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Italy, the Cradle of Ichnology: the legacy of Aldrovandi and Leonardo

Andrea BAUCON

Geopark Naturtejo Meseta Meridional. Geology and Paleontology Office, Centro Cultural Raiano, Av. Joaquim Morão 6060-101 Idanha-a-Nova, Portugal
E-mail: *andrea@tracemaker.com*
Web reference: www.tracemaker.com

SUMMARY - *Italy, the Cradle of Ichnology: the legacy of Aldrovandi and Leonardo* - During the 19th century the Italian ichnological heritage inspired the interest of many prominent paleontologists such as Villa, Meneghini, Massalongo, Peruzzi, Sacco, Gabelli. These pioneers of Ichnology focused on trace fossils and established some of the major ichnological celebrities: *Zoophycos*, *Paleodictyon*, *Lorenzinia*, *Taprhelminthopsis*, *Alcyonidiopsis*, *Urohelminthoida* and *Paleomeandron.* However, the Italian ichnoheritage has been source of scientific curiosity since the 16th century. One of the leading intellectuals of the Renaissance – Ulisse Aldrovandi – devoted part of his studies to trace fossils. In fact, Aldrovandi's *Musaeum Metallicum* includes a theory about bioerosion and magnificent illustrations of *Cosmorhaphe* and *Gastrochaenolites.* The ichnological investigations of Aldrovandi came at a critical point of scientific thought, during the early stages of development of the scientific method. And Aldrovandi was not an isolated case; even Leonardo da Vinci gave attention to trace fossils: the painter of the Mona Lisa described bioerosional and biodepositional structures and used them for paleoenvironmental reconstitutions. Moreover, Leonardo's and Aldrovandi's ichnological investigations fit within the same milieu as other contemporary intellectuals such as Bauhin and Gesner. Consequently, the Renaissance must be considered a critical step in the study of trace fossils, and an "Age of Naturalists" can be erected as a crucial stage of the history of Ichnology.

RIASSUNTO - *L'Italia, la culla dell'Icnologia: l'eredità di Aldrovandi e Leonardo* - Durante il diciannovesimo secolo il patrimonio icnologico italiano ha ispirato l'interesse di molti paleontologi come Villa, Meneghini, Massalongo, Peruzzi, Sacco, Gabelli. Questi pionieri dell'Icnologia hanno istituito alcune delle maggiori celebrità icnologiche: *Zoophycos*, *Paleodictyon*, *Lorenzinia*, *Taprhelminthopsis*, *Alcyonidiopsis*, *Urohelminthoida* e *Paleomeandron.* Tuttavia, il patrimonio icnologico italiano è stato oggetto di interesse almeno dal sedicesimo secolo. Uno dei principali intellettuali del Rinascimento – Ulisse Aldrovandi – ha, infatti, dedicato parte dei suoi studi alle tracce fossili. Il *Musaeum Metallicum* di Aldrovandi include una teoria sulla bioerosione e contiene magnifiche illustrazioni di *Cosmorhaphe* e *Gastrochaenolites.* Le ricerche icnologiche di Aldrovandi sono avvenute in un momento critico della storia del pensiero, ossia durante la nascita del metodo scientifico. Aldrovandi non è un caso isolato: anche Leonardo da Vinci ha dedicato la sua attenzione alle tracce fossili. Infatti, il pittore della Mona Lisa ha descritto strutture bioerosionali e biodeposizionali, valendosene per ricostruzioni paleoambientali. Altri intellettuali rinascimentali – ad esempio Bauhin e Gesner – hanno prestato attenzione alle tracce fossili, inserendosi così nello stesso scenario intellettuale di Leonardo e Aldrovandi. Di conseguenza, il Rinascimento va considerato una tappa cruciale nello studio delle tracce fossili, e l'"Età dei Naturalisti" può essere considerata un'epoca fondamentale nella storia dell'Icnologia.

Key words: History of Ichnology, Renaissance, Ulisse Aldrovandi, Leonardo da Vinci, *Cosmorhaphe*, *Gastrochaenolites*
Parole chiave: Storia dell'Icnologia, Rinascimento, Ulisse Aldrovandi, Leonardo da Vinci, *Cosmorhaphe*, *Gastrochaenolites*

1. THE SCIENTIFIC ROOTS OF ICHNOLOGY IN ITALY

Ichnology is considered a relatively young scientific discipline, though trace fossils are largely mentioned in folklore and popular culture (Mayor 2000; Mayor & Sarjeant 2001; Mietto *et al.* 2003; Neto de Carvalho & Cachão 2005), but only in the 19th century Ichnology emerged as a scientific discipline. The second decade of the 19th century saw the first scientific works on tetrapod footprints, beginning with the studies of William Buckland on a trackway donated by Reverend Henry Duncan (Duncan 1831; Winkler 1886; Sarjeant 1987; Mayor & Sarjeant 2001). Shortly afterwards, Sickler (1834) and Kaup (1835) focused their attention on *Chirotherium.* The discovery of the "Noah's Raven" trackway (actually a dinosaur trackway; Lockley 2002) dates back to the same period, as well as the famous Hitchcock's studies on New England Ichnology (Hitchcock 1836, 1858; Pemberton *et al.* 2007a). The 19th century is also generally held as the beginning of scientific studies on invertebrate traces. In his historical review of Ichnology, Osgood (1970) distinguished three stages, the first of which he named the "Age of Fucoids". During this period, a botanical interpretation was given to trace fossils: the term *Fucoides* associated marine algae to ichnofossils (e.g. Heer 1877; for more detailed information, see Osgood 1970, 1975; Häntzschel 1975; Pemberton *et al.* 2007b). The "Age of Fucoids" began with the work of Adolphe Brongniart (1823, 1828) (Pemberton *et al.* 2007b; Osgood 1970), who named *Fucoides* (= *Chondrites) targionii* for an Italian, Targioni-Tozzetti (Brongniart 1828). Targioni-Tozzetti did not publish his findings, but provided Brongniart material from Italy to work on. Some other prominent examples of the "Age of Fucoids" come from the Italian peninsula, where the term "fucoide" was commonly used during the 19th century in geological literature (e.g., Pasini 1831; Cossa & Taramelli 1839; Pilla 1845; Pareto *et al.* 1846; Bombicci 1881). The widespread use of the term "fucoide" left a notable legacy: in fact still nowadays there are stratigraphical units named after fucoids (i.e. the "Marne a Fucoidi" Formation). "Fucoids" are also cited by the paleontologist Antonio Stoppani, one of the founding fathers of Italian Geology; in addition to fucoids, the author took into account *Chondrites* and *Zoophycos* (Stoppani 1857). The term "fucoid" appears not only in technical, scientific papers, but also in geographical guides: Molossi (1834) described "limestones with fucoids" in his guide to the geography, demography, major monuments and parish churches of the Parma area. This approach followed in Issel's Science for Travellers (Istruzioni Scientifiche per Viaggiatori, Issel 1881) which described fucoids as ancient vegetal remains. The aforementioned works represent a preliminary insight into geotourism, highlighting, at the same time, the importance of the Italian ichnoheritage. In fact, during the "Age of Fucoids", the Alps and the Appennines were a major source of inspiration for many paleontologists dealing with trace fossils. For instance, Lyell and Murchison both visited Italy to confer with local geologists and see Italian outcrops. This supports the contention that Italians were doing noteworthy research from the start of modern Geology and Ichnology.

The Italian ichnologic heritage (Fig. 1) was the object of attention for two prominent 19th century scientists, Antonio Villa and Abramo Massalongo, whose works had enormous impact on modern Ichnology. Their names are intimately linked with the ichnogenus *Zoophycos*, described by Villa (1844; see Olivero 2007) and established by Massalongo in 1855. Massalongo (1856) instituted the ichnogenus *Alcyonidiopsis* as well.

Another important contributor to Ichnology was Giuseppe Meneghini. He established ichnogenus *Paleodictyon* (in Murchison 1850) which also received significant attention by another Italian geoscientist, Peruzzi (1881).

Meneghini collaborated with another geoscientist, Paolo Savi, and instituted the ichnospecies *Scolicia strozzii.* In Savi & Meneghini (1850) *Scolicia* was described as *Nemertilites*; this term left a considerable heritage in Italian geological literature (e.g. "*Nemertiliti*" is found in Ponzi 1862; Bombicci 1881; Sacco 1888; Caterini 1925). According to the historical review of Osgood (1970), the beginning of the end for the Age of Fucoids came in 1881 with the neoichnological experiments of Nathorst (1881), highlighting the similari-

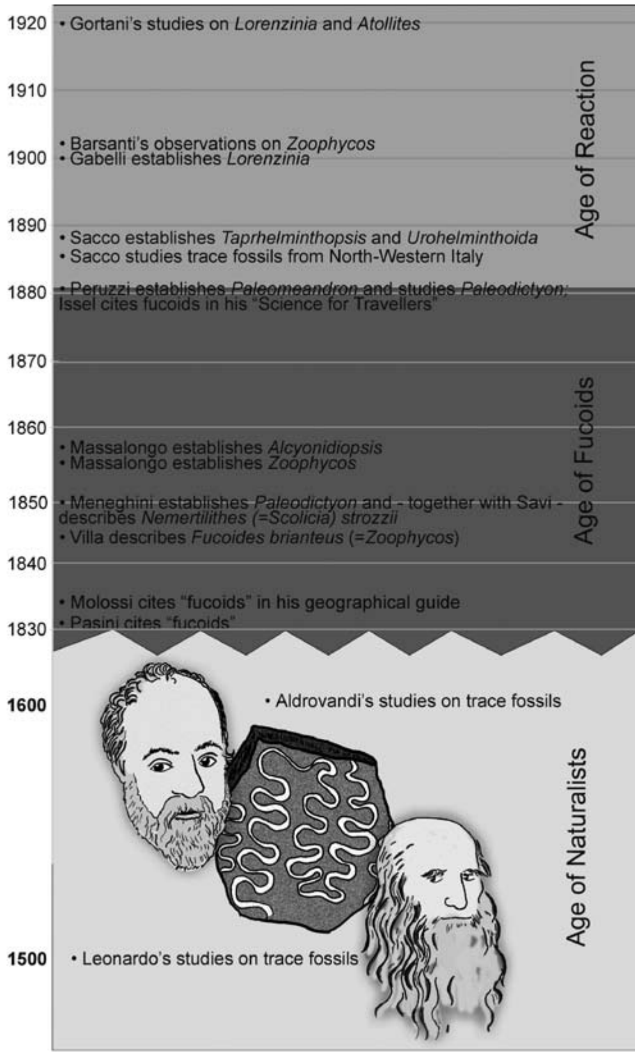

Fig. 1 - Major steps in the history of Italian Ichnology. Together with Osgood's (1970) Ages of Ichnology, the Age of Naturalists is here proposed (chapter 5.2.). For this reason, particular evidence is given to the figures of Leonardo and Aldrovandi. Concerning the chronology of the Age of Naturalists: Leonardo's ichnological studies date back to the end of the 1400s, when some peasants brought him some trace fossils during his work on the Horse of Milan (as described in Leonardo's Leicester Codex). Aldrovandi's *Musaeum Metallicum* includes observations on trace fossils, but the book was published posthumously. It is probable that Aldrovandi studied trace fossils some years before his death, which occurred in 1605.

Fig. 1 - Eventi principali nella storia dell'Icnologia italiana. Accanto alle Età dell'Icnologia di Osgood (1970), è qui proposta l'Età dei Naturalisti (capitolo 5.2.). Per questo motivo, particolare rilievo è dato alle figure di Leonardo e Aldovandi. Per quanto riguarda la cronologia dell'Età dei Naturalisti, gli studi icnologici di Leonardo risalgono alla fine del '400, quando alcuni villici portarono al naturalista alcune tracce fossili, durante la realizzazione del Cavallo di Milano (come descritto nel Codice Leicester). Il Musaeum Metallicum *di Aldrovandi include osservazioni sulle tracce fossili, ma il libro fu pubblicato postumo. È probabile che Aldrovandi si sia occupato di tracce fossili alcuni anni prima della sua morte, avvenuta nel 1605.*

ties between "fucoids" and various kinds of recent traces, and kicking off Osgood's "Age of Reaction" (Cadée & Goldring 2007). In Italy, the transition between botanical and ichnological interpretations of fucoids was gradual.

Still, in 1902 Barsanti described *Zoophycos* as vegetal remains (Barsanti 1902; Sacco 1886, 1888 and Squinabol 1890 also considered *Zoophycos* as seaweed).

The end of the 19th century saw important contributions by Federico Sacco, author of Contributions to Italian Paleoichnology (Sacco 1888). Sacco established the ichnogenera *Taphrelminthopsis* and *Urohelminthoida*, and took into consideration numerous trace fossils from Northwest Italy (Sacco 1886). Other noteworthy works on Ichnology were those of Peruzzi (1881) and Gabelli (1900), respectively establishing *Paleomeandron* and *Lorenzinia.* Senofonte Squinabol (1890) described *Zoophycos insignis.* In more recent times, Gortani (1920) studied *Lorenzinia* and *Atollites* from Flysch deposits.

The aforementioned examples indicate Italy as one of the cradles of invertebrate Ichnology (see also Serpagli 2005), with particular respect to the 19th century, the dawn of the scientific study of trace fossils.

The present work takes into account events before the dawn of the origins of Ichnology: the study of trace fossils during the Italian Renaissance, exemplified by the naturalist Ulisse Aldrovandi. Who was Ulisse Aldrovandi?

2. ULISSE ALDROVANDI: A MAN OF THE RENAISSANCE

2.1. Aldrovandi and Natural Sciences

The 16th century was a period of renewal for science, stimulated by the brilliant studies of Leonardo da Vinci and inspired by Galileo Galilei, one of the founding fathers of the modern scientific method. The figure of Ulisse Aldrovandi is situated – chronologically and intellectually – between Leonardo and Galileo: Aldrovandi is a true son of his time, the Italian Renaissance, when great minds pursued universal knowledge (cf. Olmi 1976).

The amplitude of Aldrovandi's interests is reflected in his juvenile curiosity, expressed in Aldrovandi's own words: "*essendo io spinto dal dessiderio insin dalla mia prima età di sapere*" ("being desirous of knowledge from early childhood"; Aldrovandi 1572). The ideal of "universal knowledge" that was typical of the Renaissance is mirrored in the *cursus studiorum* of Aldrovandi. At university, Aldrovandi studied humanities, law, mathematics, medicine and philosophy.

Aldrovandi wrote about his all-encompassing education in his *Discorso Naturale* (Aldrovandi 1572): "*havendo atteso alli principi necessarii delle scientie et, con ogni diligenza, alle polite et belle lettere et dopo il studio delle lettere humane, fondamenti certissimi et solidissimi d'ogni disciplina, et per conseglio de gli miei parenti […] mi diedi alli faticosi studii delle leggi*" ("having acquired an education in science and literature, and a solid grounding in every discipline, I followed my parents' advice and took up the study of law").

In 1549 Aldrovandi was accused of heresy; although he recanted, he underwent house arrest until 1550. During this period of semicaptivity, Aldrovandi deepened his knowledge for the natural sciences and arts.

As mentioned above, Aldrovandi's work covered a wide range of subjects, but where he proved most prolific is in the Natural Sciences (Fig. 2). Aldrovandi focused on Zoology, with a treatise on birds (Aldrovandi 1599), snakes and other animals, on "bloodless" animals, and on insects (Aldrovandi 1606). Aldrovandi demonstrated also a profound interest in Botany, as evidenced by his attractive illustrations of plants (reprinted by Biancastella *et al.* 2003). Illustration has a particular value for Aldrovandi, as testified by his eye-catching watercolour woodcuts (recently reprinted by Alessandrini & Ceregato 2007).

Aldrovandi himself pronounced on the importance of illustration in Natural Sciences: "to understand plants and animals there is no better way than to depict them from life" ("*in verità non si puol' fare più bella impresa, per venire in cognitione di queste piante et animali diversi, che depingerli vivamente*"; Aldrovandi 1572). Aldrovandi expressly declared his dedication to drawing: "*non voglio già tacere me stesso, che sopra modo di queste pitture varie mi sono dilettato*" ("I cannot conceal that I have dedicated much time to drawing", Aldrovandi 1572).

Illustration and research represented an immense volume of work even for the all-encompassing naturalist, who admitted to have often commissioned the illustrations to other painters ("*E' ben vero che, per non dare impedimento alli miei studii, ho avuto pittori appresso di me continuamente*") ("in order not to interrupt my studies, I have had many painters work for me", Aldrovandi 1572).

Monstruorum Historia contains some of the most impressive illustrations of Aldrovandi's work: these woodcuts are picturing "monstrua", or wonders of nature, which express Aldrovandi's desire to collect and describe all he could find that was amazing or unusual in nature (Fig. 3).

2.2. Aldrovandi's method

> "*...non iscrivendo cosa alcuna che co' propri occhi io non habbi veduto e con le mani toccato et fattone l'anatomia...*"
> "...writing only about what I have seen with my own eyes and touched with my own hands, and examined both externally and internally..."
> (Aldrovandi 1572)

The above cited words from Aldrovandi's *Discorso Naturale* show the innovative approach of the Italian naturalist. Aldrovandi pointed out the importance of direct experience. He admonished Aristotle for not having personally verified data (Aldrovandi 1572; see also Pattaro 1981). This corresponds to a critical position with respect to the classical au-

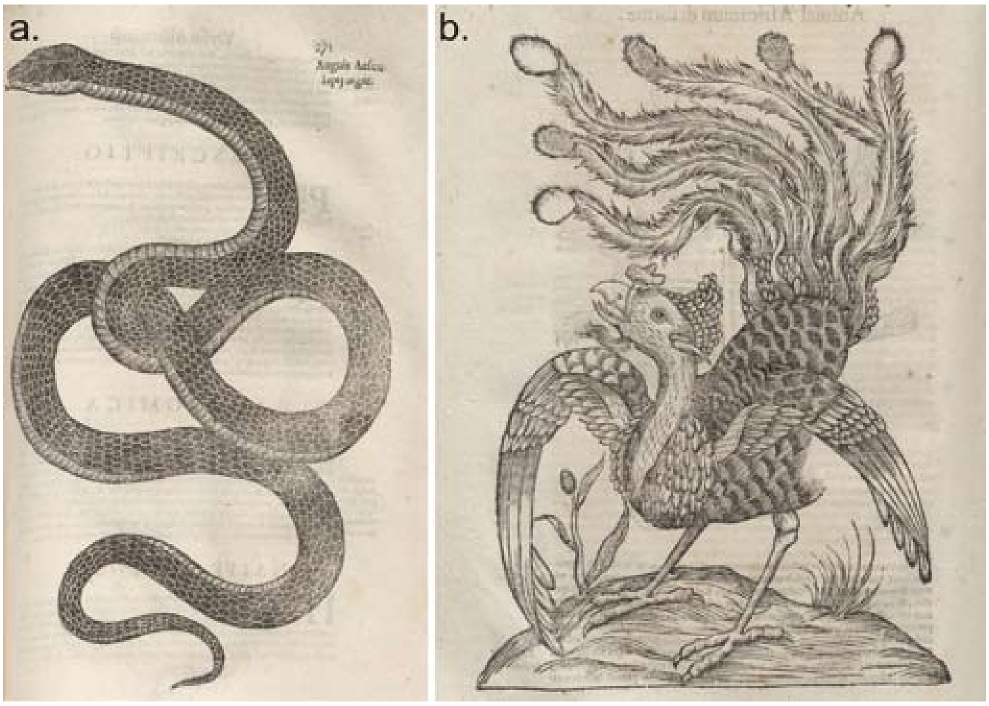

Fig. 2 - Aldrovandi, philosopher of Nature. a. Aldrovandi presents a marked interest for the Natural Sciences. More in particular, he is attracted by herpetology, as proved by his *Serpentem et Draconem*. b.This magnificent plate demonstrate the notable artistic value of Aldrovandi's work.

Fig. 3 - Aldrovandi, filosofo naturale. a. Aldrovandi dimostra un marcato interesse per le Scienze Naturali. In particolare è attratto dall'erpetologia, come mostra il suo Serpentem et Draconem. *b. Questa magnifica illustrazione dimostra il notevole valore artistico dell'opera aldrovandiana.*

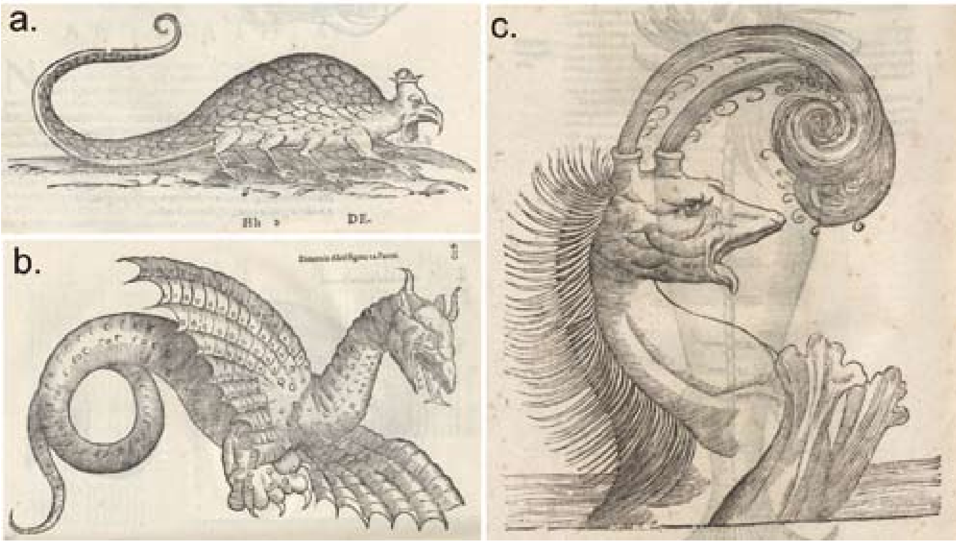

Fig. 3 - Selection of Aldrovandi's "monstrua". a. Basilisk, a legendary creature common in European bestiaries. It was said to cause death with a single glance. b. Dragon. c. Marine creature, probably inspired by marine mammals.

Fig. 3 - Alcuni dei "monstrua" di Aldrovandi. a. Basilisco, creatura leggendaria comune nei bestiari europei. Si diceva che potesse uccidere con un solo sguardo. b. Dragone. c. Creatura marina, probabilmente ispirata ai cetacei.

thors and represents an element of scientific renewal. Nevertheless, Aldrovandi frequently demonstrated the failure of his own method: classical authors are the basis for many of his observations, and scientific remarks are often intermixed with encyclopedism and pure erudition.

Aldrovandi's approach may appear contradictory to modern-day scientists (e.g. Fig. 4), but Cassirer (1967) and Olmi (1976) note that during the 16th century the old and the new were mutually interpenetrating. As a consequence, the reader must be elastic when approaching Aldrovandi, and

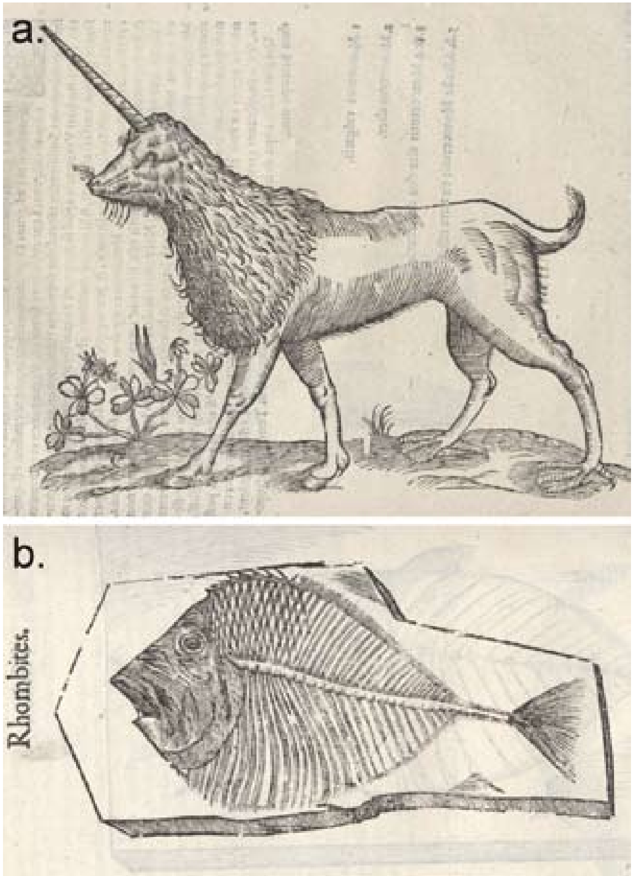

Fig. 4 - In Aldrovandi scientific notions and mythology interpenetrate. a. Unicorn-like creature illustrated in Aldrovandi's work. b. Aldrovandi illustrates in detail many body fossils such as this fish.

Fig. 4 - In Aldrovandi nozioni scientifiche e mito si interpenetrano. a. Creatura simile ad unicorno, illustrata nell'opera di Aldrovandi. b. Allo stesso tempo Aldrovandi illustra in dettaglio diversi fossili, come questo pesce.

abandon excessively rigid interpretations. Aldrovandi must be given credit for predicting several aspects of the Galilean revolution, although sustaining scientifically backward notions. In Aldrovandi's work the new and the old are not fully independent of each other: Ulisse Aldrovandi is between Leonardo and Galileo along the ideal line of continuity linking the culture of the Middle Ages to that of the Renaissance (Olmi 1976).

3. ALDROVANDI'S *MUSAEUM METALLICUM*

3.1. Aldrovandi, founding father of Geology

Aldrovandi's approach can be largely found in his *Musaeum Metallicum* (Aldrovandi 1648), which constitutes the author's most extensive work in geo-palaeontology. The *Musaeum Metallicum* portrays hundreds of minerals and body fossils with detailed descriptions and superb illustrations (Fig. 5).

Thanks to the *Musaeum Metallicum*, science historians are well aware of Aldrovandi's studies on body fossils, but – until now – his work on trace fossils has never been explored. In fact, together with body fossils, Aldrovandi describes a good number of trace fossils in the *Musaeum Metallicum*, presenting his own theories on their origin and depicting such ichnological celebrities as *Gastrochaenolites* and *Cosmorhaphe*. For these reasons, *Musaeum Metallicum* can be considered as one of the most obscure yet captivating chapters in the history of Ichnology.

The title *Musaeum Metallicum* was not chosen by Aldrovandi himself but by Bartolomeo Ambrosini, the book's editor. *Musaeum Metallicum* was published posthumously, like most of Aldrovandi's works. Ambrosini made a number of changes, starting from the title (see Marabini *et al*. 2003 and Alessandrini & Ceregato 2007).

The book was entitled originally *De Fossilibus*, which refers to *fossilia*, meaning objects excavated underground: minerals, rocks and fossils.

The term *fossilia* is also found together with the first appearance of the word "Geology": "*& anco la Giologia, ovvero de Fossilibus*" (and also Geology, that is, [the Science] of things found underground") (Aldrovandi 1603).

Not only did Aldrovandi study *fossilia*, but he also coined the word Geology itself. This is a fundamental legacy left us by Ulisse Aldrovandi: "Geology" was formulated by him as he drew up his will (Aldrovandi 1603; see Vai & Cavazza 2003; Vai & Caldwell 2006).

Geology is deep-rooted in the *Musaeum Metallicum*, which presents a very systematic organization of arguments. The layout of the *Musaeum Metallicum* presents a taxonomical purpose and it corresponds – for all practical purposes – to a classification. This fact is confirmed by Sarti (2003), who compared Aldrovandi's systematic approach to that of Linnaeus.

Each book of the *Musaeum Metallicum* corresponds to a definite group of *fossilia*: metals, soils, petrified fluids, rocks (Tab. 1). Each book is divided into chapters devoted to a particular "family" of *fossilia* and contains several "species" of fossils and minerals. For instance, book IV, *De lapidibus* (on rocks), comprises the chapter *De Glossopetra* ("on tongue-stones", actually fossilized shark teeth) divided into *Glossopetrae denticulatae* ("denticulate tongue-stones") and *non denticulatae* ("non-denticulate tongue-stones").

Aldrovandi's *Historia Fossilium* (unpublished, but partly reproduced in Marabini *et al.* 2003) contains an analogous classification, probably inspired by Dioscorides and Agricola (Marabini *et al*. 2003).

Nevertheless, it should be noted that the author cannot be considered to be fully progressive. Although Aldrovandi's classification presents innovative elements, at the same time his approach reflects the erudition and encyclopedism that were characteristic of 16th century scholars.

Aldrovandi's "double outlook" – facing forward and

Tab. 1 - The *Musaeum Metallicum* comprises four books divided in chapters, with each chapter presenting various "differentiae" of *fossilia*. This layout corresponds, for all practical purposes, to a classification. The table shows a few examples of chapters and "differentiae".
Tab. 1 - Il Musaeum Metallicum *è costituito da quattro libri divisi in capitoli, e ogni capitolo presenta varie "differentiae" di* fossilia. *Questa organizzazione corrisponde ad una vera e propria classificazione. La tabella mostra solo alcuni esempi di capitoli e "differentiae".*

Liber (Book)	Capitulum (chapter)	Differentiae ("species")
I. De Metallis (metals)	De Aere (copper)	Aes nativum figurae pangoniae (faceted native copper) Aes Corynthium figuratum (copper sculpture from Corynth)
	De Argento (silver)	Argentum Trichites sive capillare ("Trichites" silver, that is, "hairy") Argentum purum nativum (pure native silver)
	De Ferro (iron)	Ferrum in Magnetem conversum (magnetized iron) Siderammonites ("iron" ammonite)
II. De Terra (clays)	De Terra figlina, et Argilla (terracotta and clay)	Argilla candida (white clay) Vasa figlina Lusitanica adversus venena (Portuguese pottery against poisons)
	De Terra creta nuncupata ("creta" clay)	Creta Mauritana ("creta" clay from Mauritania) Creta Syriaca […] ("creta" clay from Syria)
	De Ochra (ochre clay)	Genus crustosum (encrusting variety [of ochre clay]) Veronensis ([ochre clay] from Verona)
III. De Succis Concretis (petrified fluids)	De Sale (salt)	Stiriae salis (salt icicles) Spumae salis (salt "foams")
	De Bitumine (tar)	Durum (solid [tar]) Liquidum (liquid [tar])
	De Succino, seu Electro (amber)	Succinum colore vini falernii in forma annuli redactum (amber, with the colour of wine and shaped as a ring) Succino figurae cordis (heart-shaped amber)
IV. De lapidibus (rocks)	De Lapide Arenario (sandstone)	Durus (hard [sandstone]) Mollis (soft [sandstone])
	De Glossopetra (tongue-like-stones)	Glossopetra denticulata (denticulate tongue- stone) Glossopetrae non denticulatae (non-denticulate tongue- stones)
	De Marmore (marble)	Marmor Dendrites (marble with dendrites) Marmo Cynites (marble with dog-like stains)

backward at the same time – can be found also in the interpretation of body fossils. The origin of body fossils is discussed in the *Musaeum Metallicum*: Aldrovandi observes that fossils show no trace of viscera, and argues for an inorganic origin. Aldrovandi believes that fossils are formed by fluids circulating within rocks, natural curiosities imitating the organic world. For instance, ammonites are named *Ophiomorphites* or "snake-shaped stones" (Fig. 6a); the "generative" approach is reflected by the specimen described as a "rock pregnant with a shell" (Fig. 5a). Although Aldrovandi supports the inorganic origin of fossils, he often compares them to existing animals. He calls some kind of fossilised fish "*Rhombites*", or "(stone) resembling a flatfish" (Fig. 4b).

Although Aldrovandi bases his theory on his own observation (the lack of petrified viscera), his interpretation is a move back from the more accurate intuitions of previous authors (i.e. Leonardo and Taletes).

Aldrovandi appears to put aside his inorganic theory when considering fossilized mammal teeth: he refers expli-

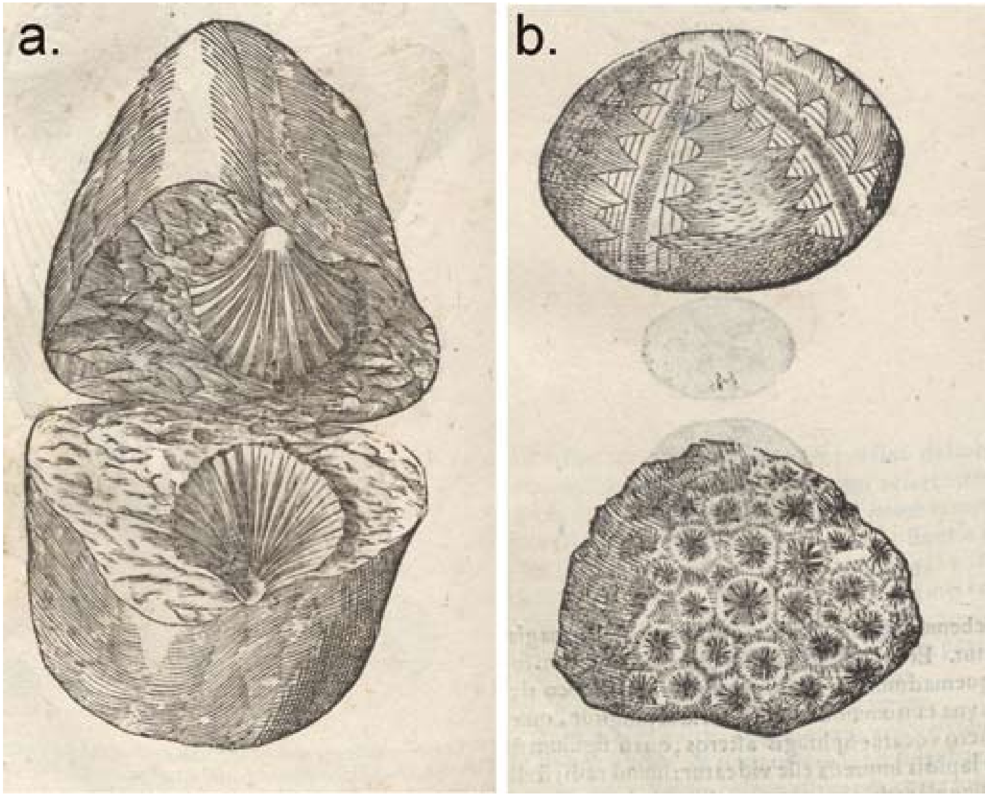

Fig. 5 - Selection of body fossils from the *Musaeum Metallicum.* a. Aldrovandi describes this specimen as a "Rock pregnant with a shell". b. Aldrovandi describes such fossils as "Astroitis", referring to the star-like morphology of certain echinoderms and corals.
Fig. 5 - Alcuni fossili del Musaeum Metallicum*. a. Aldrovandi descrive questo campione come "roccia in cinta di conchiglia". b. Aldrovandi chiama "Astroitis" alcuni echinodermi e coralli, riferendosi alla loro morfologia stellata.*

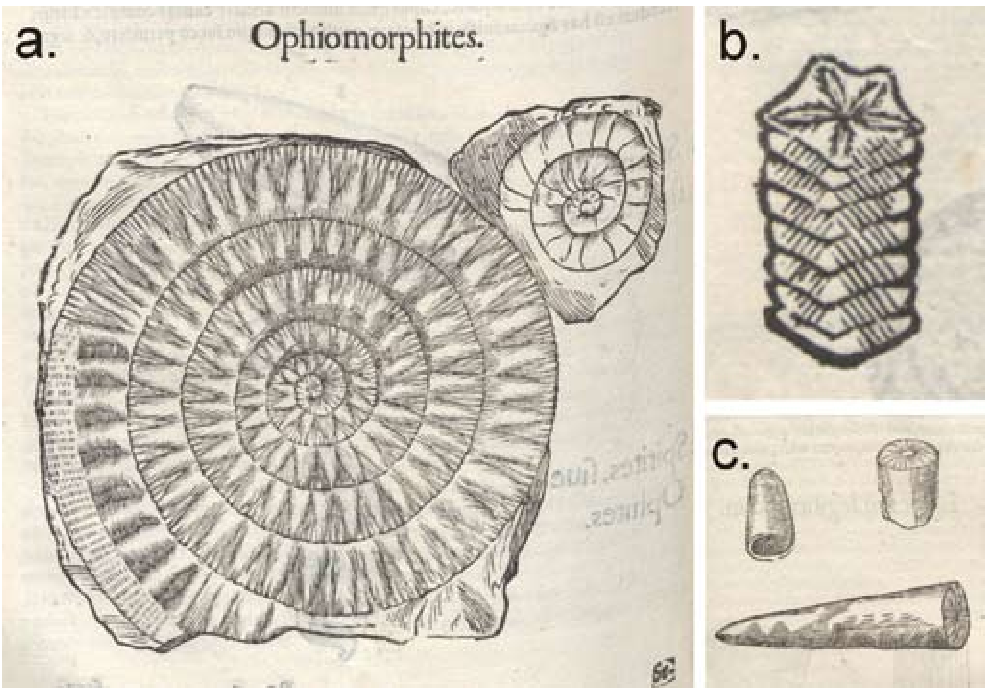

Fig. 6 - Body fossils of the *Musaeum Metallicum*: ammonites, crinoids, belemnites. a. "Ophiomorphites", or "snake-like stones" is the term used by Aldrovandi to deal with ammonites. b. Crinoid, defined as "Astroitis" (see Fig. 5b). c. Belemnites.
Fig. 6 - Fossili del Musaeum Metallicum*:* ammoniti, crinoidi, belemniti. *a. "Ophiomorphites", o rocciaserpente, termine usato da Aldrovandi per descrivere le ammoniti. b. Crinoide, definito come "Astroitis" (vedi Fig. 5b). c. Belemniti.*

citly of "petrifaction" ("*Tabella cum dente Belluae petrificato*"), as well as in the case of fossilized teeth of *Hippopotamus amphibus* (Aldrovandi 1648, p. 828: "*Tabella represantat dentes […] lapideos Elephanti*").

4. TRACE FOSSILS OF THE MUSAEUM METALLICUM

4.1. Introduction

As mentioned above, Aldrovandi's *Musaeum Metallicum* contains some of the first scientific representations of trace fossils. Aldrovandi's ichnological studies are historically important because they occur at a critical time in the development of scientific thought: the modern scientific method was in its early stages of development when Aldrovandi was dealing with trace and body fossils.

The superlative quality of the iconographic documentation and the detailed descriptions permit detailed analysis of the ichnofossils of the *Musaeum Metallicum* and, in some cases, even the ichnogeneric identification.

4.2. Gastrochaenolites and other bioerosional structures

> "*Erat […] passim sinubus diversae magnitudinis excavatus*";
> "[a rock] pitted here and there by hollows of varying size"
> (Aldrovandi 1648)

The specimen presented as "*Silicem dactylitem*" is described as a rock presenting "hollows" of varied diameter. The description is accompanied by an attractive illustration (Fig. 7) showing clearly the morphology of the "hollows": they are circular to elliptical in cross-section, and they extend obliquely, possibly with a clavate terminus. The "hollows" clearly resemble bioerosional structures; moreover, the major morphological features (circular to elliptical cross-section, oblique extension, and clavate shape) are consistent with the diagnosis of ichnogenus *Gastrochaenolites* (see Häntzschel 1975).

The detailed description given by Aldrovandi confirms this interpretation. In fact the name of the specimen – "*Silicem dactylitem*" – comes from "*Dactyli*" ("fingers", "nails"), a genus of lithophagous bivalves (Pholas; see Plinio, Naturalis Historia, IX, 87: "*Concharum e genere sunt dactyli ab humanorum unguium similitudine appellati*"; "belonging also to the class of shell-fish is the dactylus, that is so called from its strong resemblance to the human nails").

Aldrovandi is even more precise, and prosaically compares the structures to bioerosional borings: he describes the "hollows" as "resembling the cavities in which Pholads seek shelter" ("*qui imitabantur illas cavitates, in quibus Dactyli animantes delitescere solent*", Aldrovandi 1648). There is no doubt that the author explicitly refers to borings.

Fig. 7 - *Gastrochaenolites,* as figured in Aldrovandi's *Musaeum Metallicum.* The Latin caption refers to two varieties of "chert" (see text for the "chert problem"), that is, the figured specimen and the one reported in figure 8.

Fig. 7 - *Esemplare di* Gastrochaenolites *raffigurato nel* Musaeum Metallicum *di Aldrovandi. La didascalia in latino si riferisce a due varietà di "selce" (vedi testo), una delle quali è presentata in figura 8.*

In addition to these elements, it can be hypothesised that the specimen is a trace fossil (and not a recent example of bioerosion) because Aldrovandi indicates the provenance as near "a Valley called Valdense, in the territory of Siena" ("*perhibetur in Valley nuncupata Valdense Agri Senensis*").

The specimen's (supposed) lithology offers some problematic questions. In fact Aldrovandi refers the specimen to s*ilex*, that is, chert. The presence of bioerosional structures on what is apparently a flint pebble is somehow problematic, but a solution is found by examining Aldrovandi's collections. In fact some of the specimens described in the *Musaeum Metallicum* as "*silex*" are still preserved in the collections of Palazzo Poggi (Bologna). These specimens (*Silex quodammodo fungiformis*, p. 727; *Silex ex alveo Rheni Bonionensi*, p. 739; *Tabella cum novem Silicum differentijs*, p. 729) are actually limestone pebbles (Sarti 2003). Similarly, *silex qui expressam a Natura crucem fert pulcherrimam* (Aldrovandi 1648: 735) corresponds to a polished serpentine pebble (Sarti 2003). Together with these lithologies, a "true" chert nodule is found (*Silex referens Impilium, genus tegumenti pedis*; Aldrovandi 1648, p. 740).

These examples shows how loosely Aldrovandi applies the term "*silex*", using it also to describe certain limestone lithotypes. In conclusion, the bioeroded specimen is not made of chert but, in all likelihood, limestone.

"*Silicem dactylitem*" is not the only bioerosional structure described in the *Musaeum Metallicum.*

In fact Aldrovandi deals extensively with bioerosion in Chapter L of the *Musaeum Metallicum*, entitled "*De Lapide Pholadis*". The chapter addresses the theoretical bases of bioerosion: it is evident right from the title that Aldrovandi devoted this chapter to the study of rocks with pholads.

Aldrovandi's encyclopedism comes out when describing Pholads: he elucidates the etymology of Pholad, a name of Greek derivation associated with the idea of "hiding" or "living inside a shelter" ("*Nam f. Graecis latere, vel in latebris degere significat*"). Pholads are defined by Aldrovandi as "little animals of the bivalve genus" ("*animacula de genus bivalvium*") and the author strictly connects them to the term "latere", which means to hide oneself. This term is used to point out precise animal strategies, that conceal themselves and avoid hostile environments. Aldrovandi even explains why animals hide inside "*latebrae*". According to the Italian naturalist, the organisms use "*latebrae*" to avoid hostile environments, for example, cold weather ("*frigoris*").

Aldrovandi explains that these strategies are common to pholads and many other animals.

According to Aldrovandi's interpretation, "birds, reptiles, bears and other animals" ("*aves, reptilia, ursae, et aliae animantes*") habitually find shelter in "latebrae" – dens or lairs. The term "*latebra*" includes not only structures actively excavated by animals, but also natural shelters (structures not actively dug out by organisms, for example the cave where a bear might spend the winter).

By Aldrovandi's words: "*sub terra, vel in saxis excavatis, vel aliis latibulis [...] occultantur*".

("shelters dug into the soil, excavated into the rocks, and other kinds of refuges"). This interpretation shows that Aldrovandi is making a distinction between bioturbational and bioerosional structures: burrows ("*sub terra*") and borings ("*in saxis excavatis*").

4.3. Cosmorhaphe

"*erat variijs tenijs obliquis insignitus*"
"presented varied and curving stripes"
Aldrovandi (1648, p. 730)

The words above are used by Aldrovandi to describe an unbranched structure with two regular orders of meanders. The description and the illustration are both consistent with a convex relief; in all probability isooriented lineation and sole marks are present (Fig. 8).

The morphology of the structure fully meets the diagnosis of ichnogenus *Cosmorhaphe*, which is usually preserved as convex hyporeliefs with two regular orders of meanders (Häntzschel 1975; Seilacher 1977).

The structure considered here is presented together with the previously described "*Silicem dactylitem*" (= *Gastrochaenolites*): Aldrovandi describes the figure with the specimens as "*Quinta tabella monstrat duas pulcherrimas Silicis differentias*" ("the fifth plate shows two beautiful varieties of chert").

As explained above, Aldrovandi includes in term "*silex*" (literally, "chert") various lithologies such as limestone, serpentinite, and "true" chert. Therefore it is convenient to hypothesise that the considered specimen is not attributable to a siliceous lithotype but more likely constitutes a carbonate or siliciclastic rock.

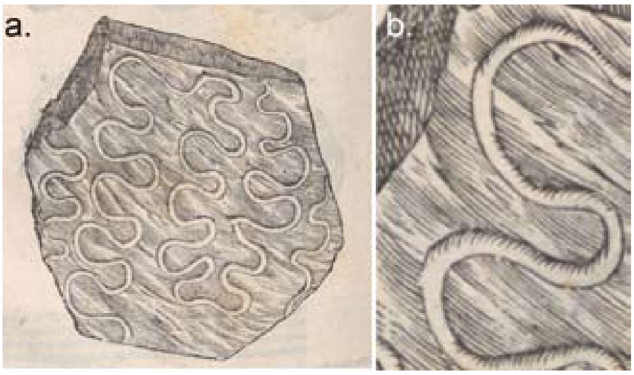

Fig. 8 - *Cosmorhaphe.* a. *Cosmorhaphe*, described by Aldrovandi as snake-like structure. b. Detail, showing the extreme attention to structure.
Fig. 8 - Cosmorhaphe. *a.* Cosmorhaphe, *descritta da Aldrovandi come struttura ad imitazione di serpente. b. Particolare, che illustra l'estrema attenzione per il dettaglio.*

When describing the structure, Aldrovandi refers to curving stripes "*quae prorsus figures Serpentum aemulabantur*" ("that resemble snake figures"). The use of "*aemulare*" ("to imitate") suggests that Aldrovandi interprets *Cosmorhaphe* as a mere natural curiosity imitating the sinuous curves of a snake. This fact recollects the inorganic origin of body fossils proposed by Aldrovandi himself.

The comparison with snakes has some interesting point of contact with popular culture: snakes are frequently used to describe meandering or winding trace fossils. For instance, the ichnogenus *Cruziana* is commonly associated with snakes. For centuries the inhabitants of Penha Garcia (Portugal) have described *Cruziana* as "*cobras*" – snakes – and some shepherds are afraid of them (Eddy Chambino, pers. com.). Similarly, the structure found in Milreu (Portugal) is described as "*bicha pintada*" – painted snake – but in reality is a big, winding *Cruziana* (Neto de Carvalho & Cachão 2005).

4.4. "Fragmentary Burrows" (Thalassinoides?; Planolites/Palaeophycus?)

"*Observatur etiam in rerum natura quidam lapis trunci alicuius arboris speciem exprimens, & duritia ferrum aemulans*"
"In nature we also find a stone that resembles the trunk of a tree and shows the hardness of iron"
(Aldrovandi 1648)

These words are used by Aldrovandi to describe "*Stelechites*", a term etymologically connected to trunk-like morphologies (Aldrovandi 1648). The plate corresponding to "*Stelechites*" shows straight, subcylindrical structures (Fig. 9a) which can be still seen in the Aldrovandi collections at

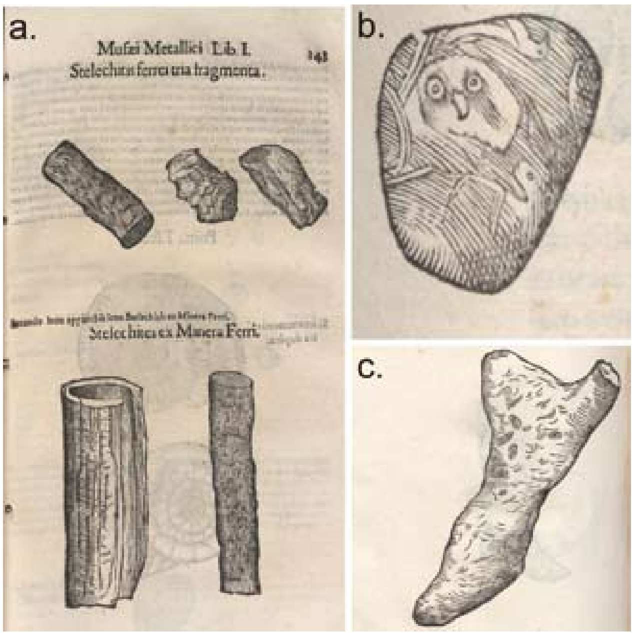

Fig. 9 - Other specimen of the *Musaeum Metallicum* resembling trace fossils. a. "*Stelechites*", possibly fragmentary burrows. b. Branched figures whose colour is different from that of the enclosing rock: Bauhin (1600) used the same style to illustrate a specimen of *Phymatoderma* (Seilacher 2007). c. "Foot-like structure", possibly *Thalassinoides.*

Fig. 9 - Altre possibili tracce fossili del Musaeum Metallicum. *a. "*Stelechite*s", probabilmente tracce fossili in frammenti. b. Figure ramificate con il colore diverso dalla roccia incassante: Bauhin (1600) usò la stessa tecnica per raffigurare* Phymatoderma *(Seilacher 2007). c. "Struttura a forma di piede", forse* Thalassinoides.

Palazzo Poggi (Bologna). Sarti (2003) described the specimens as blackish structures, characterized by a lighter core. The specimens are of problematic interpretation. There are no certain elements indicating their biogenic nature and they are completely unlinked from their original geologic context.

Nevertheless, the most plausible hypothesis is the ichnological one: "*Stelechites*" seem to represent fragmentary burrows, and no evidence to the contrary has emerged. In his revision of Aldrovandi's collection, Sarti (2003) confirms this hypothesis by interpreting "*Stelechites*" as trace fossils.

Possibly "*Stelechites*" are corresponding to unbranched burrows (i.e. *Planolites* or *Palaeophycus*); conversely, they could be part of an originally branched structure (e.g., *Thalassinoides*), which could be implicitly expressed by the etymology of "*Stelechites*".

4.5. Other structures

Rocks with figurative elements are often illustrated in Aldrovandi's *Musaeum Metallicum*: animals and monsters are depicted with different colour from the enclosing rock (Fig. 9b). Bauhin (1600) applies an analogous style to exemplify *Phymatoderma:* intricate angelic figures contrast with the darker matrix of the rock (Seilacher 2007: 142-143).

Consequently, it can be hypothesised that Aldrovandi represented branched trace fossils whose fill chromatically contrasts with the matrix (i.e. *Chondrites*). Similarly as in Bauhin (1600), the appendages of the creatures may represent the branching of trace fossils. However, the "figured stones" of the *Musaeum Metallicum* have to be discussed on a cautionary basis. The illustrator may have represented other structures such as bioclasts or post-diagenetical alterations.

Moreover, the case of Bauhin fleshes out Aldrovandi's intellectual environment. In fact, Bauhin's illustrations stand out as an important step in the history of Ichnology. As Seilacher (2007) rightly points out, the work of Bauhin (1598, 1600) includes some of the earliest illustrations and comments on trace fossils.

5. ALDROVANDI, LEONARDO, BAUHIN: PIONEERS OF ICHNOLOGY

5.1. Trace fossils in Leonardo's Leicester Codex

"*Come nelle falde, infra l'una e l'altra si trovano ancora gli andamenti delli lombrici, che caminavano infra esse quando non erano ancora asciutte.*"
"Among one and another rock layer, there are still the traces of the worms that crawled in them when they were not yet dry."
Leonardo da Vinci, Leicester Codex, folio 10 v.

The above quotation demonstrates that Aldrovandi and Bauhin were not the only naturalists dealing with trace fossils. In fact, one of the major figures of the Renaissance – none other than Leonardo da Vinci – focused several times on trace fossils.

Leonardo's literary labours were continuously maintained during his life and travels: according to Richter (1970), they had been carried out since he was 37 up to his death (1519). Leonardo's notes cover an enormous range of subjects including the arts, literature, science, philosophy and anatomy.

This all-encompassing knowledge is mirrored in his artistic works. He is regarded as one of the major painters of all time, and his works include masterpieces such as the Annunciation, the Virgin of the Rocks, the Last Supper, Mona Lisa.

Furthermore, Leonardo's manuscripts provide an exceptional insight into his scientific thought; in particular the Leicester Codex contains some of his major scientific observations, including comments on trace fossils.

Intriguingly, the ichnological observations of Leonardo are given as a complement to his theory on marine body fossils. The discussion, presented in vernacular Italian, considers "the shells that are seen nowadays within the territory of Italy, far from the sea and at such heights" ("*li nichi, che per li confini d'Italia, lontano da li mari, in tanta altezza si vegghino alli nostri tempi*").

In the Leicester Codex, Leonardo proposes a remarkably modern theory on body fossils. For Leonardo, marine shells found on the mountains once corresponded to living animals, which have been "petrified" together with marine sediments. To quote Leonardo's own words: "*Come tutti li fanghi marini ritengano ancora de' nicchi, ed è petrificato il nicchio insieme col fango*" ("All the marine muds still contain shells, and the shells are petrified together with the mud").

Moreover, Leonardo da Vinci addresses his arguments against the Flood hypothesis, which states that marine fossils were transported to the mountains by the biblical Deluge. In fact, one of the major questions formulated by natural philosophers was, "Why are marine shells found on the top of the mountains?" (Vai 2003). In order to answer to this question, some intellectuals proposed the Deluge as a geological agent. Leonardo systematically confutes all the assumptions of the Flood hypothesis. As Vai (2003) rightly points out, Leonardo's analysis surpasses four centuries of scientific debate on Diluvianism. In his methodical analysis against the Deluge theory, da Vinci takes into consideration the locomotion of mollusks. He observes that a certain species of mollusk "does not swim, but it makes a furrow in the sand and crawls by means of the sides of the mentioned furrow" ("*perchè no nota, anzi si fa un solco per l'arena mediante i lati di tal solco ove s'appoggia, caminerà*").

This fragment demonstrates that Leonardo observed in details some biogenic structures produced by living animals. It is provocative to speak about Neoichnology, although this is a key example for understanding Leonardo's approach on trace fossils. In brief, da Vinci investigates ichnofossils by comparing them to the traces produced by living animals. This approach is particularly evident when Leonardo describes borings on fossil shells: "The trace of the course [of the moving animal] is still preserved on the shell that has been consumed in the same manner of woodboring beetles" ("*Ancora resta il vestigio del suo andamento sopra la scorza che lui già, a uso di tarlo sopra il legname, andò consumando*"). The modernity of Leonardo is impressive: the mentioned traces – possibly meandering structures such as *Maeandropolydora* – are interpreted and successively compared to woodworm borings.

The comparison with woodworms is found in other parts of the Leicester Code. In fact Leonardo makes use of the term "*intarlati*", that literally means "worm-eaten (in the sense of borings resembling those of woodworms)". In Leonardo's words: "*Vedesi in nelle montagnie di Parma e Piacentia le moltitudini di nichi e coralli intarlati, ancora appiccicati alli sassi, de' quali quand'io facevo il gran cavallo di Milano, me ne fu portato un gran sacco nella mia fabbrica da certi villani*" ("There is to be seen, in the mountains of Parma and Piacenza, a multitude of shells and corals full of borings, still sticking to the rocks. When I was at work on the great horse of Milan, certain peasants came into my workshop and brought a large sackful of them to me").

The cited area of Piacenza (northeastern Italy) is still famous nowadays as a classic locality for the Pliocene, and it is common to find mollusks there with borings (Savazzi 1981).

The bioerosional structures cited in the Leicester Codex have a central part in Leonardo's observations about the Deluge. In fact, trace fossils are considered (together with other arguments) to demonstrate the organic origin of fossils: Leonardo refers to trace fossils as an evidence for past marine environments.

In other words, Leonardo da Vinci uses trace fossils for paleoenvironmental analysis.

However, borings are not the only trace fossils used by Leonardo as palaeoenvironmental tool.

Leonardo focuses also on biodepositional structures in the same stratigraphic units as fossilised marine shells: "among one and another rock layer, there are the traces of the worms that crawled in them when they were not yet dry" ("*Come nelle falde, infra l'una e l'altra si trovano ancora gli andamenti delli lombrici, che caminavano infra esse quando non erano ancora asciutte*").

This excerpt definitely proves the progressive approach of Leonardo on trace fossils, which can be summarised in the following points:

- Trace fossils are biogenic structures left by living organisms;
- Particular trace fossils provide evidence for the marine origin of "petrified shells" and rock layers;
- Traces produced by living organisms are the key to interpret trace fossils;
- Trace fossils are distinct structures with respect to body fossils.

It appears evident that Leonardo's theories on trace fossils are extraordinarily innovative and accurate. His approach also takes distance from the almost contemporary Aldrovandi, who considered a great part of body and trace fossils as natural curiosities with an inorganic origin.

5.2. *The Age of Naturalists: rediscovering the origins of Ichnology*

Aldrovandi, Bauhin and Leonardo are prominent examples of the study of trace fossils during the Renaissance, but they are – most likely – not isolated. Many naturalists studied "fossilia" during the Renaissance (Rudwick 1985; Morello 2003), but their relationship with Ichnology still remains poorly studied. For instance the famous naturalist Conrad Gesner possibly fits within the same milieu as the aforementioned naturalists. In his *De rerum fossilium* (Gesner 1565), Gesner reports "*Stelechites*" ("treestones", p. 351; probably fragmentary burrows), "*silex pertusus foraminibus*" ("Flint" with hollows, p. 31; doubtfully bioerosional structures), "*de lapidibus qui serpentes re-*

Tab. 2 - The table reports the major ichnological observations in Da Vinci's Leicester Codex. The reference numbers correspond to the logical order in Richter's (1970) edition of Leonardo's Notebooks.
Tab. 2 - La tabella riporta le principali osservazioni icnologiche del Da Vinci nel Codice Leicester. I numeri di riferimento corrispondono all'ordine logico dell'edizione di Richter (1970) dei manoscritti di Leonardo.

Leonardo's original text	Translation	Field	Reference
vedesi in nelle montagnie di Parma e Piacentia le moltitudini di nichi e coralli intarlati, ancora appiccicati alli sassi, de' quali quand'io facevo il gran cavallo di Milano, me ne fu portato un gran sacco nella mia fabbrica da certi villani	there is to be seen, in the mountains of Parma and Piacenza, a multitude of shells and corals full of borings, still sticking to the rocks. When I was at work on the great horse of Milan, certain peasants came into my workshop and brought a large sackful of them to me	Bioerosion	721
[...] perchè no nota, anzi si fa un solco per l'arena mediante i lati di tal solco ove s'appoggia, caminerà	[a certain species of mollusk] does not swim, but makes a furrow in the sand and crawls by means of the sides of the aforementioned furrow	Neoichnology	987
ancora resta il vestigio del suo andamento sopra la scorza che lui già, a uso di tarlo sopra il legname, andò consumando.	the trace of the course [of the moving animal] is still preserved on the shell that has been consumed in the same manner of woodboring beetles	Bioerosion	988
come nelle falde, infra l'una e l'altra si trovano ancora gli andamenti delli lombrici, che caminavano infra esse quando non erano ancora asciutte.	among one and another rock layer, there are still the traces of the worms that crawled in them when they were not yet dry	Biodeposition	990
li coralli, li quali inverso Monte Ferrato di Lonbardia esser si tutto dì trovati intarlati appiccicati alli scogli, scoperti dalle correnti de' fiumi	the corals which are found every day towards Monte Ferrato in Lombardy, are full of borings, sticking to rocks left uncovered by the currents of rivers	Bioerosion	991

Tab. 3 - Characterizing elements of the Age of Naturalists.
Tab. 3 - Elementi salienti dell'Età dei Naturalisti.

Element	Comments
The Age of Naturalists corresponds to the earliest scientific approaches to traces	During the Renaissance, several intellectuals devoted part of their studies to traces. At these times, the scientific method was in its initial stages of development.
Individual researchers made important advances in the study of traces	Aldrovandi illustrated trace fossils and proposed an appropriate theory for bioerosion. Leonardo interpreted accurately both bioerosional and biodepositional structures, and proposed their use for paleoenvironmental reconstruction. Bauhin commented on and illustrated trace fossils. Gesner may also have dealt with ichnofossils.
Ichnology existed as disconnected ideas about traces	During the Renaissance there was no leading line of thought about traces: for instance, some ideas of Aldrovandi markedly contrast with Leonardo's. Only in the 19th century Ichnology became a coherent and systematically structured science.

ferut" ("snake-like stones", pp. 167-169; some snake-like stones could be trace fossils, even though most of them represent body fossils).

Aldrovandi, Leonardo, Bauhin, and Gesner gave fundamental contributions to the development of Ichnology: for this reason, an "Age of Naturalists" can be erected, complementing the three stages of the history of Ichnology established by Osgood (1970). On the basis of these pioneering works, it is possible to trace a general scenario for the Age of Naturalists.

During the Age of Naturalists, Ichnology existed as isolated, disconnected ideas about traces, before it became a coherent science in the 19th century. During the Renaissance, individual researchers made important advances, but the study of trace fossils was never systematically restructured until recent times. There was no general theory about traces, as demonstrated by the partly contrasting ideas of Leonardo and Aldrovandi. In conclusion, the "Age of Naturalists" represents a fundamental step in the history of Ichnology, although the influence of the Naturalists still remains to be evaluated: probably the ichnological works of Naturalists have been neglected until recent times, despite their precious content.

6. CONCLUSIONS

The Italian ichnological heritage has stimulated the interest of many paleontologists since the 19th century, as well as the curiosity of leading intellectuals since the Renaissance times.

In greater detail, the present study gave evidence to support the following points.

6.1 . The role of Italian Ichnology in the 19th century

During the 19th century, Italy saw the activity of prominent paleontologists who extensively dealt with trace fossils: Villa, Meneghini, Massalongo, Peruzzi, Sacco are just some of the most important. Many ichnological celebrities – such as *Zoophycos*, *Paleodictyon*, *Lorenzinia*, *Taprhelminthopsis*, *Alcyonidiopsis*, *Urohelminthoida*, *Paleomeandron* – were established by these pioneers of Ichnology.

Aldrovandi's Musaeum Metallicum: the Roots of Ichnology during the 1500s.

The naturalist Ulisse Aldrovandi, known as one of the founding fathers of Geology, dedicated part of his research to trace fossils. Aldrovandi's studies came at a critical time to the history of science. This author researched trace fossils in the years following Leonardo and preceding Galileo, when the scientific method was in its early stages. In his *Musaeum Metallicum* Aldrovandi illustrates and describes *Cosmorhaphe* and *Gastrochaenolites*; he proposes a theory about the origin of bioerosional structures; he probably depicts other traces, such as *Chondrites* and *Thalassinoides*.

These elements demonstrate the fundamental importance of Aldrovandi's work, which represents a major step in the history of Ichnology: *Musaeum Metallicum* includes one of the first examples of a scientific approach to trace fossils. Moreover, *Musaeum Metallicum* includes some of the earliest artistic representations of invertebrate trace fossils. For Aldrovandi, trace fossils are objects of attraction (he called *Cosmorhaphe* and *Gastrochaeonolites* "*pulcherrimas*", "beautiful"). The aesthetic appreciation of trace fossils is still now passionate, as proofed by the ichnologic-artistic exhibition "Fossil Art" (Seilacher 1997).

6.1.1. Leonardo and his contemporaries

The Renaissance was a period of growing interest in Earth Sciences. Many naturalists have been devoted to the study of body fossils (Leonardo, Gesner, Cesalpino, Agricola, Fracastoro, Cardano, Falloppio, Encelius, to mention but a few) and even the term "Geology" has its origin in the Renaissance, coined by Aldrovandi himself.

Aside from Aldrovandi, other prominent personalities of the Renaissance dedicated part of their work to trace fossils. Leonardo da Vinci is demonstrated as one of the major pioneers of Ichnology (Tab. 2): in the Leicester Codex da Vinci dealt with traces, describing bioerosional and biodepositional structures with a very progressive approach. Leonardo correctly interprets trace fossils as biogenic structures left by living organisms, and he uses them as palaeoenvironmental tools: according to his observations, certain trace fossils prove the marine origin of "petrified shells" and rock layers.

Aldrovandi and Leonardo do not constitute isolated cases: Bauhin (1598, 1600) is recognized by Seilacher (2007) as one of the first artists to illustrate and comment on trace fossils. Also, Conrad Gesner (1565) probably took trace fossils into account.

6.1.2. The Age of Naturalists

Science historians have dedicated ample interest to the study of body fossils during the Renaissance, but have paid scant attention to the pioneering studies on trace fossils. The present study brings to light Aldrovandi's work on trace fossils, and emphasises the investigations of other pioneers of Ichnology: Leonardo, Bauhin and, probably, Gesner.

The central role of the naturalists in the study of trace fossils is manifest. For this reason an "Age of Naturalists" (Tab. 3) can be erected, as a complement to the three traditional stages of the history of Ichnology (established by Osgood 1970).

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