11,000 yrs.)	Guerra et al., 2001; Guerra, 2002
<i>Ixodes</i> spp.	Birds, mammals	Larva (Ixodidae)	Felid coprolites (Holocene, 11,000 yrs.)	Guerra et al., 2001; Guerra, 2002

^a List of hosts from Klompen et al. (1996).

^b Age of amber deposits from Poinar (1992), except for New Jersey amber deposit (Klompen & Grimaldi, 2001).

Source: Adapted from De la Fuente (2003).

Evaluating the impact of the finds listed in Chart 2, we begin by analyzing the finding of *Ornithodoros antiquus*, described by the author, who also found remains of feces and fibrous plant material included in amber (Poinar, 1995). Poinar (1995) emphasized that the material's characteristics, in addition to knowledge of the tick's life cycle, allow suggesting that the host was a rodent. According to the author, these ticks may even have been vectors of spirochetes, considering the current epidemiological models in which many species of genus *Ornithodoros* are vectors of these microorganisms.

The *Carios jerseyi* larva finding (Klomplén & Grimaldi, 2001) does not mention the larval instar of this argasid tick. According to current knowledge on representatives of Argasidae, the larval stage is the only one that remains attached to the host for several days, until engorging. Fasting larvae remain in hiding places in the nests of hosts, mostly Chiroptera mammals, which allows finding various larvae due to the etology of the stage; engorged larvae or those with feeding interrupted by any cause could be isolated and far from the host's nest, even very far away, being transported by the winged host. A more detailed description is needed of the material preserved in the amber together with the tick for a better understanding of the scenario, as done by Poinar (1995).

Guerra et al (2001) and Guerra (2002) found specimens of genera *Amblyomma* and *Ixodes* in felid coprolites from the same archaeological site (Furna do Estrago) in the county of Brejo da Madre de Deus, Pernambuco State, Brazil. They attributed the presence of ixodid ticks in felid coprolites to the animal's predation of tick-parasitized prey. Occupation of the site dates from 11,000 to some 2,000 years BP, during which the archaeological records show the presence of hunter-gatherer groups in the region. In this region, presence of the following wild felids has been described: jaguar (*Panthera onca*), mountain lion (*Puma concolor*), jaguarundi or eyra cat (*Herpailurus yagouaroundi*), and oncilla or little spotted cat (*Leopardus tigrinus*). Also described are animals from the following families: Myrmecophagidae (anteater), Cervidae (deer), Caviidae (capybara, rock cavy, guinea pig), Taiassuidae (peccary), and Echimyidae (spiny rat), all considered prey of those felids.

Most fossil ticks have been recorded in amber from the Baltic or the Dominican Republic, from deposits where the largest number of fossilized specimens have been studied. According to De la Fuente (2003), many pieces of amber containing tick specimens are mined and sold by amber traders, sometimes without allowing correct classification of the inclusions. Numerous ticks may have gone undiscovered because the amber pieces are in the hands of merchants and private collectors, unbeknownst to the scientific community.

The finding of *Dermacentor reticulatus* in the auditory canal of a woolly rhinoceros (Schille, 1916) from 2-5x10⁶ BP is interesting in light of current knowledge on Ixodidae. In relation to the taxonomic position, there are persistent scientific discussions on the validity of the genus. Some experts include it as a subgenus of genus *Dermacentor*. From the morphological point of view, the strong taxonomic character to separate the two genera is the number of aeropiles on the peritrematic plate (Serra-Freire & Mello, 2006). The number has been shown to vary from 6 to 15 in *Anocentor nitens* (Gazeta & Serra-Freire, 1995, 1996; Gazeta et al., 2001), with bilateral asymmetry and the possibility of regional variation and cline formation, while in *Dermacentor* spp. there are always more than two dozen aeropiles. Another difference is the preference for the site of parasitism in the host, which for *A. nitens* is the auditory canal both in equids and felids (Flechtmann, 1975; Amaro et al., 1999), while genus *Dermacentor* displays a preference for non-cavitary areas on the host's skin. Such differences, taxonomic and in parasite etology, can raise the following question: could *A. nitens* descend from *D. reticulatus* in terms of behavior? A possible attempt to answer this question would be studying this fossil's peritrematic plate. In the context of this paleoacarological finding, one intriguing doubt remains: why was only the male tick found in the site?

The conditions in which ixodids (hard ticks) are found in ancient material potentially leads to some epidemiological inferences. Based on the accumulated knowledge from the 19th century to the present, hard ticks do not display nesting habits, i.e., they do not live in hosts' nests, dens, or shelters. Rather, they live in open habitats such as savannahs, forest vegetation, scrub forests, and in the peri- or intradomicile. One exception is genus *Ixodides*, in which some species display nesting behavior, like the argasids (soft ticks), which show nesting behavior, colonizing the nests of hosts.

Finding these ectoparasites indicates the antiquity of parasitism by ticks and the potential for transmission of pathogenic bioagents vectored by them to animals and even to humans. Their presence in modern times helps

understand how the conditions in remote times were favorable and highlights their adaptive capacity. It is thus important to know details of the climatic alterations that took place and thus the characteristics of the modern-day biomass, including vegetation, and their hosts in order reconstruct what happened (the paleoscenario) or still happens for the perpetuation or extinction of species.

In the Acariform cohort, most of the known fossils belong to order Oribatida. Members of this order are not usually associated with other organisms such as other arthropods or vertebrates and humans. The known oribatids are free-living mites and are the most predominant representatives of the edaphic (soil-dwelling) fauna, thus present in forest ecosystems, observed in lichens, humus (facilitating cultivation of the soil), fungi, plants, and as secondary fauna of decomposers. This diversity of habitats and niches in different ecosystems makes them an essential component in recycling energy for the biomass, even in environments in which sunlight contributes less to the energy pyramid (Chart 1). This group's biodiversity is high when compared to Gamasida, Actinedida, and Astigmata mites. Considering their feeding habits, species belonging to Oribatida are different. They are thus classified among the macrophytophagous, microphytophagous, panphytophagous, coprophagous, zoophagous, and necrophagous organisms (Wallwork, 1983).

The review by Krivolutsky & Druk (1986) lists records of oribatids in the Mesozoic (Jurassic and Cretaceous periods), from 208 to 66 million years ago, and in the Cenozoic, Tertiary Period, in the Paleocene, Miocene, and Pleistocene ages, from 66 to 1×10^6 years ago. The review shows the wide diversity and temporal distribution of these mites. Some species died out, while others survived to this day, indicating that this group can be a reference for evolutionary studies of mites. Chart 3 shows the records of mite finds in fossil material.

Chart 3 – Fossil mite finds according to taxa, niche, stage, origin, and bibliographic reference

Mites	Current niche(s)	Stage	Origin	References
Family Anoetidae	Free-living mites	Hypopus	Coprolites from pelvis of mummified body (Nevada, USA)	Radovsky, 1970
Family Acaridae	Free-living mites; parasites of mammals	Tritonymph	Coprolites from pelvis of mummified body (Nevada, USA)	Radovsky, 1970
Family Lardoglyphidae	Free-living mites; stored products	Hypopus	Coprolites from pelvis of mummified body (Nevada, USA)	Radovsky, 1970
Family Cheyletidae	Parasites of carnivorous and herbivorous mammals; predators of arthropods	Adults	Hair and tissues from mummified body (Minas Gerais, Brazil)	Araújo et al., 1986
Order Astigmata	Parasites of vertebrates; free-living mites	Adults and eggs	Desiccated tissues of Peruvian and Aleutian mummies	Kliks, 1988
Family Lardoglyphidae	Free-living mites; stored products	Not mentioned	Intestinal content of North American and Chilean mummies	Baker, 1990
Order Actinedida Family Tarsonemidae	Free-living mites; parasites of vertebrates, invertebrates, and humans	Not mentioned	Coprolites from Furna do Estrago (Pernambuco, Brazil)	Guerra et al., 2001
Order Gamasida	Free-living mites; parasites of vertebrates, invertebrates, and humans	Not mentioned	Coprolites from Furna do Estrago (Pernambuco, Brazil)	Guerra et al., 2001
Order Astigmata Family Atopomelidae	Free-living mites; related to diseases in felids	Not mentioned	Coprolites from Furna do Estrago (Pernambuco, Brazil)	Guerra et al., 2001

Chart 3 – Fossil mite finds according to taxa, niche, stage, origin, and bibliographic reference (continued)

Mites	Current niche(s)	Stage	Origin	References
Order Astigmata Family Acaridae	Free-living mites; parasites of felids, cavies, and humans	Not mentioned	Coprolites from Furna do Estrago (Pernambuco, Brazil)	Guerra et al., 2001
Order Astigmata Family Glycyphagidae	Free-living mites; related to diseases in felids	Not mentioned	Coprolites from Furna do Estrago (Pernambuco, Brazil)	Guerra et al., 2001
Order Astigmata Family Pyroglyphidae	Free-living mites; related to diseases in cavies	Not mentioned	Coprolites from Furna do Estrago (Pernambuco, Brazil)	Guerra et al., 2001
Order Astigmata Anoetidae	Free-living mites; related to diseases in felids	Not mentioned	Coprolites from Furna do Estrago (Pernambuco, Brazil)	Guerra et al., 2001
Order Actinedida Family Tarsonemidae	Free-living mites; related to diseases in felids and deer	Not mentioned	Coprolites from Furna do Estrago (Pernambuco, Brazil)	Guerra et al., 2001
Order Oribatida Family Hypochthoniidae	Free-living mites; related to diseases in felids	Not mentioned	Coprolites from Furna do Estrago (Pernambuco, Brazil)	Guerra et al., 2001
Order Oribatida Family Cosmochthoniidae	Free-living mites; related to diseases in humans and felids	Not mentioned	Coprolites from Furna do Estrago (Pernambuco, Brazil)	Guerra et al., 2001
Order Oribatida Family Ctenacaridae	Free-living mites; related to diseases in felids	Not mentioned	Coprolites from Furna do Estrago (Pernambuco, Brazil)	Guerra et al., 2001
Order Oribatida Family Perlohmanniidae	Free-living mites; related to diseases in felids	Not mentioned	Coprolites from Furna do Estrago (Pernambuco, Brazil)	Guerra et al., 2001
Order Oribatida Family Eutegaeidae	Free-living mites; related to diseases in felids	Not mentioned	Coprolites from Furna do Estrago (Pernambuco, Brazil)	Guerra et al., 2001

Some of records (up to Guerra et al., 2001) are quoted from the review by Guerra (2002). 7

According to Radovsky (1970), mites in the coprolites were probably transported to the feces by coprophilic insects. Anoetid and acarid mites (order Astigmata) display free-living habits and are associated with stored products such as grain, bran, and flour (Serra Freire & Mello, 2006) and can also be swallowed with food and eliminated in the excreta. As for lardoglyphids, based on what is now known of their biology, they reached the body during the advanced stage of desiccation, but before mummification. The presence of these mites suggests that the pelvic region did not remain intact, but it is also possible that they either were ingested or entered the corpse through the anus. Remains of saprophytic arthropods (which feed on dead matter) are frequently found in the intestinal content of mummified human bodies but are not properly recorded (Kliks, 1988). The author goes on to state that they are ancient or recent invaders of dead organic tissues. In the case of lardoglyphid mites found in the intestinal content of the mummies examined by Baker (1990), the researcher states categorically that they were ingested with food, since in the desiccation of the bodies a protein concentrate was found called pemmican (a mixture of meat jerky, raisins, lard, and sugar). Besides the fact that the bodies showed no signs of orifices caused by insects, pemmican is consistent with the feeding preferences of these mites.

The descriptions of mite specimens found by Guerra (2002) and listed in Chart 3 are classified at the family level. For readers interested in species-level descriptions, we suggest directly consulting the researcher's dissertation, since her finds include mites from the family Tarsonemidae (order Actinedida). Representatives of this family are

generally associated with other arthropods (beetles), where the species display phoretic activity, or use arthropods for transportation, or are even parasitoids (parasitizing other parasites). Considering the biology of these mites, we can conclude that finding them in coprolites indicates that they invaded the excreta after defecation.

REFERENCES

- AMARO, A. L. et al. Oite purulenta em *Felis catus* L., 1758 induzida por *Anocentor nitens* (Neumann, 1897). *Entomología y Vectores*, 6: 501-507, 1999.
- ARAÚJO, A. & FERREIRA, L. F. (Orgs.). *Paleopatologia e Paleopidemiologia: estudos multidisciplinares*. Rio de Janeiro: Panorama Ensp, 1992.
- ARAÚJO, A. & FERREIRA, L. F. Homens e parasitos: a contribuição da paleoparasitologia para a questão da origem do homem na América. *Revista da Universidade de São Paulo*, 34: 58-70, 1997.
- ARAÚJO, A. et al. Microscopia de varredura de larvas de ancilostomídeos encontradas em coprólitos humanos datados de 3490 ± 120 a 430 ± 70 anos. In: SIMPÓSIO DE TÉCNICAS ESPECIAIS EM MICROSCOPIA ELETRÔNICA, Caxambu, 1986.
- ARAÚJO, A. et al. Exame parasitológico: mumificações naturais na pré-história brasileira. *Boletim do Museu Paraense Emilio Goeldi, Antropologia*, 1: 32-33, 1986.
- ARAÚJO, A. et al. Parasitism, the diversity of life, and paleoparasitology. *Memórias do Instituto Oswaldo Cruz*, 98, supl. 1: 5-11, 2003.
- BAKER, A. S. Two new species of *Lardoglyphus* Oudemans (Acari: Lardoglyphidae) found in the gut contents of human mummies. *Journal of Stored Product Research*, 26: 139-147, 1990.
- BARKER, S. C. & MURRELL, A. Phylogeny, evolution and historical zoogeography of ticks: a review of recent progress. *Experimental and Applied Acarology*, 28: 55-68, 2002.
- BARKER, S. C. & MURRELL, A. Systematics and evolution of ticks with a list of valid genus and species names. *Parasitology*, 129(supl.): 815-836, 2004.
- BENNER, S. A. et al. Planetary biology: paleontological, geological, and molecular histories of life. *Science*, 296: 863-868, 2002.
- CHANG, S. Planetary environments and the origin of life. *Biology Bulletin*, 196: 308-310, 1999.
- COURA, J. R. *Dinâmica das Doenças Infecciosas e Parasitárias*. Rio de Janeiro: Guanabara Koogan, 2005.
- DE LA FUENTE, J. The fossil record and the origin of ticks (Acari: Parasitiformes: Ixodida). *Experimental and Applied Acarology*, 29: 331-344, 2003.
- DUNLOP, J. A. & ALBERTI, G. The affinities of mites and ticks: a review. *Journal of Zoological Systematics and Evolutionary Research*, 1: 439-469, 2007.
- FERREIRA, L. F. & ARAÚJO, A. Parasitismo, doença parasitária e paleoparasitologia. In: Coura, J. R. *Dinâmica das Doenças Infecciosas e Parasitárias*. Rio de Janeiro: Guanabara Koogan, 2005.
- FERREIRA, L. F.; ARAÚJO, A. & CONFALONIERI, U. Subsídios para a paleoparasitologia do Brasil: parasitos encontrados em coprólitos no município de Unaf, MG. In: CONGRESSO DA SOCIEDADE BRASILEIRA DE PARASITOLOGIA, 5, 1979.
- FERREIRA, L. F.; ARAÚJO, A. & CONFALONIERI, U. *Paleoparasitologia no Brasil*. Rio de Janeiro: PEC/Ensp, 1988.
- FERREIRA, L. F.; REINHARD, K. & ARAÚJO, A. *Paleoparasitologia*. 1 ed. Rio de Janeiro: Editora Fiocruz, 2008.
- FLETCHMANN, C. H. W. *Elementos de Acarologia*. São Paulo: Nobel, 1975.
- FORATTINI, O. P. *Ecologia, Epidemiologia e Sociedade*. São Paulo: Artes Médicas, 2004.
- GAZETA, G. S. & SERRA-FREIRE, N. M. *Anocentor nitens* (Neumann, 1897) na região sudeste do Brasil: constatação da assimetria entre placas peritremáticas e reavaliação do caráter festões. *Revista Brasileira de Medicina Veterinária*, 17: 21-25, 1995.

- GAZETA, G. S. & SERRA-FREIRE, N. M. Reavaliação dos caracteres da placa peritremática para diagnose de *Anocentor nitens* (Neumann, 1897), na região sudeste, Brasil. *Arquivos Brasileiros de Medicina Veterinária e Zootecnia*, 48: 133-140, 1996.
- GAZETA, G. S. et al. Seasonal analysis of the number of aeropiles in *Anocentor nitens* (Neumann, 1897) (Acari: Ixodidae) from the State of Rio de Janeiro, Brazil. *Memórias do Instituto Oswaldo Cruz*, 96: 733-736, 2001.
- GIRIBET, G. & RIBERA, C. A. Review of arthropod phylogeny: new data based on ribosomal DNA sequences and direct character optimization. *Cladistics*, 16: 204-231, 2000.
- GUERRA, R. M. S. N. C. *Análise Ecológica de Ácaros Associados a Coprólitos Provenientes do Sítio Arqueológico da Furna do Estrago, Município do Brejo da Madre de Deus, Estado de Pernambuco, Brasil*, 2002. PhD dissertation, Rio de Janeiro: Instituto Oswaldo Cruz, Fundação Oswaldo Cruz, 2002.
- GUERRA, R. M. S. N. C. et al. Mites associated with coprolites from the archaeological site of Furna do Estrago, Pernambuco state, Brazil. *Entomología y Vectores*, 8: 463-479, 2001.
- HICKMAN, C. P.; ROBERTS, L.S. & LARSON, A. *Integrated Principles of Zoology*. 13th Edition, McGraw-Hill, 2006.
- HORAK, I. G.; CAMICAS, J. L. & KEIRANS, J. E. The Argasidae, Ixodidae and Nuttalliellidae (Acari: Ixodida): a world list of valid tick names. *Experimental and Applied Acarology*, 28: 27-54, 2002.
- KLIKS, M. McK. Paleoparasitological analysis of fecal material of Amerindian (or New World) mummies: evaluation of saprophytic arthropod remains. *Paleopathol News*, 164: 7-11, 1988.
- KLOMPEN, H. & GRIMALDI, D. A. First Mesozoic record of a parasitiform mite: a larval argasid tick in Cretaceous amber (Acari: Ixodida: Argasidae). *Annals of the Entomological Society of America* 94: 10-15, 2001.
- KRANTZ, G. W. *A Manual of Acarology*. 2nd Ed. Corvallis: Oregon State University Press, 1978.
- KRANTZ, G. W. & WALTER, D. E. *A Manual of Acarology*. 3rd Ed. Lubbock: Texas Tech University Press, 2009.
- KRIVOLUTSKY, D. A. & DRUK, A. Y. Fossil oribatid mites. *Annual Review of Entomology*, 31: 533-545, 1986.
- LANE, R. S. & POINAR Jr., G. First fossil tick (Acari: Ixodidae) in New World amber. *International Journal of Acarology*, 12: 75-78, 1986.
- NAVAJAS, M. & FENTON, B. The application of molecular markers in the study of diversity in acarology: a review. *Experimental and Applied Acarology*, 24: 751-774, 2000.
- OBENCHAIN, F. D. & GALUM, R. *Physiology of Ticks*. Oxford: Pergamon Press, 1982.
- OLIVEIRA, H. H. & SERRA-FREIRE, N.M. Embriogênese de *Amblyomma cajennense*. *Revista Entomología y Vectores*, 1: 139-141, 1994.
- POINAR Jr., G. O. *Life in Amber*. Palo Alto: Stanford University Press, 1992.
- POULIN, R. Evolution of parasite life history traits: myths and reality. *Parasitology Today*, 2: 342-345, 1995.
- RADOVSKY, F. Mites associated with coprolites and mummified human remains in Nevada. *Archaeological Research Facility*, 10: 186-190, 1970.
- RANDOLPH, S. E. Ticks are not insects: Consequences of contrasting vector biology for transmission potential. *Parasitology Today*, 14: 186-192, 1998.
- REY, L. *Parasitologia*. Rio de Janeiro: Guanabara Koogan, 2001.
- SERRA-FREIRE, N. M. *Planejamento e Análise de Pesquisas Parasitológicas*. Niterói: Eduff, 2002.
- SERRA-FREIRE, N. M. Considerações sobre o bem-estar animal. In: VALLE, S. & TELLES, J.L. *Bioética e Biorrisco: Abordagem transdisciplinar*. Rio de Janeiro: Interciência, 2003.
- SERRA-FREIRE, N. M. & MELLO, R. P. *Entomologia e Acarologia na Medicina Veterinária*. Rio de Janeiro: L.F. Livros, 2006.
- WALLWORK, J. A. Oribatids in forest ecosystems. *Annual Review of Entomology*, 28: 109-130 1983.

- WEIDNER, H. Eine Zecke, *Ixodes succineus* sp. n., im Baltischen Bernstein. *Veröff Überseemuseum, Bremen*, 3: 143-151, 1964.
- WEYGOLDT, P. Evolution and systematics of the Chelicerata. *Experimental and Applied Acarology*, 22: 63-79, 1998.
- WHEELER, W. C. & HAYASHI, C. Y. The phylogeny of the extant chelicerate orders. *Cladistics*, 14: 173-192, 1998.
- WOOLEY, T. A. *Acarology: mites and human welfare*. New York: Wiley, 1988.
- ZELMER, D. A. An evolutionary definition of parasitism. *International Journal for Parasitology*, 28: 532-533, 1998.