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First Global Survey of Evidences the Ichnogenus *Osedacoides* and it Relates to the Rezent Zombie-Worms *Osedax*

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Abstract- In this paper, I present the first global overview of the members of fossil ichnotaxon *Osedacoides* and it recent relatives of the morphogenus *Osedax*. Close on 15 years ago those worms were found on sea floor fallen whalebones that dissolve last recyclers in the food chain to the bone [25]. Before that time it was simply technically not possible to observe a whale carcass over a longer period of time and to study the dynamics of the submarine carcasse- societies. Probably the *Osedacoides* do not specialize in whales, but they did also in past geological ages already been feasting on carcasses, as boreholes show in fossils. The main focus of this work is on the fossil evidences.

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I. Introduction

The Recent osteophagous marine "Zombie- worm" morphogenus *Osedax* (Polychaeta) was originally discovered in 2002 with two species on the ocean bottom in a depth of approximately, 2.800 m in bones of whales where it produces borings, by now, a dozen are described. Up to now it was believed that it co-evolved with the whales, the source of its preferred diet [8,10]. The cetacean size did not determine the whale-fall communities [25]. In the meantime it could be also experimentally cultivated in cattle bones [13]. This fact as well as the reconstructed molecular clock back to at least the Cretaceous period led to the conclusion that *Osedax* originally might have infested fish or marine "reptiles" long before the marine Mammalia evolved [3,15]. In spite of the fact that the borings most probably were produced by an organism similar to *Osedax* there is no direct evidence that it was the genus *Osedax* itself. There are only ichnofossils known, but not body remains of the animal. A definite assignment of the borings to a particular body-based taxon (morphotaxon) is impossible. In agreement with Bromley [2] the name of the Recent morphospecies *Osedax* should no more be used for fossil borings in vertebrate bones [15], therefore they prefers to establish a new ichnotaxon *Osedacoides* for these fossils, and follows Bromley [2] who proposed not to use the names of the animals but to establish ichnotaxa for borings in hard substrates, even if the producers (like for example Bivalvia or Bryozoa) can be largely ascertained by their typical morphology. Bromley [2] used the ichnogenus *Trypanites* Mägdefrau, [20] as an example, which he defined as simple shaft- or pocket-like borings with a single opening whose producer is not incontestably known. Based upon his revised diagnosis, and calibrated by its type ichnospecies *Trypanites weisei* Mägdefrau, ("Simple, unbranched borings in hard substrate with a single opening to the surface") *Trypanites* can now be generally used in a wider sense for such borings. The principal difference between the two ichnotaxa is: *Trypanites* is mostly in inorganic substrates, *Osedacoides* exclusively in organic substrates (Fig. 1-C). Accorging Muniz et al. [24] the morphology of *Trypanites ionasi* exhibits a proximal, cylindrical, smooth-walled portion of the fossil boring with the deeper, enlarged and more irregular portion may have accommodated the bulbous root-structure. These are features of *Osedacoides* [14]. In compare, Furlong et al. [5] describes a high diversity of biota and low diversity, but high abundance, of borings is present along a modern *Trypanites*-type ichnofacies (Fig. 1-A). Species richness reaches 37 organisms within the study area, and two boring bivalves (*Petricola pholadiformis* and *Zirfaea pilsbryi*), which produce *Gastrochaenolites*-like traces (Fig. 1-B). *Trypanites* isp. seems to descend from cemented strata directly to crocodilian remains also, which occur in massive sandstone bodies [9,28].

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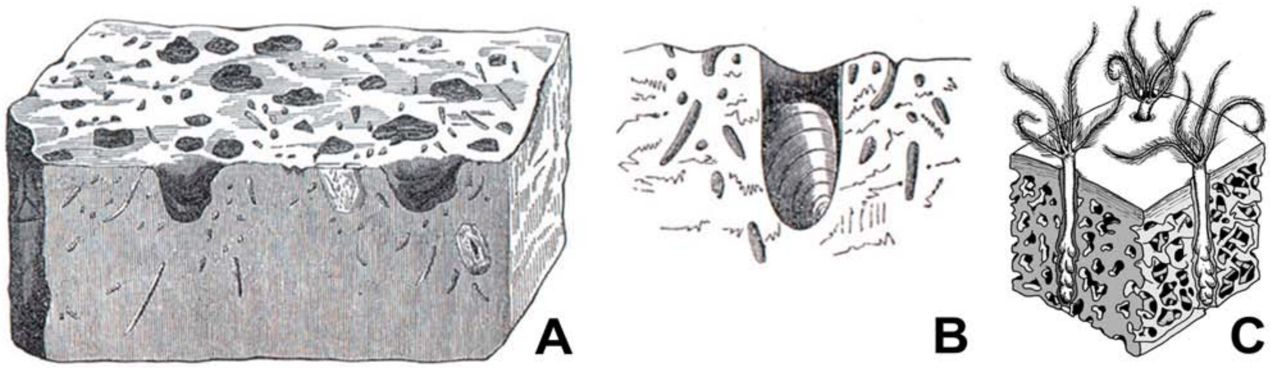

Figure 1 : A - *Trypanites*, B - *Gastrochaenolites*, Jurassic rocky-shore trace fossils from England according De La Beche [5], C - *Osedacoides*, Pliocene whalebone according Muniz et al. [23]

II. Relations between *Osedax* Like Borings and Ichnofossils

Systematics: Kingdom Animalia, Phylum Annelida, Class Polychaeta, Order Sabellida, Family Siboglinidae, Morphogenus *Osedax* Rouse et al., 2004, Type species *Osedax rubiplumus* Rouse, Goffredi & Vrijenhoek, 2004.

Osedax rubiplumus is a species of bathypelagic Polychaetes that is reported to sustain itself on the bones of falling whales. Their paedomorphic males are 0.4–1.1 millimeters (0.016–0.043 in), and have an incomplete prototroch with a posterior hooked chaete [26]. The species have 16 hooks with 6-8 capitium teeth, which have handles that are 18–23 micrometers (0.00071–0.00091 in). The female ovisac is measured 8 mm by 4 mm by 0.3 mm, with four posterior roots, which have spherical lobes. They also have a trunk, which is 3.8 centimeters (1.5 in) in length and 2 millimeters (0.079 in) wide with the crown plumes, which are 2.1 centimeters (0.83 in) in length. The species is found in East North Pacific where it is abundant. They are used in Calmodulin (CaM, an abbreviation for calcium-modulated protein), a calcium-binding messenger protein expressed in all eukaryotic cells [27]. Higgs et al. [10] published modern *Osedax* traces and also used CT scans to construct 3d models of the borings, and reported borings that were roughly similar to that reported by Kiel et al. [15,18,19,20]. Higgs et al. [10] further found that the borings were mostly restricted to dense cortical bone, generally avoiding lipid-rich cancellous zones. Apparently some isotopic evidence suggests that *Osedax* synthesizes collagen rather than lipids, although other studies have documented *Osedax* in Japanese waters that subsist on blubber in spermaceti [10,11,12]. The hitherto described and named *Osedacoides* ichnofossils are:

a) *Ichnogenus Osedacoides Karl, Brauckmann & Groening, 2012*

LSIDurn:lsid:zoobank.org:act:527977AE-F51F-436D-81AC-A7F75E924913

Type ichnospecies: *Osedacoides jurassicus* Karl, Brauckmann & Groening, 2012

Etymology: Osedacoides = *Osedax*-like.

Diagnosis: Simple, basally thickened to branched borings in marine vertebrate bones with a single opening to the surface.

b) *Osedacoides jurassicus Karl, Groening & Brauckmann 2012*

LSIDurn:lsid:zoobank.org:act:371B736C-4E88-4F88-9CDA-E01C46143FB4

Holotype: Geozentrum Göttingen-GZG.V.773-34: Borings in hyoplastron sin. (Maack [21]: plate 35, fig. 35 = original of *Stylemys lindenensis*, now: *Tropidemys seebachi*, pl. 2 figs. 3-4, pl. 3-4) [19].

Etymology: jurassicus = Jurassic, the type stratum.

Locality: Lindener Berg, Hanover, Lower Saxony, Germany.

Horizon: Middle Kimmeridgian, Late Jurassic.

Dascription: Average diameter of openings 1 - 3, 5 mm, mode of life in groups.

c) *Osedacoides cretaceous Karl & Niehuys 2012*

LSIDurn:lsid:zoobank.org:act:377D8C46-93CF-4451-A57E-1C6D1BF70C0C

Holotype: BGR- Federal Institute for Geology and Minerals- LBEG Hanover, Germany, leg. and coll. Mosbach, 1915, old no. Gr.A.24 no. 8: One boring in peripheral plate of *Ctenochelys stenopurus* described by Karl & Niehuys [14] at their page 174 (4) and illustrated at plate 4, fig. 1- 4).

Etymology: cretaceous = Cretaceous, the type stratum.

Locality: Alsen quarry in Lägerdorf near Itzehoe, 30 m (TK 25: 2123 Lägerdorf), Germany.

Horizon: Lägerdorf-Formation, Chalk Group (Schreibkreide- Gruppe), Untercampanian-Obersantonian, Upper Cretaceous (Lithostratigraphic units of Germany ID: 2008074).

Description: Average diameter of opening = 10, 5x 10, 1 mm, inner diameter = 15, 5 mm and deep = 19, 5 mm (pl. 4 fig. 4), single mode of life.

d) *Osedacoides ionasi (Muniz, de Gibert & Esperante 2010)*

LSID urn:lsid:zoobank.org:pub:A3A8A74F-4C5F-40DF-B3BD-F2A3B76CD19C (under work)

Original ichnospecies: *Trypanites ionasi* Muniz, de Gibert & Esperante 2010

Holotype: Muniz et al. 2010: 271, figure 2: Arrows in A and B indicate the specimen selected as the holotype.

Etymology: ionasi = from the name Jonas.

Locality: Almería, Spain.

Horizon: Middle platform, lower Pliocene.

Description: Average diameter of opening 0.9 mm, inner diameter 1.9 mm and deep 40 mm, mode of life in groups.

III. Cladistic Analysis

Character coding

1 - life in anorganic substrate= 0, or organic substrate= 1; 2 - single mode of life= 0, or mode of life in groups= 1; 3 - diameter of openings and inner diameter lesser than 10 mm= 0, or more than 10 mm= 1; 4 - inner diameter slightly larger than opening= 0, or significantly larger than opening= 1; 5 - deep equal to or slightly greater than the greatest diameter= 0, or more times greater= 1.

Data matrix

*T.weisei*00001,*O. jurassicus*11001, *O.cretaceous*10110, *O.ionasi*11011

The character differentiation with DOLMOVE (Interactive Dollo and Polymorphism Parsimony by JOSEPH FELSENSTEIN, 1986a) shows a simple tree: (O. ionasi,(O. cretaceous,O. jurassicus,T. weisei))) this calculated with PARS (Discrete character parsimony algorithm, version 3.6a3 by JOSEPH FELSENSTEIN, 1986b) is conform with that. Two most parsimonious trees found: (O. cretaceous:2.50,(O. ionasi:0.50, O. jurassicus:0.50):1.00, T. weisei:1.50)[0.5000];

((O. ionasi:0.50, O. cretaceous:2.50):1.00, O. jurassicus:0.50, T. weisei:1.50)[0.5000]; that are clear specific differentiation in the genus Osedacoides. Two most parsimonious tree found and requires a total of 6.000 in tree A (fig. 2-A)

between	and	length
1	*cretaceous*	2.50
1	2	1.00
2	*ionasi*	0.50
2	*jurassicus*	0.50
1	*weisei*	1.50

Also requires a total of 6.000 in tree B (fig. 2-B)

between	and	length
1	2	1.00
2	*ionasi*	0.50
2	*cretaceous*	2.50
1	*jurassicus*	0.50
1	*weisei*	1.50

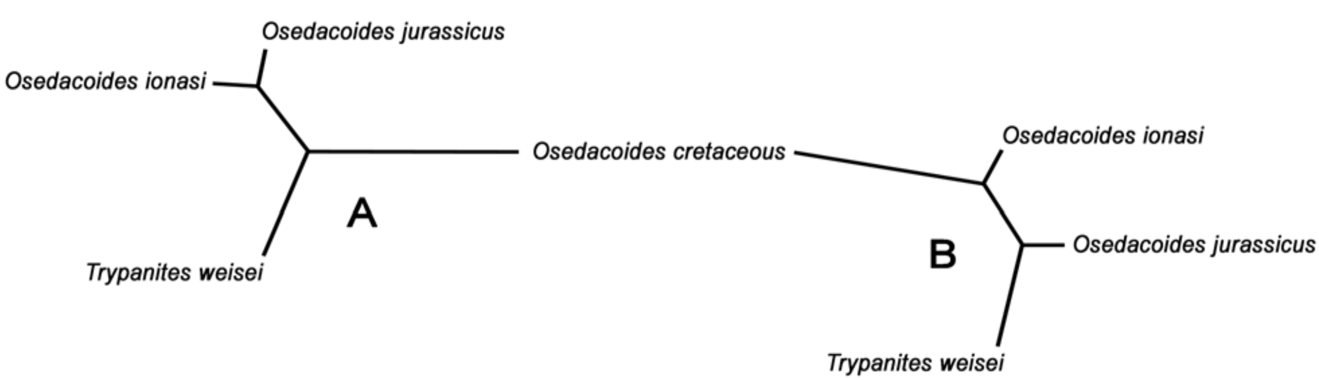

Figure 2 : Cladogram of the hitherto described *Osedacoides* ichnospecies) made with TreeView©Roderic Page. A - Unrooted tree A shows a larger distance of *O. jonasi* and O. *jurassicus* to *O. cretaceous*; B - Tree B construction of the same calculation by PARS shows a larger distance of *O. jonasi* and *O. cretaceous* to *O. jurassicus*.

IV. Results

A shell remain of the quite recently re-discovered type material of the upper Jurassic turtle *Tropidemys seebachi* Portis, 1878 was covered by borings of presumed marine "worms" similar to the Recent *Osedax* for which the new ichnotaxon *Osedacoides jurassicus* was introduced. One another turtle shell remain, a peripheral plate of the upper Cretaceous *Ctenochelys stenoporus* shows a boring of *Osedacoides cretaceous*, which differs to the type species *Osedacoides jurassicus* with the larger dimensions and the single mode of life. An overview of the corresponding fossil ichnofossils hitherto known is given here:

Age	Horizon	Ichnotaxon	Source	Material
Neogene	Pliocene	*Osedacoides ionasi*	[14,23]	whalebones
		undescribed	[12]	whalebones
	Miocene	undescribed	[1]	whalebones
Palaeogene	Oligocene	undescribed	[19]	whalebone and teeth fishbone
		undescribed	[18]	whalebones
		undescribed	[19]	birdbones
Upper Cretaceous	Cenomanian	*Osedacoides cretaceous*	[14,16]	sea turtlebones
		undescribed	[3]	sea turtlebones
Early Cretaceous	Albian	undescribed	[3]	plesiosaurbones
Late Jurassic	Kimmeridgian	*Osedacoides jurassicus*	[14,15]	sea turtlebones
	Oxfordian	undescribed	[3]	ichthyosaurbones

The examination of the Late Jurassic *Osedacoides jurassicus* by Karl et al. [15] shows that *Osedax*-like marine animals lived even much earlier. This would be another strong reference to the fact that the specialization on whalebones evolved secondarily and a long time later. Additionally, the occurrence of *Osedax*-like animals in the Late Jurassic epicontinental sea in North Germany shows that such organisms were originally not restricted to the deep-sea. This is supported by the discovery of a third recent species in 2005, which fed on whalebones in a depth of about 120 m. As osteophagous polychaetes *Osedax* belongs to the decomposing animals among the carcass feeders. As a detritus feeder *Osedax* might not have been closely adapted to particular hosts like a true parasite. *Osedacoides ionasi* from the Pliocene of Spain may represent the first trace-fossil evidence of an *Osedax*-like behavior in whalebones. The first record in bones of birds [19] proves that *Osedax* evidently feed upon penguin-like diving birds. As already mentioned the environmental reconstruction of the Lägerdorf Formation shows pelagic sediments of an open epicontinental sea with 100-150 m water depth. Recent *Osedax*- species fed on whalebones in a depth of about 120 m, but the occurrence of *Osedax*-like animals in the Late Jurassic epicontinental sea in North Germany shows that such organisms were originally not restricted to the deep-sea [15]. The deeper marine areas were not the habitat of the turtles alive. These are only post mortem dropped to the ground. The bones were fragmented before their embedding. The surfaces of all bones showing erosions, which are typical for necrophages animals, such as cancers, echinoderms, worms, snails, mussels or lampreys. One bone fragment shows bite marks. Also fossil traces of *Osedax* like borings from Late Cretaceous plesiosaur and sea turtle bones reports of Danise & Higgs [3], and from early Cretaceous by Danise et al. [6] from ichthyosaur bones.

V. Acknowledgement

My friend and brother Mike Schuster I thank for the correction of English final version.

VI. Phylogenetic Programs

I. Felsenstein, J. (1986a): PHYLIP/ DOLMOVE-Interactive Dollo and Polymorphism Parsimony © Copyright 1986-2002 by the University of Washington.
II. Felsenstein, J. (1986b): PHYLIP/ PARS-Discrete character parsimony © Copyright 1986-2000 by the University of Washington.
III. TreeView©Roderic Page

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