

“Fossil Art”: the importance and value of the palaeobiodiversity in the Naturtejo Global Geopark, under UNESCO (Portugal)

“Arte Fóssil”: a importância e valorização da paleobiodiversidade no Geopark Naturtejo, geoparque global sob os auspícios da UNESCO (Portugal)

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Recebido em 30/05/2013 / Aceite em 24/09/2014

Disponível online em Dezembro de 2014 / Publicado em Dezembro de 2014

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Artigo original
Original article

Abstract: The Geopark Naturtejo da Meseta Meridional (Centre Iberian Zone, Portugal) is developing the inventory of geological and mining heritage since 2004. This inventory in a concluding stage shows 18 fossil geosites, including classical and newly discovered sites evidencing international to regional importance. Some of the oldest fossils of the Iberian Peninsula were found at Naturtejo Geopark, corresponding to Middle - Late Ediacaran marine cyanobacteria found in a turbidite sequence cropping out at Erges River valley, near Salvaterra do Extremo locality. Most of the inventoried fossil sites belong to the Armorican Quartzite Formation, which is a peri-Gondwanan distributed biofacies famous for its trace fossils, such as the classic *Skolithos* (in piperock ichnofabrics) and the *Cruziana rugosa* group, as well as for obolid brachiopod shell beds, but lacking almost any other body fossils. The Penha Garcia Ichnological Park, a popular attraction of Naturtejo Geopark, is becoming internationally recognized for the unusual abundance and preservation of such trace fossils, with remark for the diverse feeding patterns made during the life cycle of giant trilobites. The remaining Ordovician period is well represented by fossil sites with calymenid, illaenid, dalmanitid, trinucleid and pliomerid trilobites, bivalves, orthoceratid cephalopods, orthid brachiopods, didymograptid graptolites, diploporitid echinoderms and ostracod arthropods. Fossils from Lower Silurian age (Llandovery) were found recently and for the first time in Naturtejo Geopark. Graptolites, cephalopods, bivalves and possible remains of eurypterids are among the first fossils identified.

In the continental Cenozoic deposits, the fluvial terrace of Pinhal records the first incision of the Tejo River on the Neoproterozoic-to-Lower Palaeozoic and Palaeogene-Neogene rocks of Naturtejo Geopark during lower Pleistocene. In these conglomerates, at least 7 fossil tree trunks were found, due to the erosion by the Tejo river of Middle - Late Miocene aged arkoses and their deposition in flooding plain environment. The fossil trees were found by the Romans almost two thousand years ago during exploitation of the fluvial conglomerates for gold. The most recent fossil site was dated to 33500 years and corresponds to sandstones from the last fluvial terrace developed by the Tejo River. Foz do Enxarrique fossil site provided remains of large mammals such as red deer and auroch. But the most important finding was the remains of *Elephas antiquus*, corresponding to the latest record of this important elephant before its final extinction from Europe mainland.

Fossil sites and palaeontological data achieved from active ongoing research at Naturtejo Global Geopark are being included in several tourism packages and educational programmes proposed by Naturtejo for national and international tour operators and schools. *Cruziana* trace fossils and trilobites that produced them have become the geobrand for nature tourism and landscape touring, not only for the Geopark area but also for the whole Portuguese Centre Region. Actually, they are already being used in innovative business opportunities.

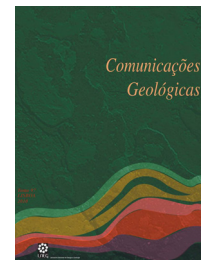
Keywords: Fossils, Geological Heritage, Neoproterozoic, Ordovician-Lower Silurian, Cenozoic, Tourism & Development, Naturtejo Geopark.

Resumo: O Geopark Naturtejo da Meseta Meridional (Zona Centro-Ibérica, Portugal) desenvolve o seu inventário do património geológico e mineiro desde 2004. Em fase de conclusão, este inventário identifica 18 geossítios de relevância paleontológica, incluindo sítios clássicos e recentemente identificados, de importância internacional a regional. Alguns dos mais antigos fósseis da Península Ibérica foram encontrados no Geopark Naturtejo, correspondendo a cianobactérias marinhas datadas do Ediacárico Médio-Superior oriundas de uma sequência turbidítica aflorante na bacia do Rio Erges próximo de Salvaterra do Extremo.

A maioria dos geossítios paleontológicos inventariados encontra-se na Formação do Quartzito Armoricano, uma biofacies de distribuição peri-gondwanica famosa pelos seus icnofósseis tais como os clássicos *Skolithos* (em icnofábricas do tipo *piperocks*) e o grupo *Cruziana rugosa*, assim como as lumachelas de braquiópodes obolídeos, mas destituídas de outros somatofósseis. O Parque Icnológico de Penha Garcia, um atractivo popular do Geopark Naturtejo, tem vindo a obter reconhecimento internacional pela abundância e preservação extraordinária de icnofósseis destes tipos, nomeadamente pela diversidade de padrões comportamentais desenvolvidos durante o ciclo de vida de trilobites gigantes. O restante período Ordovícico encontra-se bem representado por sítios paleontológicos com trilobites calimenídeos, illaenídeos, dalmanitídeos, trinucleídeos e pliomerídeos, bivalves, cefalópodes ortoceratídeos, braquiópodes ortídeos, graptólites didimograptídeos, equinodermes diploporitídeos e ostracodos. Fósseis de idade Silúrico Inferior (Llandovery) foram encontrados recentemente e pela primeira vez no Geopark Naturtejo. Entre os primeiros fósseis identificados encontram-se graptólites, bivalves e prováveis restos de artrópodes eurípterídeos.

Entre os depósitos continentais cenozóicos, o terraço fluvial de Pinhal regista a primeira incisão do Rio Tejo nas sequências do Neoproterozóico-Paleozóico Inferior e do Paleogénico-Neogénico durante o Plistocénico inferior. Nestes conglomerados foram encontrados pelo menos sete troncos fósseis resultantes da erosão das arkoses datadas do Miocénico médio-superior e da sua posterior deposição em ambiente de planície de inundação. Os troncos fósseis terão sido encontrados pelos Romanos há cerca de dois mil anos durante a exploração mineira de ouro nos conglomerados fluviais. O sítio paleontológico mais recente está datado de há 33500 anos e corresponde a um depósito arenítico do último terraço fluvial desenvolvido pelo Rio Tejo. O sítio paleontológico da Foz do Enxarrique deu restos de grandes mamíferos, tais como veados e auroques. Mas a descoberta mais importante foi a de restos de *Elephas antiquus*, correspondendo aos mais recentes registos deste elefante na Europa continental antes da sua extinção.

Estes sítios e os dados obtidos a partir de projectos de investigação em desenvolvimento no Geopark Naturtejo estão a ser incluídos, com os devidos cuidados conservacionistas, em vários programas geoturísticos e educativos pela Naturtejo, entidade promotora e gestora do geoparque, para os operadores turísticos nacionais e estrangeiros e escolas. Os icnofósseis de *Cruziana* e as trilobites que as produziram tornaram-se frequentemente uma marca identitária para produtos como o turismo de



natureza e *touring* cultural e paisagístico, não apenas para a região do geoparque, como para toda a Região Centro. De facto, esta tem vindo a ser aplicada em novas oportunidades de negócio.

Palavras-chave: Fósseis, Património Geológico, Neoproterozóico, Ordovícico-Silúrico Inferior, Cenozóico, Turismo & Desenvolvimento, Geopark Naturtejo.

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1. Introduction

The Geopark Naturtejo da Meseta Meridional (Portugal) has been developing the inventory of geological and mining heritage since 2004, due mostly to three reasons: the large size of the territory, spanning over 4624 km²; the high geodiversity at the southern border of the Centre Iberian Zone of the Iberian Massif, part of the Variscan Belt, where the Geopark is included; the lack of detailed geological mapping in most of the area as well as updated studies for several disciplines of geosciences. This inventory, which will be formally presented at the end of this year, includes 18 fossil sites (Fig. 1), classical and newly discovered ones (Tab. 1), showing international to regional relevance. Early in the history of the territory as Geopark project, the fossils included in the Naturtejo became the brand of a region dedicated to nature (resumed *in* Neto de Carvalho, 2009; Neto de Carvalho e Rodrigues, 2010). This paper aims to present the first comprehensive view over the fossil diversity and relevance from Naturtejo Geopark based on previous references and ongoing work. Moreover, it shows some examples of how Naturtejo Geopark uses the fossil record for educational programmes and geotourist activities in the territory and abroad. Most of the approaches were already

presented by the authors elsewhere so interested readers may find here a global account on them that includes also where to look for in the bibliography.

2. Some of the most ancient fossils from Iberia

The long geological history of the Naturtejo Geopark began in the Neoproterozoic Era and constitutes one of the most ancient stratigraphic records in Portugal. Rocks from Salvaterra do Extremo were studied for the first time by the founder of Portuguese Geology, Carlos Ribeiro, the first director of both the Geological Survey and the Mines Institute, in the mid 1800's. But António Sequeira, also from the Portuguese Geological Survey, was the geologist that studied the area in detail during the late eighties and demonstrated the importance of the stratigraphy of the Erges River section, in several papers (*e.g.*, Sequeira, 1993a; Sousa e Sequeira, 1993; San José *et al.*, 1995; Ribeiro e Sequeira, 1997; Sequeira, 2011). The Erges, one of the few remaining wild rivers in Portugal, guards areas of rare natural value with emphasis on geodiversity. The deep-incised valley instructs about Earth dynamics in its most ancient stages from the territory that is presently the Iberian Peninsula. Between Tenda and Figueiracedo streams, the Carril das Travessas and Cabeço das Popas formations held planktonic Chroococcales cyanobacteria microfossils (Sequeira, 1993a, 2011) of the species *Palaeogomphosphaeria cauriensis* (Fig. 2a) and *Bavlinella faveolata* (endospore-forming cyanobacteria or microalga), characteristic for Middle to Late Ediacaran (<580 million years ago). Fossils as old as these were already found in Ossa-Morena Zone, in Alentejo (Gonçalves e Palácios, 1984) and related sequences in Extremadura (resumed in Vera, 2004). However, the scarce occurrence of such fossil sites and the absence of older unambiguous fossil record make the Erges River section a time-key for evolution of life in the dawn of Metazoa, among the few oldest palaeontological sites known in the Iberian Peninsula.

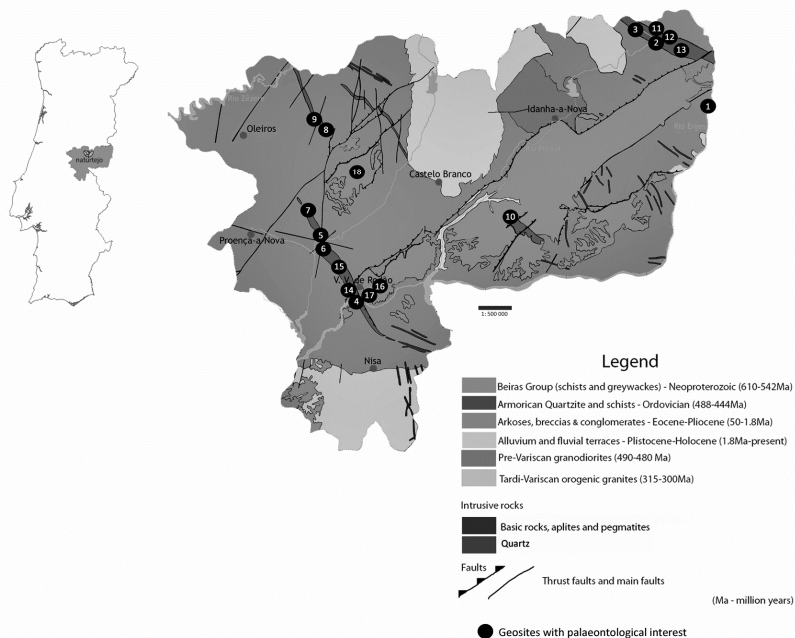


Fig.1. Simplified geological map of the Naturtejo Geopark with the fossil sites included in the Inventory of the Geological and Mining Heritage (source: Naturtejo, adapted from the Geological Map of Portugal 1:500000 published by Serviços Geológicos de Portugal, 1992, sheets Norte and Sul).

Fig.1. Mapa geológico simplificado do Geopark Naturtejo com a indicação dos sítios paleontológicos incluídos no Inventário do Património Geológico e Mineiro (fonte: Naturtejo, adaptado da Carta Geológica de Portugal na escala 1:500000 publicada pelos Serviços Geológicos de Portugal, em 1992, folhas Norte e Sul).

Table 1. Palaeontological geosite names and their ages; the numbers refer to site locations on the map of figure 1; ages from the 2009 International Stratigraphic Chart published by the International Commission on Stratigraphy (m.y.- million years ago).

Tabela 1. Designação dos geossítios paleontológicos e a sua idade; os números referem-se à sua localização no mapa da figura 1; idades de acordo com a Tabela Cronostratigráfica Internacional publicada pela Comissão Internacional de Estratigrafia (m.y.- milhões de anos).

Period	Palaeontological sites
Neogene-Quaternary (circa 15 m.y.-33,000 years ago)	Monte do Pinhal Terrace (16), Foz do Enxarrigue Archaeozoological site (17)
Early Silurian (443.7±1.5-428.2±2.3 m.y.)	Portela da Milhariça roadcut (15)
Middle-Late Ordovician (468.1±1.6-443.7±1.5 m.y.)	Fonte dos Cucos (11), Ribeira do Reça roadcut (12), Penha Garcia Syncline (13), Barroca da Senhora (14)
Early-Middle Ordovician (circa 488-468.1±1.6 m.y.)	Ichnological Park of Penha Garcia (2), Ramilo (3), Ródão Bridge roadcut (4), Portas de Almourão (5), Foz do Cobrão roadcut (6), Venda Quarry (7), Moradal (8) and (18), Zebro Quarry (9), Sancada (10)
Middle-Late Ediacaran (circa 580-542±1 m.y.)	Erges Section (1)

3. Fossil behaviour: “art” depicted almost 490 million years ago

The first fossils were collected in Penha Garcia during September 1883 for the pioneering work of Nery Delgado (Delgado, 1885, 1908) that established the first approach to the Palaeontology and Stratigraphy of the Ordovician rocks from Penha Garcia-Cañaverl Syncline. From the stratigraphic work in the Portuguese sector of the syncline a total of 8 geological formations were lately defined (i.e., Serra Gorda, Quartzito Armoricano, Brejo Fundeiro, Monte da Sombadeira, Fonte da Horta, Cabril, Louredo and Ribeira da Laje formations) that cover basically all the Ordovician Period from Tremadocian at least till Katian (Young, 1985, 1988; Sequeira, 1993b). Two regional stratotypes, Serra Gorda Formation and Vaca Member from Louredo Formation were defined close to Penha Garcia (Young, 1988; Sequeira, 1993b).

Most of the “Bilobites” fossils described by Nery Delgado in his influent monographic work of 1885 came from Penha Garcia, and are now included in the Paleontological Collections of the Geological Museum (LNEG). This work is still one of the most important classical papers on trace fossils and worldwide known as it was one of the few Portuguese references for the two existing volumes of Treatise on Invertebrate Paleontology about trace fossils. Moreover, it was fundamental for the establishment of modern Ichnology by “Dolf” Seilacher (e.g., Seilacher, 1955; resumed in Seilacher, 1970). During the end of the seventies, Roland Goldring visited Penha Garcia for studying *Cruziana* trace fossils with the help of locals. From the sampling season in the Armoricano Quartzite Formation, Goldring published a very important paper on the formation of *Cruziana* that was vital for understanding *Cruziana* behaviour, preservation and relationship to trilobites (Goldring, 1985). The abundance, unusual preservation and diversity of trace fossils combined with the wonderful exposure conditions in the Ponsul valley allowed the development of more systematic ichnological studies for a decade with the revision of old collections and description of many new findings (e.g., Neto de Carvalho *et al.* 1998; Neto de Carvalho, 2003, 2006a). A total of 21 ichnogenera and 33 ichnospecies were already identified and/or described by the senior author at Penha Garcia and ascribed to behaviour of trilobites (*Cruziana rugosa*, *C. furcifera*, *C. goldfussi* (Fig. 2a), *C. imbricata*, *C. rouaulti*, *C. bagnolensis* (Fig. 2g, j), *C. problematica*, *C. beirensis*, *Rusophycus carleyi* (Fig. 2d), *R. morgati*, *R. didymus*, *R. pedroanus*, *R. biloba*, *R. latus*, *Diplichnites* *isp.*, *Monomorphichnus lineatus*, *M. bilinearis*, *Cheichnus* *isp.*), phyllocarid crustaceans (*Merostomichnites* *isp.*), bivalves (*Lockeia amygdaloides* (Fig. 2f),

Protovirgularia cf. rugosa), anemones (*Bergaueria hemispherica*) and worms (polychaetes and/or phoronids: *Helminthopsis hieroglyphica*, *Helminthoidichnites tenuis*, *Gordia marina*, *Palaeophycus tubularis*, *P. alternatus*, *Planolites berverleyensis*, *Arthropycus alleghaniensis*, *Diplocraterion paralellum* wide form, *Arenicolites* *isp.*, *Skolithos linearis*, *S. annulatus*, *Monocraterion cf. tentaculatum*, *Rosselia socialis*, *Daedalus halli* (Fig. 2h), *D. labechei*). Sequeira (1993) reported the oldest fossils in the Ordovician sequence of Penha Garcia as *Skolithos* and horizontal burrows dated from the (?)Tremadocian. Neto de Carvalho (2006a) described in detail an amazing variety of feeding behaviours in *Cruziana*, “nowhere are they as varied as near Penha Garcia” (Seilacher, 2001). Fancy burrowing behaviours were coined by Adolf Seilacher in his Fossil Art international exhibition as “The trilobite circus of Penha Garcia”. Examples of tunnelling, teichichnoid, circling and gregarious feeding behaviours are evidences for the evolution of the same feeding strategies in different groups of trilobites (Seilacher, 2007; see Fig. 2). Suspected microbial mats as grazing fields, sometimes showing deeper tier foraging, are indicated by the presence in the quartzite beds of deep burrows, synaeresis and polygonal shrinkage cracks, wrinkle marks, mud chips, flat-topped ripple marks and, possibly, biolamination. Neto de Carvalho (2006a) also noticed a width span between 2 mm and 260 mm in *Cruziana* burrows which is allowing to track the pattern of ecospace exploitation during ontogeny of a giant, almost half a meter producer assigned to Asaphid trilobites. Besides the large ichnodiversity made by detritus, filter and suspension feeding burrowers, the first body fossils recovered in the upper member of Armoricano Quartzite Formation are giant obolids (brachiopods) confirmed by Neto de Carvalho (2006b) and the important fossil of thorax fragment of an asaphid, which may confirm the previous attribution of *Cruziana* to this group of trilobites.

For centuries Penha Garcia inhabitants admired or even feared *Cruziana* traces, calling them the “Painted Snakes” and involving them in legends of Moorish princesses and treasures. The acculturation of palaeontological information by Penha Garcia inhabitants is also being followed (e.g., Neto de Carvalho e Cachão, 2005). This multidisciplinary work has been the support for the protection of the geological and cultural heritage for the creation of the Fossils Trail in the Penha Garcia Ichnological Park (e.g., Neto de Carvalho, 2004; Sequeira and Serejo Proença, 2004; Neto de Carvalho and Baucon, 2007) as the starting point for building a Geopark, which were awarded with the 1st and 4th Geoconservation prizes by ProGEO – Portugal/National Geographic –Portugal. Internationalization of the palaeontological heritage from Penha Garcia was conducted both in scientific (Neto de Carvalho, 2006a; Seilacher, 2007) and geotouristic basis, through the Ichnological Park and as one of the stars of the travelling exhibition Fossil Art of the famous paleobiologist Adolf Seilacher (Seilacher, 2001, 2003, 2005a) and one major attraction of Geopark Naturtejo Meseta Meridional – European and Global Geopark under UNESCO (e.g., Neto de Carvalho, 2005a; Neto de Carvalho and Martins, 2006). The palaeontological heritage from Penha Garcia can now be seen as a successful and every improving tourist attraction (cf. Seilacher, 2005b), with about 1000 visitors per month in the Fossils Trail, and an example of exomuseum (*sensu* Meléndez and Rodrigues, 2008) to be followed in Portugal.

Other new fossil sites can be found at Penha Garcia syncline. Ramilo mountain range is the prolongation of shallow marine quartzite facies from Penha Garcia to NW. Outcrops show outstanding *Daedalus halli* preservation (Fig. 2h), abundant *Cruziana rugosa*, *C. furcifera*, *C. goldfussi*, *C. rouaulti* and *Rusophycus* *isp.*, besides remarkable *Cruziana problematica* 1mm wide still with scratch marks made by the very small trilobite

producer. In the Penha Garcia syncline NE limb, Fonte dos Cucos fossil site, also from Floian-Dapingian Age, shows the trace fossils *Cruziana rugosa*, *C. furcifera*, *C. goldfussi*, *C. rouaulti*, *C. imbricata*, *Rusophycus* isp., *Monomorphichnus lineatus*, *Palaeophycus* isp., *Skolithos linearis*, *Daedalus halli*, *Monocraterion* isp., *Arenicolites* isp. The transition to the Brejo Fundeiro Formation shales, highly-bioturbated by *Planolites montanus*, evidences the occurrence of *Didymograptus* (*D.*) *murchisoni* (Fig. 3e) and *Neseuretus tristani*, typical of Darrwilian Age 1 m above the last quartzite bed from the Armorican Quartzite Formation.

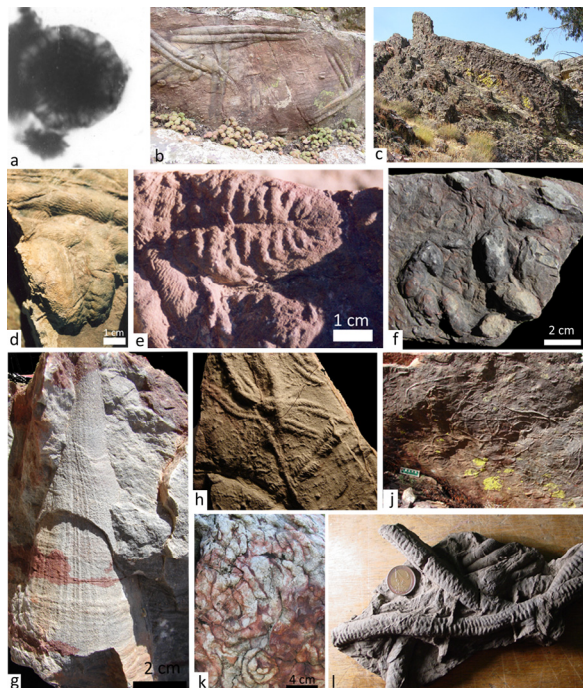


Fig.2. Neoproterozoic fossil and trace fossils from the Early-Middle Ordovician (Floian-Dapingian age) of the Armorican Quartzite Formation: a) *Palaeogomphospaeria cauriensis* from Erges (photo from António Sequeira, size of cyanobacteria approximately 5µm); b) trilobite dynamic and static feeding burrows (burrow width 4 cm, Ichnological Park of Penha Garcia); c) high bioturbation of *Cruziana* in lower bedding planes (slab 15 m long at Ichnological Park); d) *Rusophycus carleyi* with endopodite-made burrows and scratch marks, with central coxal impressions (Frágua Bar private collection, Penha Garcia); e) trilobite ventral morphology in mortichnion *Rusophycus* ("Palaeozoic Museum" collection of Penha Garcia); f) Repichnia in *Lockeia amygdaloides* ("Domingos collection", Penha Garcia); g) exquisite preservation of minute *Cruziana* (burrows less than 1 cm wide; Venda Quarry); h) impressive preservation of an enigmatic behaviour: *Daedalus halli* (Ramilo); i) Scribbling burrowing in minute *Cruziana rouaulti* (Penha Garcia; scale with 10 cm); j) spiral crowding by *Daedalus desglandi* (Muradal); k) *Arthropycus brongiartii* produced by an unknown arthropod (Ponte de Ródão; LNEG Geological Museum collection).

Fig.2. Fósseis neoproterozóicos e icnofósseis do Ordovício Inferior a Médio (idade Floiano-Dapingiano) na Formação do Quartzito Armoricano: a) *Palaeogomphospaeria cauriensis* provenientes do Erges (foto de António Sequeira, tamanho aproximado das cianobactérias de 5µm); b) escavações de alimentação estática e dinâmica produzidas por trilóbitos (largura da escavação de 4 cm, Parque Icnológico de Penha Garcia); c) elevada bioturbação de *Cruziana* a muro das camadas (exposição com 15 m de extensão no Parque Icnológico); d) *Rusophycus carleyi* produzido pelas endopodites evidenciando ao centro as impressões das coxas (coleção privada do Frágua Bar, Penha Garcia); e) morfologia ventral de trilóbitos num *Rusophycus mortichnion* (coleção do "Museu do Paleozóico" de Penha Garcia); f) Repichnia em *Lockeia amygdaloides* ("coleção Domingos", Penha Garcia); g) preservação exemplar de *Cruziana* diminutas (escavações com menos de 1 cm de largura; pedreira de Venda); h) preservação notável de um comportamento enigmático: *Daedalus halli* (Ramilo); i) padrão de escavação "rabiscado" em *Cruziana rouaulti* diminutas (Penha Garcia; escala de 10 cm); j) multidão de espirais do tipo *Daedalus desglandi* (Muradal); k) *Arthropycus brongiartii* produzido por um artrópode desconhecido (Ponte de Ródão; coleção do Museu Geológico do LNEG).

At Portas de Almourão geomonument, two fossil sites were found and described (Portas de Almourão and Foz do Cobre roadcut), mostly composed by trace fossils but also with oboloid brachiopod shell beds. The quartzite lithofacies is composed by shoreface pure quartzites with *Skolithos linearis* piperocks and *Daedalus* dense ichnofabrics in planar cross bedding and HCS levels, revealing colonization of high hydrodynamic, shifting substrates under storm influence. Rippled- and mica-rich beds, deposited in quieter conditions, show commonly the ichnocoenosis *Diplocraterion paralellum* wide form, isolated *Skolithos linearis*, *Cylindrichnus* isp., *Monocraterion* cf. *tentaculatum* and *Rosselia socialis*. *Rosselia* is a somewhat common burrow structure restricted to sandy facies from the lower shoreface, at Portas de Almourão, and the Armorican Quartzite Formation in general. In one bed *Rosselia* is found with several preservational transitions of *Monocraterion* and *Skolithos* revealing probable geometrical relationship. This may represent equilibrium behavior resulting from rapid sedimentation. *Rosselia socialis* and related traces were interpreted to be dwelling structures of a detritus-feeding worm-like animal (Neto de Carvalho and Baucon, 2010). The quartzite lithofacies is succeeded by mixed flat-to-subtidal related sequence of decimeter-scale rippled fine sandstones alternated with micaceous siltstones. This ichnoassociation is common and composed by undetermined ichnospecies of *Palaeophycus*, *Diplocraterion*, *Helminthopsis*, *Lockeia*, *Bergaueria*, as well as trilobite feeding burrows, such as *Rusophycus* isp., *Cruziana furcifera*, *C. goldfussi*, *C. beirensis* and *C. rouaulti*. The flat dorsal side of a *Cruziana furcifera* shows corrugations resulted from tunneling by forward impulses. Stiff- to firmgrounds shows 1 mm width *Cruziana rouaulti* and oblique *Planolites*. *Arthropycus alleghaniensis* is not rare, showing palmate retrusive J-shaped burrow systems radiating in a teichichnid fashion, i.e., from one opening. This behavior, transverse annulations and lateral backfilling are consistent with worm-like bulldozing producers (Neto de Carvalho *et al.*, 2003).

Most interesting straight *Nereites missouriensis* var. *Phyllocites* (previously determined as *Nereites jacksoni* by Neto de Carvalho e Baucon, 2010), following a rippled topography were found in very shallow *Skolithos* ichnofacies, being interpreted as simple feeding trails made by an unknown arthropod while exploiting a microbial mat (Neto de Carvalho and Baucon, 2010).

To NW at Vila Velha de Ródão complex syncline, Venda Quarry shows well preserved trace fossils (Fig. 2g) like giant *Cruziana rugosa*, besides *C. rouaulti*, *C. problematica*, *C. bagnolensis*, *Arthropycus alleghaniensis*, *Planolites* isp., and the brachiopod *Lingulobolus hawkei*. To SE, the Ponte de Ródão roadcut site shows a good section of the Armorican Quartzite Formation composed by quartzite beds intercalated by shales which become predominant to the top of the sequence. The stratigraphy is somewhat complicated by dense Variscan D1 folding and faulting. The lower part decimetre-thick quartzite beds dominate with subordinate mica-rich grey shales, showing asymmetric ripples and the typical *Skolithos* ichnofacies, *Skolithos linearis*, *S. annulatus*, *Daedalus halli*, *D. aff. labechei*, *Diplocraterion paralellum* wide form as well as three different species of bivalves, possibly including *Coxiconchia*. To the top greyish pink or green shales prevail with *Cruziana rugosa*, *C. furcifera*, *C. goldfussi*, *C. imbricata*, *C. rouaulti*, *C. beirensis*, *Monomorphichnus lineatus*, *Rusophycus* isp., *Arthropycus alleghaniensis* var. *lateralis* and the interesting *A. brongiartii* (Fig. 2i). Giant oboloid brachiopods, such as *Lingulobolus hawkei* and *Lingulella* sp. are found in shell beds distributed along the sequence, in storm-related quartzites (Neto de Carvalho, 2006b).

The amazing exposure from Serra do Muradal found by the authors, with a vertical quartzite bed showing 70 m² of extensive bioturbation by spiral burrows covering nearly 100% of the available area, was reported preliminarily by Rodrigues *et al.* (2009) in the scope of a proposal to protect this as geosite included in the Naturtejo Geopark Inventory of Geosites. This and two more overlying beds show dense coverage by convex-epirelief *Daedalus desglandi* spiral burrows, with a diameter of 1-2 cm and between 5-30 cm whorl radiuses. Helical shape may be inferred by change of level in the sediment, but structures develop mostly on the bedding plane (Fig. 2k). Bioturbation tend to occur towards the top of the beds, reaching 40 cm deep in the main bed without evident lateral branching or terminal expansion. Burrow fill is the same as the bed, burrow wall is knobby without lining, burrow diameter vary in the same structure and indiscriminate over crossings prevail. The dense bioturbation as horizontal scribbles, larger and mostly helicoid structures occurring in event beds from the basal-to-lower sequence from the Lower Ordovician Armorican Quartzite Formation, may represent colonization by wormlike bulldozers, possibly large polychaetes or enteropneusts. Animals reworked sandy substrates searching for food in water-rich and oxygenated shifting sands. The infaunal habit protected the organism against the environmental stress and burrow architecture optimized feeding behaviour in more than 50 cm-deep, crowded deep tiers.

To NW from this fossil site is the Zebro Quarry with large bedding exposures with *Skolithos* piperock and large and extensive burrows of *Cruziana goldfussi* and *C. isp.* (Rodrigues *et al.*, 2009). The last fossil site from Armorican Quartzite facies to be newly described is Sancada, with well preserved *Skolithos annulatus* equilibrium "in situ" and *Daedalus desglandi* dense ichnofabrics.

4. Middle and Late Ordovician trilobite-dominated fossil sites

Coming back to the Penha Garcia syncline, Ribeira do Reça fossil site shows dark shales from Brejo Fundeiro Formation (Darrivilian – about 470 to 460 million years age) with some levels crowded of badly preserved fossil debris. However, other levels show nice preservations of internal molds, mostly exuviae from the trilobite *Neseuretus tristani*. Juvenile stages of this trilobite (meraspids) were also found; the trace fossil *Arachnostega gastrochaenae* preferentially occur in cephalon from this trilobite, which infer the work of a detritus-feeder worm specialist (see also Fig. 3c). Other trilobites identified by the authors were *Placoparia (Coplacoparia) tournemini*, *Eodalmanitina destombesi nava*, the ostracod crustaceans *Beyrichia bussacensis* and *Primitia simplex*, the epibenthonic brachiopod *Sivorthis noctilio*, an orthoceratid cephalopod, the bivalve *Praeleda costae*, a thick-ornamented bivalve, crinoid echinoderms and the trace fossil *Planolites montanus*. The Penha Garcia syncline North from Vaca is as well protected as badly known. The important private chasing farm Herdade de Vale Feitoso, with an area of 7000 ha, is well protected against intruders but hardly one can go inside for research until last summer. With the support of Monfortur the palaeontological site representing a complete sequence from Middle to latest Ordovician is now being under study. The list of fossils known is still mostly based on previous works and fossils housed at "Litoteca" from the Geological Survey (LNEG), that are now preliminarily revised: graptolites include *Didymograptus bifidus*, *D. cf. artus*, *D. nanus*, *D. murchisoni* var. *geminus*, *D. amplus*, *Diplograptus* sp., *Glyptograptus* cf. *teretiusculus*; trilobites *Neseuretus tristani*, *Salterocoryphe salteri*, *Ectillaenus giganteus*, *Colpocoryphe grandis*, *Placoparia (Coplacoparia) tournemini*, *Eodalmanitina destombesi nava*; the orthid brachiopods *Sivorthis noctilio* and

Eorhipidomella muscosa, ?*Cacemia* cf. *ribeiroi*; bryozoans, crinoids, orthoceratids (Fig. 3f), the bivalve *Ctenodonta* sp. and the trace fossil from Katian age *Nereites missouriensis* (former *Nereites delgadoi* from Perdigão, 1971, a junior synonym). Also remarkable was the newly finding of a bed rich of well preserved *Deanaspis pongerardi* and other fossils.

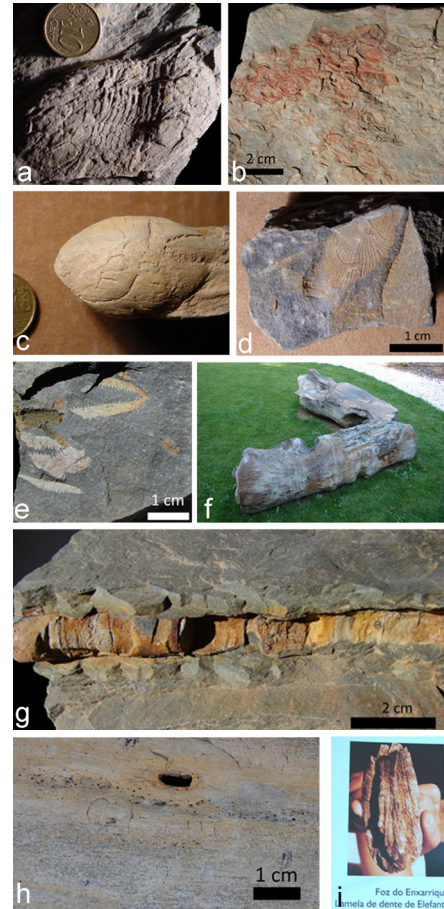


Fig.3. Fossils and trace fossils from Naturtejo Geopark (Middle Ordovician, middle late Miocene and late Pleistocene): a) *Ectillaenus giganteus* afectado pela xistosidade penetrativa (Barroca da Senhora; LNEG Geological Museum collection); b) hidrodinâmica acumulação de exúvias de *Neseuretus tristani* (cefalões e pigídios) (Barroca da Senhora; "Centro Cultural Raiano" collections); c) *Arachnostega* harvesting an internal mold of an enrolled *Ectillaenus giganteus* enrolada (Barroca da Senhora, LNEG Geological Museum collection); d) orthid brachiopod from Barroca da Senhora (LNEG Geological Museum collection); e) well preserved *Didymograptus* from Fonte dos Cucos ("Centro Cultural Raiano" collections); f) orthoceratid cephalopod from Penha Garcia syncline ("Centro Cultural Raiano" collections); g) *Annonoxylon teixeirae* fossil logs (House of Arts and Culture of Tejo); h) *Xylonichnus* isp. open boring with surrounding reaction halo on *Annonoxylon teixeirae*; i) tooth remain of *Elephas antiquus* from Foz do Enxarrique, at Portas de Ródão Nature Monument (Archaeological Museum of Vila Velha de Ródão).

Fig.3. Somatofósseis e icnofósseis do Geopark Naturtejo (Ordovícico médio, Miocénico superior e Pliocénico superior): a) *Ectillaenus giganteus* afectado pela xistosidade penetrativa (Barroca da Senhora; colecções da Litoteca do LNEG); b) acumulação hidrodinâmica de exúvias de *Neseuretus tristani* (cefalões e pigídios) (Barroca da Senhora; colecções "Centro Cultural Raiano"); c) *Arachnostega* infestando o molde interno de uma *Ectillaenus giganteus* enrolada (Barroca da Senhora, colecções da Litoteca do LNEG); d) braquiópode orthídeo de Barroca da Senhora (colecções da Litoteca do LNEG); e) *Didymograptus* bem preservado proveniente de Fonte dos Cucos (colecções "Centro Cultural Raiano"); f) cefalópode orthoceratídeo do sinclinal de Penha Garcia (colecções "Centro Cultural Raiano"); g) troncos fósseis de *Annonoxylon teixeirae* (Casa das Artes e da Cultura do Tejo); h) *Xylonichnus* isp. Perfuração aberta com halo de reacção circundante em *Annonoxylon teixeirae*; i) fragmento de dente de *Elephas antiquus* da Foz do Enxarrique, no Monumento Natural das Portas de Ródão (Museu Arqueológico de Vila Velha de Ródão).

Barroca da Senhora, at Portas de Ródão Nature Monument, presents the highest diversity of Middle Ordovician fossils from the Naturtejo Geopark area (Fig. 3a, b, c). Brejo Fundeiro Formation pinkish shales show the trilobites *Placoparia (Placoparia) cambriensis*, *Ectillaenus giganteus* (Fig. 3a), frequently harvested by *Arachnostega gastrochaenae* (Fig. 3c), *Neseuretus tristani* post-exuviae mechanical aggregations (Fig. 3b), *Prionocheilus mendax*; the bivalves *Praealeda costae* and *Redonia deshayesi*; the rostroconchs *Ribeiria cf. pholadiformis* and *Tolmachova sp.*; *Primitia simplex* ostracods in clusters; the brachiopod *Sivorthis noctilio* (Fig. 3d); echinoderms such as crinoids and diploporitid cystoids, including *Calix sp.* The black shales provided 5 species of graptolites including *Didymograptus (D.) murchisoni*, *D. (D.) var. geminus*, *D. (Didymograptellus) bifidus*, *D. nanus* and the first occurrence of *Didymograptus amplus* found in Portugal (Romariz e Gaspar, 1968). The oldest collections of fossils for study from this Naturtejo territory came from Barroca da Senhora, collected in 1874.

5. Recent finding of Early Silurian fossils

Portela da Milhariça motorway road cut is a reference section for the Lower Palaeozoic stratigraphy of Ródão region. In this section the Vale da Ursa Formation quartzites, with *Skolithos* trace fossils and ripple-marks, and the Aboboreira Formation shales, correlated to Early Silurian (Llandovery Epoch, between 445 and 426 million years age) based on the recently discovered graptolites genera (Metodiev *et al.*, 2009), are in contact with the Armorican Quartzite Formation due to overthrust faults. Also important was the recovery of common orthoceratid cephalopods, bivalves and possible opisthosoma and chelicerae portions of eurypterids for the present work.

6. Neogene and Quaternary continental fossil sites

Ródão-Moraleja continental basin is almost devoid of fossil findings. However, the two fossil sites that were studied proved to be highly important to understand tectono-climatic conditions that lead to the incision of Tejo River in its present valley, during the last 2,6 Ma (Cunha *et al.* 2005).

The oldest fluvial terrace of the Tejo River, dated from the lower Pleistocene (Cunha *et al.*, 2008) and located in Charneca at 183 m high, lies by an angular unconformity over the Eocene-Oligocene arkoses from Cabeço do Infante Formation. Monte do Pinhal site shows a small gold Roman mining area (Henriques and Caninas, 1984) where, at least, 7 fossil tree trunks from were found and left some two thousand years ago (Neto de Carvalho and Rodrigues, 2008). This mining area belongs to the Charneca mining complex that spreads by a very extensive area of several km². Fossil trees were described as *Annonoxylon teixeirae*, a species from the middle to late Miocene (about 15 to 5 million years old; Pais, 1991). They are rare examples of fossils found in Cenozoic deposits from Beira Baixa and some of the few annona-tree related species found in Portugal. Abrasion, the incisions induced by pebble impacts and diagenetic fractures enable to reconstitute high-energy conditions of the river flow that remobilized these fossils from the Miocene Silveirinha dos Figos Formation and deposited them among other cobbles and pebbles in the fluvial terrace. Besides, well visible growth rings provide information about climate seasonality during the life of the trees. On the other hand, *Annonoxylon* relatives are found nowadays only in subtropical areas of evergreen forest, which is very useful to reconstitute climate during the Neogene. Some of the fossil trees show high rates of decaying after death and before

permineralization. *Stiptichnus* isp. tangential borings with dark walls resulting from fungal attack are evidences of xylophagy behaviour by insects. Also, *Xylonichnus* isp. longitudinal borings with rectangular cross sections (Fig. 3h) are typical of saprophagic buprestid coleopterans. An association of fossil behaviours in xylic environments presented here is the first record for Portugal, somehow anticipated by Neto de Carvalho (2005b). Two specimens, the most imposing ones, are placed at the House of Arts and Culture of Tejo (Fig. 3g) and two other belong to collections of the Archaeological Museum of Vila Velha de Ródão (Fig. 4d). Possibly these fossils, including the fossil collected at Coutada that is now missing (Fig. 4e), were parts of the same tree (Neto de Carvalho and Rodrigues, 2008).

Foz do Enxarrique fluvial terrace, located at 82 m high, corresponds to the last aggradational phase before the present incision of Tejo River. In these sandstones an abundant lithic industry of Mousteriense age was found with mammalian fossil remains (*Elephas antiquus*, *Cervus elaphus*, *Equus caballus*, *Bos primigenius*, *Oryctolagus sp.* and *Vulpes vulpes*), birds and fishes (Raposo, 1987a, b, 1995a, b). Radiometric age given by an upper molar lamella of *Elephas antiquus* shows that these last elephants from Europe lived in the Tejo River valley 33000-34000 years ago before their final extinction (Antunes and Cardoso, 1992; Fig. 3i). Thus, relevance of Foz do Enxarrique is international due to scientific importance. Foz do Enxarrique fossil site is protected by national laws and was included also within the Portas de Ródão Nature Monument. The fossil site is now part of a project from the municipality of Vila Velha de Ródão to give new attractions to the riverside area while fostering new scientific excavations.

7. Example: cruziana as “geobrand” for a strategy of geotourism

Ichnoanthropology and *ichnoarchaeology* are new approaches to the way the human society culturally interacts with trace fossils (Baucon *et al.*, 2008). Portugal has a remarkable cultural heritage based on these special types of fossils, for which *Cruziana* trace fossils are particularly relevant (Neto de Carvalho and Cachão, 2005). The mystical importance of former times is nowadays favoured by palaeobiological reinterpretations branding new strategies of tourism (Neto de Carvalho, 2009). The Ichnological Park of Penha Garcia with its outstanding fossil record of trilobite behaviours is being one of the well succeed prototypes in Portugal, with a growing number of annual visitors and stronger impact in national media and attracting an increasing number of school visits to the Naturtejo Geopark (Fig. 4).

In 2004, the Association of Municipalities “Natureza e Tejo”, together with local private companies related to tourism, created Naturtejo public enterprise. This company was projected for regional tourism development and promotion, both national and abroad. Despite natural and cultural values known, Naturtejo territory never had a strong-based tourism development strategy. In this context, the Geopark would be called for the first time in Portugal, as umbrella for development and management (Neto de Carvalho, 2005a, 2008). The idea started with the *Cruziana* trace fossils from Penha Garcia and the need to protect them, leading to an unprecedented successful workshop that joined scientists and local politicians. The resulted integration of Naturtejo Geopark in the *European and Global Geoparks Network* (EGN/GGN) marked a turning point in the internationalization of a geologically-based tourism destination. EGN/GGN brands brought the prestige and centrality that differentiate Naturtejo

Geopark from surrounding tourism destinations, opening new ways for innovation and a golden opportunity for sustainability through best practices for convergence of Society and environment (Neto de Carvalho and Baucon, 2007; Neto de Carvalho and Rodrigues, 2010).



Fig. 4. Conservation, interpretation and education through fossils at Naturtejo Global Geopark: a) the keeper of the Ichnological Park of Penha Garcia, Mr. Domingos with the legendary “Painted Snakes”, *Cruziana furcifera* and *C. goldfussi*; b) and c) fossils to be touched at the “Palaeozoic Museum”, Penha Garcia; d) interpretation of the local fossils at the Archaeological Museum of Vila Velha de Ródão; e) using a disaster as an educational tool: the national impact of the stolen fossil tree trunk from Coutada; f) Deciphering *Cruziana* in the Geopark’s educational programmes; g) the young “meraspids” from Penha Garcia acclaiming their Geopark during a parade; h) educational programme in action; i) learning with fossils at Vila Velha de Ródão.

Fig. 4. Conservação, interpretação e educação através dos fósseis no Geoparque Naturtejo: a) o guarda do Parque Icnológico de Penha Garcia, Sr. Domingos, com as lendárias “Cobras Pintadas”, *Cruziana furcifera* e *C. goldfussi*; b) e c) fósseis para serem tocados no “Museu do Paleozóico”, em Penha Garcia; d) interpretação dos fósseis locais no Museu de Arqueologia de Vila Velha de Ródão; e) uso de um desastre como exemplo de educação para a cidadania: o impacto nacional que teve o furto da árvore fóssil da Coutada; f) decifrando *Cruziana* nos programas educativos do geoparque; g) os jovens “meraspídeos” de Penha Garcia celebrando o seu geoparque; h) programa educativo em acção; i) aprendendo com os fósseis em Vila Velha de Ródão.

Cruziana, those remarkable communication icons between long-extinct trilobites and the modern society starving for knowledge, allow multiple approaches in a palimpsest of interpretations, from popular and mythical to scientific that gain life and evolve with social demand (Neto de Carvalho, 2009). Fossils gain in our days a totally new opportunity to relate with society that sustains research and, at the same time, requests further discoveries to become evaded for daily life routine, fostering innovative approaches to tourism business and promotion as the ones being developed in Naturtejo Geopark and other geoparks and protected sites in Portugal and abroad (Neto de Carvalho, 2010; Fig. 5). May awareness raise about palaeontological heritage, if fully protected and well managed as it should be expect in an EGN/GGN, help for a citizenship more conscientious about our place in a sustainable Earth.



Fig. 5. Geotourist approach to *Cruziana* and trilobites at Naturtejo Geopark: a) Naturtejo Geopark with the Iberian Geoparks representing the Global Network of Geoparks under UNESCO at the International Tourism Trade Show of Madrid, FITUR; b) Terras d’Idanha olive oil branded with *Cruziana rugosa*; c) Casa do Forno georesort & outdoor activities leaving its own traces during a four by four thematic environmental visit, TTransGeopark; d) *Trilobites*, “the most ancient flavours” from Casa do Forno geobakery; e) Trilobite.Aventura active tourism company from the Ichnological Park of Penha Garcia during the official visit of the President of the Republic of Portugal; f) Trilobite.Aventura image for summer activities at Penha Garcia; g) guided thematic visits in the Fossils Trail of the Ichnological Park of Penha Garcia; h) “Making *Cruziana*”, an interactive videogame from the “From Trilobites to Man” travelling exhibition at the Petrified Forest Museum, Lesvos European and Global Geopark; i) Naturtejo Geopark participation in the closure event of the International Year of Planet Earth; j) Fossils Trail flyer.

Fig. 5. Abordagens geoturísticas à *Cruziana* e às trilobites no Geopark Naturtejo: a) Geopark Naturtejo conjuntamente com os geoparques ibéricos em representação da Rede Global de Geoparques na Feira Internacional de Turismo de Madrid, FITUR; b) Azeite Terras d’Idanha tendo no rótulo *Cruziana rugosa*; c) Casa do Forno georesort & actividades ar livre deixando as suas pistas durante uma visita todo-terreno de carácter ambiental, TTransGeopark; d) *Trilobites*, “os sabores mais antigos” da geo-padaria Casa do Forno; e) Trilobite.Aventura empresa de turismo activo no Parque Icnológico de Penha Garcia durante a visita oficial do Presidente da República, Professor Anibal Cavaco Silva; f) imagem da Trilobite.Aventura para as suas actividades de verão em Penha Garcia; g) visitas temáticas guiadas na Rota dos Fósseis do Parque Icnológico de Penha Garcia; h) “Faz *Cruziana*”, um jogo interativo incluído na exposição itinerante “Das Trilobites ao Homem” patente ao público no Museu da Floresta Petrificada, Lesvos European and Global Geopark; i) participação do Geopark Naturtejo no evento de encerramento do Ano Internacional do Planeta Terra; j) folheto da Rota dos Fósseis.

Acknowledgments

We thank the Geological Museum of LNEG for the permission to study the fossils from Naturtejo Geopark territory stored at their offices. To Monfortur for the permission to start the research fieldwork at Vale Feitoso. We acknowledge all the colleagues and friends that have been studying and supporting our work, contribution to raise the knowledge of the Naturtejo Geopark area. We also thank to reviewers for valuable comments.

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