New insights into the early evolution of horizontal spiral trace fossils and the age of the Brioverian series (Ediacaran–Cambrian) in Brittany, NW France

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Short title: Early evolution of horizontal spiral trace fossils

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Keywords: Ediacaran-Fortunian, ichnology, planispiral, *Spirodesmos*, U-Pb dating

1. Introduction

The potential of ichnology to decipher macro-evolutionary trends in animal behavior has a long history. Compilation of ichnological data was a major part of the work of A. Seilacher and P. Crimes. Seilacher (1974, 1977, 1986) focussed on the variety of graphoglyptid trace fossils from the deep-sea (i.e. patterned trace fossils forming nets, regular meanders and spirals), aiming to understand their environmental adaptation through time (e.g. size changes, functional optimization). Seilacher (1956) was the first to recognize the potential of trace fossils to delineate the Precambrian-Cambrian boundary; Crimes (1987, 1992*a*, 1994) extended this idea by reviewing worldwide literature, and developed an ichnostratigraphic scheme that helped defining the Cambrian GSSP (Narbonne *et al.* 1987; Brasier *et al.* 1994). In Crimes' comprehensive work, horizontal spiral trace fossils (as defined in this contribution) were consistently absent from the Ediacaran and the Cambrian (Crimes, 1987, 1992*a*, 1992*b*, 1994), only appearing by the Ordovician in the deep-marine realm (Crimes *et al.* 1974, 1992). Crimes suspected that most deep-marine graphoglyptids originated in shallow-marine environments during the Cambrian (Crimes, 1987; Crimes & Anderson, 1985; Crimes & Fedonkin, 1994), but the absence of regular planispiral trace fossils in the Cambrian was then problematic (Crimes *et al.* 1992).

The Ediacaran-Cambrian transition (*c.* 539 Ma) was a time of striking changes in Earth ecosystems. Ediacaran seafloors were dominated by microbially-stabilized surfaces on which epifaunal and very shallow infaunal grazers thrived (Seilacher & Pflüger, 1994; Gehling, 1999). Macroscopic animals of the earliest Cambrian started to disrupt the sediment at depth, affecting the substrate ventilation (e.g. Mángano & Buatois, 2014; Gougeon *et al.* 2018*a*), trophic webs (e.g. Bottjer *et al.* 2000; Meysman *et al.* 2006), and geochemical cycles (e.g. Logan *et al.* 1995; Canfield & Farquhar, 2009; Boyle *et al.* 2018). In northwestern France, the Brioverian of central Brittany is a thick siliciclastic succession that was deposited

during the Cadomian cycle (*c.* 750–540 Ma). Despite the report of fossils since the 19th century, the age of its uppermost beds (Ediacaran or early Cambrian) is a long-standing conundrum. Recently, new investigations unraveled a unique assemblage of trace and body fossils in the vicinity of Rennes (Néraudeau *et al.* 2016, 2019; Gougeon *et al.* 2018*b*, 2019). Trace fossils are dominantly simple, horizontal, and associated with microbially-stabilized surfaces; of these, planispirals stand as a surprising discovery.

The aim of this study is threefold: (1) to describe a new assemblage of planispiral trace fossils from the Brioverian of northwestern France; (2) to place this assemblage within a macro-evolutionary framework, and to interpret its significance; and (3) to provide new radiometric dating, in order to discuss the age of the uppermost Brioverian deposits.

2. General background

2.a. Geological setting and previous work

The Brioverian (*c.* 660–540 Ma; Le Corre *et al.* 1991; Guerrot *et al.* 1989, 1992) is an informal name given to a thick sedimentary succession deposited during the Cadomian cycle (*c.* 750–540 Ma) in northwestern France (Fig. 1a, b; Chantraine *et al.* 2001; Ballèvre *et al.* 2013). In the Rennes area (Fig. 1b), only the uppermost Brioverian beds are exposed, with a thickness evaluated at *c.* 1300 m (Trautmann *et al.* 1999). The Brioverian of Brittany lies unconformably on an Icartian basement (*c.* 2200–1800 Ma) and is unconformably overlain either by the Ordovician Red Bed Series (‘Séries Rouges Initiales’) or by the Ordovician Armorican Sandstone (‘Grès Armoricain’; Cogné, 1959; D’Lemos *et al.* 1990; Le Corre *et al.* 1991). The terrigenous siliciclastic sediments of the Brioverian resulted from the erosion of the Cadomian belt in northern Brittany and accumulated in a marginal, intra-plate basin in central Brittany (Denis, 1988; Dissler *et al.* 1988; Rabu *et al.* 1990; Dabard *et al.* 1996). Locally, carbonaceous cherts (‘phtanites’), limestones, and igneous intrusions have also been

reported (Denis & Dabard, 1988; Dabard, 1990, 2000; Chantraine *et al.* 2001). On a regional scale, the correlation of the Brioverian sedimentary deposits is hindered by the discontinuous outcropping, facies changes, the absence of biostratigraphic markers, and the metamorphic overprint from the Devonian-Carboniferous Variscan orogeny (Denis & Dabard, 1988; D'Lemos *et al.* 1990; Le Corre *et al.* 1991; Ballèvre *et al.* 2013). While traditionally interpreted as deeper-marine turbiditic deposits (Dangeard *et al.* 1961; Denis, 1988; Trautmann *et al.* 1999), the Brioverian sedimentary beds also show evidence of shallow-marine storm-influenced (Dabard & Loi, 1998; Dabard & Simon, 2011) and marginal-marine tidally-influenced conditions (Graindor, 1957; Dabard, 1990, 2000; Néraudeau *et al.* 2019).

[insert Figure 1]

Fossils recovered from the Brioverian are algal or bacterial organic-walled microfossils in cherts and limestones (Cayeux, 1894; Deflandre, 1955; Chauvel & Schopf, 1978; Chauvel & Mansuy, 1981; Mansuy & Vidal, 1983), macroscopic body fossils of unknown origin (Néraudeau *et al.* 2019), and trace fossils. Ichnofossils were first discovered in the late 19th century (Lebesconte, 1886), but did not draw the attention of the scientific community for a long time. Recently, new investigations in the vicinity of Rennes (Fig. 1b) have unraveled an assemblage dominated by simple horizontal grazing trails (*Circulichnis, Gordia*, *Helminthoidichnites*, *Helminthopsis*), passively-filled horizontal burrows (*Palaeophycus*), and horizontal spiral trace fossils (*Spirodesmos*; Néraudeau *et al.* 2016; Gougeon *et al.* 2018*b*, 2019). In addition, microbially-textured surfaces (MISS of Noffke *et al.* 2001) are common both in fossiliferous and azoic intervals (Lebesconte, 1886; Gougeon *et al.* 2018*b*).

The age of the uppermost Brioverian sedimentary beds in Brittany, Normandy, and Mayenne, has been highly debated (Fig. 1b). In Brittany, the overlying Red Bed Series gave an age of 472 ± 5 Ma (Rb-Sr dating from volcanic rocks; Auvray *et al.* 1980), 465 ± 1 Ma (U-

Pb dating from volcanic rocks; Bonjour *et al.* 1988; Bonjour & Odin, 1989), and 486 ± 28 Ma (Pb-Pb dating from volcanic rocks; Guerrot *et al.* 1992), placing these beds within the Ordovician period (*contra* McMahon *et al.* 2017; Went, 2017). In the westernmost part of Brittany (Crozon area; Fig. 1b), Guerrot *et al.* (1992) obtained an age of 543 ± 18 Ma (Pb-Pb dating) for a tuff intercalated within Brioverian beds, whereas a maximum deposition age of 546 ± 2 Ma (U-Pb dating) has been obtained by Ballouard *et al.* (2018) from detrital zircon grains extracted from a sandstone (see also Dabard *et al.* 2021). In the vicinity of Rennes (Fig. 1b), detrital zircon grains gave a maximum deposition age of *c.* 550 Ma (U-Pb dating from sandstone and siltstone; Gougeon *et al.* 2018*b*); however, five zircon grains, dated at 532.1 ± 3.9 Ma, were problematic to interpret (Gougeon *et al.* 2018*b*). In Normandy, Brioverian sediments were deposited in a different palaeogeographic domain than in central Brittany, as they are separated by the North-Armorican Shear Zone (Fig. 1b; Chantraine *et al.* 1982; Guerrot *et al.* 1992). In this domain, granitoid intrusions within Brioverian sediments have been dated at 540 ± 10 Ma (U-Pb dating on monazite; Pasteels & Doré, 1982). In Mayenne, where the Brioverian is in continuity with its equivalent of central Brittany (Fig. 1b), radiometric dating on zircon grains yielded an age of 540 ± 17 Ma (tuff and detrital horizons; Guerrot *et al.* 1992).

2.b. Outcrops under study and depositional environments

The outcrop at ‘La Lammerais’ village nearby St-Gonlay (Fig. 1b) yields slates with trace fossils, stacked in a pile about two metres high and fifty metres long (outcrops for this contribution are located on private properties, which do not allow details on their exact locations). These slates were extracted from a pit that was exploited by locals to build houses and pathways decades ago; unfortunately, the pit is now covered with vegetation and therefore impossible to sample *in situ*. Slates are made of siltstone and rare very fine- to fine-grained sandstone. One loose sandstone sample was collected for U-Pb dating, coming from a

nearby agricultural field. At 'La Lammerais' outcrop, sedimentary structures are parallel-lamination organised in siltstone-sandstone bundles (i.e. rhythmite-like; Néraudeau *et al.* 2019, fig. 3), current-ripples (Néraudeau *et al.* 2019, fig. 2), tool-marks/spindle-shaped flute-marks, possible load-casts, and pustular and wrinkled microbially-textured surfaces (Gougeon *et al.* 2018*b*, figs 4, 7).

Nearby St-Gonlay, another outcrop has been investigated at 'Le Lorinou' village, located 1.4 kilometres to the east of 'La Lammerais'. This outcrop is very poor in trace fossils (no spiral trace fossils were found there), but beds are preserved *in situ* and a sandstone sample was collected for U-Pb zircon dating.

The outcrop of 'Le Bois-du-Buisson' is located at the entrance of a small forest in Montfort-sur-Meu (Fig. 1b). It consists of a small quarry of about three metres high and ten metres long, with vegetation extensively covering the sedimentary beds. However, a few siltstone beds are accessible and reveal fresh surfaces with trace fossils. Sedimentary structures are parallel-lamination organised in siltstone-sandstone bundles (i.e. rhythmite-like, similarly to what is found at 'La Lammerais'), and pustular and wrinkled microbially-stabilized surfaces.

In addition, Montfort-sur-Meu is the host of 'Les Grippeaux' quarry, where P. Lebesconte recovered fossils for the first time in the late 19th century (Lebesconte, 1886; Gougeon *et al.* 2018*b*). Nowadays, the quarry is secured by a fence preventing any access. Many samples were collected in the late 19th and early 20th century by P. Lebesconte, F. Kerforne, and other geologists; they are housed at the Geological Institute of the University of Rennes 1 and at the Museum of Natural History of Nantes, and are available for study. Sedimentary structures are pustular microbially-stabilized surfaces.

The outcrop in Crozon (Fig. 1b) is located on the coastal cliff at 'La Plage-du-Goulien'. This outcrop has not been visited by the authors, and the only trace fossil discovered was reported by E. Hanson in 2014 (pers. comm.). The sedimentology of the Brioverian from the Bay of Douarnenez and the Cove of Dinan (both in the vicinity of Crozon) has been studied in two doctoral theses (Darboux, unpubl. Ph.D. thesis, University of Brest, 1973; Denis, 1988). The succession displays parallel-laminated/bedded sandstone and siltstone with flute-casts, load-casts, tool-marks, rip-up clasts, carbonate concretions, normal and reverse grading, convolute bedding, flame structures, and current, wave, and climbing ripples. Both authors interpreted the succession as deposited by turbidites, located either below the limit of the storm wave-base action, or deeper in an abyssal plain. However, Denis (1988) noted the presence of oscillatory flow structures, lenticular bedding (Facies 3 of Denis, 1988) and mud-drapes, which are more typical of shallower environments.

In Montfort-sur-Meu and St-Gonlay, the dominance of siltstone intercalated with laminated very fine-grained sandstone, and the record of rhythmite-like bundles and current ripples, suggest a marginal-marine, tidally-influenced depositional environment (cf. Nio & Yang, 1991; Tessier *et al.* 1995; Dalrymple, 2010). This conclusion is strengthened by observations in Chanteloup and Nouvoitou (both in the vicinity of Rennes), where a sandstone facies displays mudstone drapes within fine-grained sandstone samples (i.e. flaser lamination; Supplementary Figure 1); these areas could represent the seaward, sandier part of the intertidal system. Sedimentary structures made by oscillatory flows (e.g. wave ripples, hummocky cross-stratification) have not been observed in the area so far. These conclusions are preliminary and await further support, notably from Brioverian outcrops revealing bedding architecture, and from more sampling of sedimentary structures.

3. Material and methods

3.a. Terminology of planispiral trace fossils

This contribution focusses only on spirals formed on a horizontal plane (i.e. planispirals). Three-dimensional, vertically (e.g. *Gyrolithes*, *Lapispira*) or horizontally (e.g. *Avetoichnus*, *Helicodromites*, *Helicolithus*) oriented spirals, are not comparable with the Brioverian material. In order to describe spiral morphologies, the following terms will be used: a *regular* spiral maintains a constant distance between whorls (Fig. 2b, c); an *irregular* spiral has a variable distance between whorls (Fig. 2a, d); a *one-way* spiral is a simple spiral with no central turnaround (Fig. 2a, b, d; Seilacher, 1977; Crimes & McCall, 1995); a *two-way* spiral is a double spiral with a central turnaround (Fig. 2c; Seilacher, 1977; Crimes & McCall, 1995); and a *bounded* spiral is an irregular, one-way spiral that decreases the distance between whorls outward (Fig. 2d).

[insert Figure 2]

3.b. U-Pb dating method

A classic mineral separation procedure has been applied to concentrate zircon grains for U-Pb dating. Rocks were crushed and only the powder fraction with a diameter < 250 µm was kept. Heavy minerals were successively concentrated by Wilfley table, heavy liquids, and with an isodynamic Frantz separator. Zircon grains were then handpicked under a binocular microscope to produce the most representative sampling, with the aim to avoid any intentional bias (see Malusà *et al.* 2013 and references therein). Selected grains were then embedded in epoxy mounts, grounded and polished. Zircon grains were imaged by cathodoluminescence (CL) using a Reliotron CL system equipped with a digital color camera available at the GeOHeLiS analytical platform (University of Rennes 1).

U-Pb geochronology was conducted by *in situ* laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) at the GeOHeLiS analytical platform using an ESI NWR193UC Excimer laser coupled to a quadripole Agilent 7700x ICP-MS. Instrumental

conditions are reported in Supplementary Table S1, while the analytical protocol can be found in Manzotti *et al.* (2015). Kernel density diagrams for analyses that are 100 ± 10% concordant were generated using IsoplotR (Vermeesch, 2018). When dealing with detrital zircon geochronology, a minimum of 3 different ages obtained on 3 different zircon grains overlapping in age at 2σ has been demonstrated to produce a statistically robust maximum deposition age (Dickinson & Gehrels, 2009). The second important criteria in order to determine this maximum deposition age is the degree of concordance of the individual analysis used to calculate this age. Most authors consider all analyses that are 90% concordant or more, while others only analyses that are at least 95% concordant. In this study, because of the complexity of one of the data set ('La Lammerais'), only analyses that were at least 95% concordant were considered to calculate the maximum deposition age, in order to avoid using apparent ages that could be younger than the true age due to a non-negligible Pb loss.

3.c. Museum repository

From 'La Lammerais' and 'Le Bois-du-Buisson', samples were collected and reposited at the Geological Institute of the University of Rennes 1 (collections Gougeon and Néraudeau). Historical specimens from 'Les Grippeaux' are reposited at the Museum of Natural History of Nantes (collections Barrois and Lebesconte) and the Geological Institute of the University of Rennes 1 (collections Kerforne, Rolland and Rouault). The trace fossil from 'La Plage-du-Goulien' has not been collected and was only photographed in the field by E. Hanson.

4. Results

4. a. Planispiral trace fossils from the Brioverian

The Brioverian of central Brittany contains a rich assemblage of simple horizontal trace fossils, with *Helminthoidichnites* and *Helminthopsis* being the most common forms.

Originally, Lebesconte (1886, pl. 34, fig. 7) figured a planispiral trace fossil from Montfort-sur-Meu, without further discussion. Since then, spiral trace fossils have not been reported in the Brioverian. Here, we describe two types of planispiral trace fossils: (1) irregular, one-way spiral trace fossils; and (2) regular, one-way spiral trace fossils.

[insert Figure 3]

Four irregular, one-way spiral trace fossils were recovered from 'La Lammerais', 'Le Bois-du-Buisson', and 'Les Grippeaux' (Fig. 3a). Specimens are 0.3–1 mm wide, have 1¼–1¾ whorls, and are preserved in positive and negative reliefs (preservation as epirelief or hyporelief is unknown because slates with trace fossils are not preserved *in situ*). One specimen (Fig. 3a) has a different infill than the host rock and a lining; this is potentially a burrow. Rarely, they are associated with *Helminthoidichnites*, small-scale branching trace fossils (cf. *Pilichnus*), and pits of uncertain affinity. They are commonly found on pustular microbially-textured surfaces.

Two regular, one-way spiral trace fossils were recovered from 'La Plage-du-Goulien' and 'Les Grippeaux' (Fig. 3b, c). Specimens are 1–3 mm wide, have 2¼–2½ whorls, and are preserved in positive and negative reliefs. The distance between whorls remains constant until the last whorl, where the course detaches from the spiral system and progressively disappears. They are associated with *Helminthopsis* and pits of uncertain affinity. The surfaces they are found on are not textured.

Spirodesmos, *Spirophycus* and *Spirorhaphe* are the most common planispirals from the trace fossil record: however, their morphological boundaries are unclear. *Spirodesmos* is a regular to irregular, one-way spiral trace fossil (Geinitz, 1867; Andrée, 1920; Huckriede, 1952; Xia *et al.* 1987). For Seilacher (1977), *Spirodesmos* has a wide spacing between whorls; although this is clearly so in the type ichnospecies *S. interruptus* Andrée, 1920, *S.*

archimedeus Huckriede, 1952 has a narrower spacing between whorls. This issue becomes critical with *Spirodesmos kaihuaensis* Xia, He & Hu, 1987 and *S. spiralis* (Geinitz, 1867), both having irregular courses with variable distances between whorls. *Spirophycus* is a regular to irregular, one-way spiral trace fossil that commonly grades into meanders (Heer, 1876; Häntzschel, 1975). Seilacher (1977) argued that *Spirophycus* has wide strings with a tubercular surface and backfilled laminae (see also Książkiewicz, 1977; but see Uchman, 1998). The spiral portion of *Spirophycus* (e.g. Heer, 1876, pl. 66, fig. b; Sacco, 1888, pl. 2, fig. 14), with regular whorls distinctly spaced from each other, can however be very similar to *Spirodesmos archimedeus*. *Spirorhaphe* is a regular to irregular spiral trace fossil with either a one-way (*S. azteca, S. graeca*) or two-way (*S. involuta*) course (Seilacher, 1977; Crimes & McCall, 1995). The inclusion of one-way spirals in *Spirorhaphe* is overlapping with *Spirodesmos* and *Spirophycus* morphologies, which is problematic.

Despite these taxonomical issues (see also Crimes & Crossley, 1991; Uchman, 1998; Minter & Braddy, 2009), planispirals from the Brioverian are comparable to *Spirodesmos*. Brioverian irregular, one-way spiral trace fossils are reminiscent of *Spirodesmos spiralis* (cf. Geinitz, 1867; Stepanek & Geyer, 1989). However, because of its irregular course and the poor extent of its whorls, *Spirodesmos spiralis* needs to be re-evaluated taxonomically; in this study, Brioverian forms are referred to *Spirodesmos* isp. Conversely, Brioverian regular, one-way spiral trace fossils belong to *Spirodesmos archimedeus (*cf. Huckriede, 1952; Zapletal & Pek, 1971; Horn, 1989). *Spirodesmos* ranges from the Ediacaran-Cambrian (this study) to the Holocene (e.g. Kitchell *et al.* 1978; Smith *et al.* 2005).

4.b. U-Pb dating

For the sandstone sample from ‘La Lammerais’, 118 zircon grains were analysed, among which 107 analyses have a concordance of 100 ± 10%. Their U (49 to 1195 ppm) and Pb (6 to 493 ppm) contents, as well as their Th/U ratios (0.02 to 1), are highly variable

(Supplementary Table S2). A first group of 12 analyses yields apparent ages between 2.8 and 1.06 Ga. The remaining analyses form two major peaks at 600 Ma and 550 Ma, with minor peaks around 850 and 650 Ma (Fig. 1c). The 10 youngest analyses that are more than 95% concordant yield a weighted average $^{206}Pb/^{238}U$ date of 540 ± 5 Ma (MSWD = 1.2) that we consider as the maximum deposition age for this sandstone.

For the sandstone sample from 'Le Lorinou', 89 grains were analysed, out of which 68 are 100 ± 10% concordant (Supplementary Table S2). They are characterized by variable U and Pb contents (21 to 726 ppm and 2 to 242 ppm, respectively), with Th/U ratios between 0.05 and 1.4. A first group of 22 zircon grains yields Neoarchean (2.9 Ga) to Palaeoproterozoic ages (1.8 Ga), followed by a gap until the end of the Mesoproterozoic. The remaining grains present apparent ages around 1000, 900, 800, and 680, with a major peak around 600 Ma (Fig. 1c). The youngest three grains provide a weighted $^{206}Pb/^{238}U$ date of 551 ± 7 Ma (MSWD = 0.009) that we consider as the maximum deposition age for this sandstone.

6. Discussion

6.a. Radiometric age of the uppermost Brioverian beds with trace fossils

At 'Le Lorinou' (St-Gonlay), zircon grains from a sandstone bed associated with trace fossils yielded a maximum deposition age of 551 ± 7 Ma, whereas zircon grains from a loose sandstone sample at 'La Lammerais' (St-Gonlay) gave a maximum deposition age of 540 ± 5 Ma (this study). In Crozon, the youngest U-Pb dating on zircon grains from Brioverian tuff gave an age of 543 ± 18 Ma (Guerrot *et al.* 1992), whereas another U-Pb dating on zircon grains from a sandstone gave a maximum deposition age of 546 ± 2 Ma (Ballouard *et al.* 2018). In Montfort-sur-Meu, no radiometric dating has been done so far.

The radiometric age for the base of the Cambrian is given by U-Pb dating on zircon grains from tuff in southern Oman, dated at 541.0 ± 0.13 Ma (Bowring *et al.* 2007). However,

recent U-Pb dating on zircon grains from tuff in southern Namibia constrained the age of the basal Cambrian within a 538.6–538.8 Ma interval (Linnemann *et al.* 2019). If we consider a radiometric age of *c.* 539 Ma for the base of the Cambrian, the Brioverian of Crozon could either be Ediacaran (*c.* 635–539 Ma) or younger, while the Brioverian of St-Gonlay could be Ediacaran but is suspected to be Fortunian (*c.* 539–529 Ma) or younger. Indeed, the new results of this study agree with earlier dating elsewhere (maximum deposition age of *c.* 550 Ma in Néant-sur-Yvel, Brittany, with 5 zircons grains dated at 532.1 ± 3.9 Ma; 540 ± 10 Ma in Normandy; and 540 ± 17 Ma in Mayenne; Pasteels & Doré, 1982; Guerrot *et al.* 1992; Gougeon *et al.* 2018*b*) and suggest an early Cambrian age for the uppermost Brioverian beds, from a radiometric standpoint (see also Guerrot *et al.* 1989, 1992; Dabard *et al.* 2021). In terms of trace fossil biostratigraphy, the matground ecology of the Brioverian is more typical of late Ediacaran assemblages (Gougeon *et al.* 2018*b*). Because of the differences provided by these two proxies (radiometric dating and ichnostratigraphy), definitive conclusions on the age of the uppermost Brioverian beds with trace fossils are not possible, at this point.

6.b. Critical review on Ediacaran and Cambrian planispiral trace fossils

Several trace fossils inaccurately described or suggested to be planispirals, have been reported from the Ediacaran and the Cambrian. Fedonkin (1985, 1990) erected *Planispiralichnus* Fedonkin, 1985 and *Protospiralichnus* Fedonkin, 1985 from the Fortunian Kessyuse Formation (Fm.) of northern Russia. *Planispiralichnus* is made of dense, overlapping loops (Fedonkin, 1990; Marusin & Kuper, 2020), whereas *Protospiralichnus* starts as a bounded spiral until it scribbles abundantly (Fedonkin, 1990); because of their scribbling patterns, neither of them represent spirals (Buatois *et al.* 2017). Jenkins (1995, pl. 2, fig. E) reported cf. *Protospiralichnus* from the Ediacaran Rawnsley Quartzite of southern Australia; the development of a full circle and/or a loop affiliates this trace fossil to *Circulichnis* or *Gordia* instead (see also Buatois & Mángano, 2016, fig. 2.8e).

Multilaqueichnus Yang & Yin, 1982 from the Cambrian Stage 3 Jiulaodong Fm. of central China has overlapping loops (Yang *et al.* 1982, pl. 2, fig. 1); these trace fossils distinctly scribble and are not spirals either (*contra* Mángano & Buatois, 2016, 2020). Finally, a trace fossil from the Fortunian part of the Chapel Island Fm. of eastern Canada was considered a spiral by Crimes & Fedonkin (1994, fig. 2i). This trace fossil has been observed in the field by one of the authors (R. G.) and represents the scribbling burrow of a large infaunal deposit-feeder.

In addition, non-ichnological structures from the Ediacaran and the Cambrian have been mistaken for planispiral trace fossils. An important debate arose with the report of Precambrian spiral fossils from the Lower Vindhyan Limestone of northeastern India (Beer, 1919) and from the Belt Series of northwestern USA (Walcott, 1899). Both authors suggested a trace fossil origin, an opinion followed by Seilacher (1956). However, Cloud (1968) suspected an algal origin, and re-evaluation of both materials confirmed that view (Walter *et al.* 1976; Runnegar, 1991). *Arenicolites spiralis* Billings, 1872 and *Helminthoidichnites sangshuanensis* (Du, 1986) in Yan & Liu, 1998 are certainly of similar algal affinity (Hofmann, 1971; Walter *et al.* 1990; Shaowu, 1998). Furthermore, Aceñolaza (2005) reported circular structures from the Cambrian Mesón Group of northwestern Argentina, and erected the new ichnospecies *Spirodesmos milanai*; Minter *et al.* (2006) argued these structures were formed by shrinkage cracks in matgrounds instead (cf. Pflüger, 1999; Buatois *et al.* 2013; Sedorko *et al.* 2019).

Finally, rare horizontal spiral trace fossils have been reported from the Ediacaran and the Cambrian. *Planispiralichnus rarus* Menasova, 2003 is a one-way spiral trace fossil discovered in the Fortunian Khmelnitsky Fm. of western Ukraine. The holotype is made of 3 whorls, with angular intervals along the course; the first two whorls are continuous, while the last one is made of unconnected segments (Ivantsov *et al.* 2015, pl. 7, fig. 4a, b). This

specimen possesses the key features of a spiral trace fossil and should not be affiliated to *Planispiralichnus* as described by Fedonkin (1990). Jensen & Palacios (2016, fig. 4b) reported one-way spiral trace fossils from the Ediacaran-Fortunian Cíjara Fm. of central Spain. The photographed specimen is a continuous to discontinuous trail, with 2½ whorls and an irregular course. Carbone & Narbonne (2014, fig. 4.5) also figured an irregular one-way spiral with 1¾ whorls and a continuous course from the Fortunian part of the Ingta Fm. of northwestern Canada. Finally, Runnegar (1992, fig. 3.9) figured an irregular two-way spiral transitional with a meandering trace fossil from the Ediacaran Rawnsley Quartzite of southern Australia. Jensen (2003) considered this trace fossil to represent *Helminthorhaphe* grading into *Spirorhaphe*.

6.c. Macro-evolutionary profile and onshore-offshore migration

Our detailed literature review (Section 6.b above and Supplementary Material) unraveled the environmental and temporal distribution of *Spirodesmos* (Fig. 4). The Ediacaran-Fortunian is then marked by the appearance of a *Spirodesmos* pool, composed of irregular and regular forms colonizing marginal-marine to shelf environments. The Brioverian assemblage represents a key component of that pool, holding the oldest regular one-way planispirals (*Spirodesmos archimedeus*) both in marginal-marine and open shelf settings (in Montfort-sur-Meu and Crozon, respectively). During the Ediacaran and the Cambrian, deposit-feeding was the dominant feeding strategy (MacNaughton & Narbonne, 1999; Carbone & Narbonne, 2014), and early *Spirodesmos* were arguably made by epifaunal detritus-feeders and shallow-infaunal deposit-feeders. Indeed, 'surplus stretches' as observed in *Spirorhaphe* and inferring open-burrow systems (Seilacher, 1967*a*, *b*, 1977) have not been observed in Ediacaran-Fortunian material. Moreover, Ediacaran-Fortunian *Spirodesmos* are often preserved on microbially-stabilized surfaces, which could represent the nutritive resource of their tracemaker (Carbone & Narbonne, 2014). Possible producers are

enteropneusts and nematodes, both suspected to first appear during the Cambrian or before (Knoll & Carroll, 1999; Budd & Jensen, 2000; Maletz, 2014; Cunningham *et al.* 2017). Enteropneusts produce regular horizontal spirals on the modern deep-sea floor on areas of greater nutritional values, using tactile sensory systems in their head (Lemche *et al.* 1976; Smith *et al.* 2005; Jones *et al.* 2013). Nematodes spiral by contracting all the muscles of one side of their body (Wharton, 2004). However, spiraling in nematodes has been suggested for other purposes than feeding (e.g. responses to increasing temperature, osmotic stress, desiccation, and for reproduction; Huettel, 2004; Wharton, 2004).

[insert Figure 4]

Although deep-marine deposits with trace fossils have been reported both from the Ediacaran (e.g. Narbonne & Hofmann, 1987; Liu *et al.* 2010) and the Cambrian (e.g. Hofmann *et al.* 1994; Seilacher *et al.* 2005), planispirals are consistently absent. However, planispirals are common through the rest of the Phanerozoic in the deep-sea, and *Spirodesmos* forms a conspicuous Ordovician–Recent deep-marine trend (Fig. 4 and Supplementary Material). Deep-marine seafloors are characterized by an absence of light, high hydrostatic pressure, oxygen and temperature fluctuations, and low nutrient content (Sanders & Hessler, 1969; Gage & Tyler, 1991, pp. 9–29; Rex & Etter, 2010, pp. 1–49). These stressful conditions play an important role on animal fitness and their physiology (e.g. Childress & Thuesen, 1992; Yancey *et al.* 2004; van der Grient & Rogers, 2015). However, with the increased competition for space and food on early Cambrian shelves (Orr, 2001), planispiral tracemakers may have adapted their metabolisms to the deep-sea. An onshore-offshore migration in *Spirodesmos* is then suggested from the Ediacaran-Fortunian to the Ordovician, similarly to the migration observed in graphoglyptids (Crimes & Anderson, 1985; Crimes *et al.* 1992; Crimes & Fedonkin, 1994; Orr, 2001; Uchman, 2003). The existence of an onshore-offshore migration is also reinforced by the presence of an important gap (*c.* 230 Ma) between

the Ediacaran-Fortunian *Spirodesmos* pool, and the next shallow-marine *Spirodesmos* report from the Permian Vryheid Fm. of eastern South Africa (Mason *et al.* 1983; Fig. 4).

7. Conclusion

The age of the uppermost Brioverian deposits of central Brittany, northwestern France, is a long-standing question. Here, two U-Pb detrital zircon grain dating on sandstone samples collected in St-Gonlay gave maximum depositional ages of 551 ± 7 Ma and 540 ± 5 Ma. Although an Ediacaran age for the uppermost Brioverian beds cannot be discarded, a Fortunian age is suggested in this study, following previous dating in Brittany, Normandy, and Mayenne. However, the intervals of error of the radiometric dating and trace fossil biostratigraphy do not allow definitive conclusions.

A unique assemblage of irregular and regular, one-way planispiral trace fossils of *Spirodesmos* affinity has been recovered from the uppermost Brioverian beds in Crozon, Montfort-sur-Meu, and St-Gonlay. Planispiral trace fossils are unusual in the Ediacaran and the Cambrian, and an in-depth literature review revealed that the Brioverian assemblage belonged to an Ediacaran-Fortunian, marginal-marine to shelf *Spirodesmos* pool. Ediacaran-Fortunian *Spirodesmos* were arguably made by detritus- or deposit-feeders, possibly related to enteropneusts or nematodes. However, by the Ordovician, *Spirodesmos* became conspicuous mostly in the deep-marine realm, underscoring an onshore-offshore migration similar to what has been reported in graphoglyptids.

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Declaration of Interest

None.

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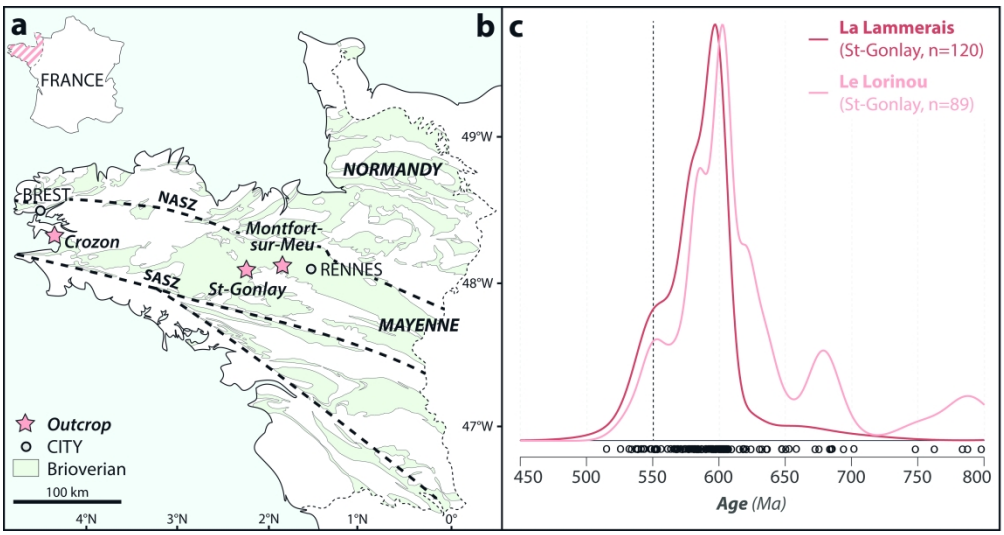
Figure 1. Geological map of northwestern France, and new U-Pb dating. (a) Location of the Brioverian deposits in northwestern France. (b) Close-up showing the Brioverian deposits, and the three localities with planispiral trace fossils. NASZ = North-Armorican Shear Zone; SASZ = South-Armorican Shear Zone. (c) Kernel Density Estimation diagrams for 'La Lammerais' and 'Le Lorinou' samples.

Figure 2. Terminology of planispirals. (a) An irregular one-way spiral. (b) A regular one-way spiral. (c) A regular two-way spiral. (d) A bounded spiral. See text for further explanations.

Figure 3. *Spirodesmos* isp. and *Spirodesmos archimedeus* from the uppermost Brioverian beds of Brittany. (a) *Spirodesmos* isp. (irregular one-way spiral trace fossil) from 'Le Bois-du-Buisson'. (b, c) *Spirodesmos archimedeus* (regular one-way spiral trace fossils) from 'Les Grippeaux' (b) and 'La Plage-du-Goulien' (c). Scale bars are 1 cm across.

Figure 4. Macro-evolutionary profile of *Spirodesmos* comparable to the Brioverian material, with emphasis on the Ediacaran and the Cambrian (colored diagrams). Positions suggested for the Brioverian material are emphasized by diagrams with dashed lines. Brioverian *Spirodesmos* belonged to an Ediacaran-Fortunian, marginal-marine to shelf pool. A *Spirodesmos* onshore-offshore migration is suggested, from the Ediacaran-Fortunian to the Ordovician. See text for further explanations.



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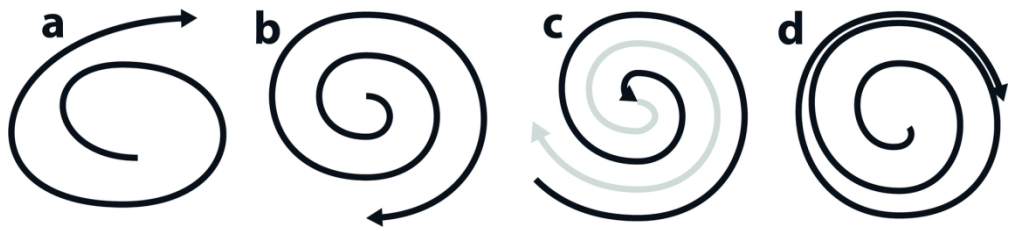

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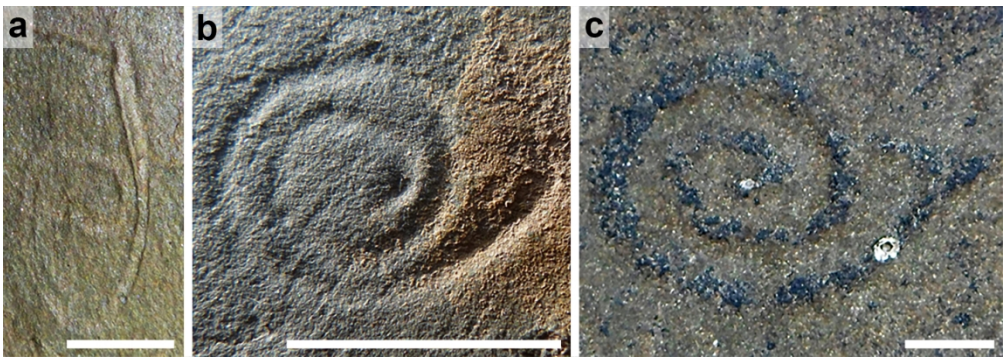

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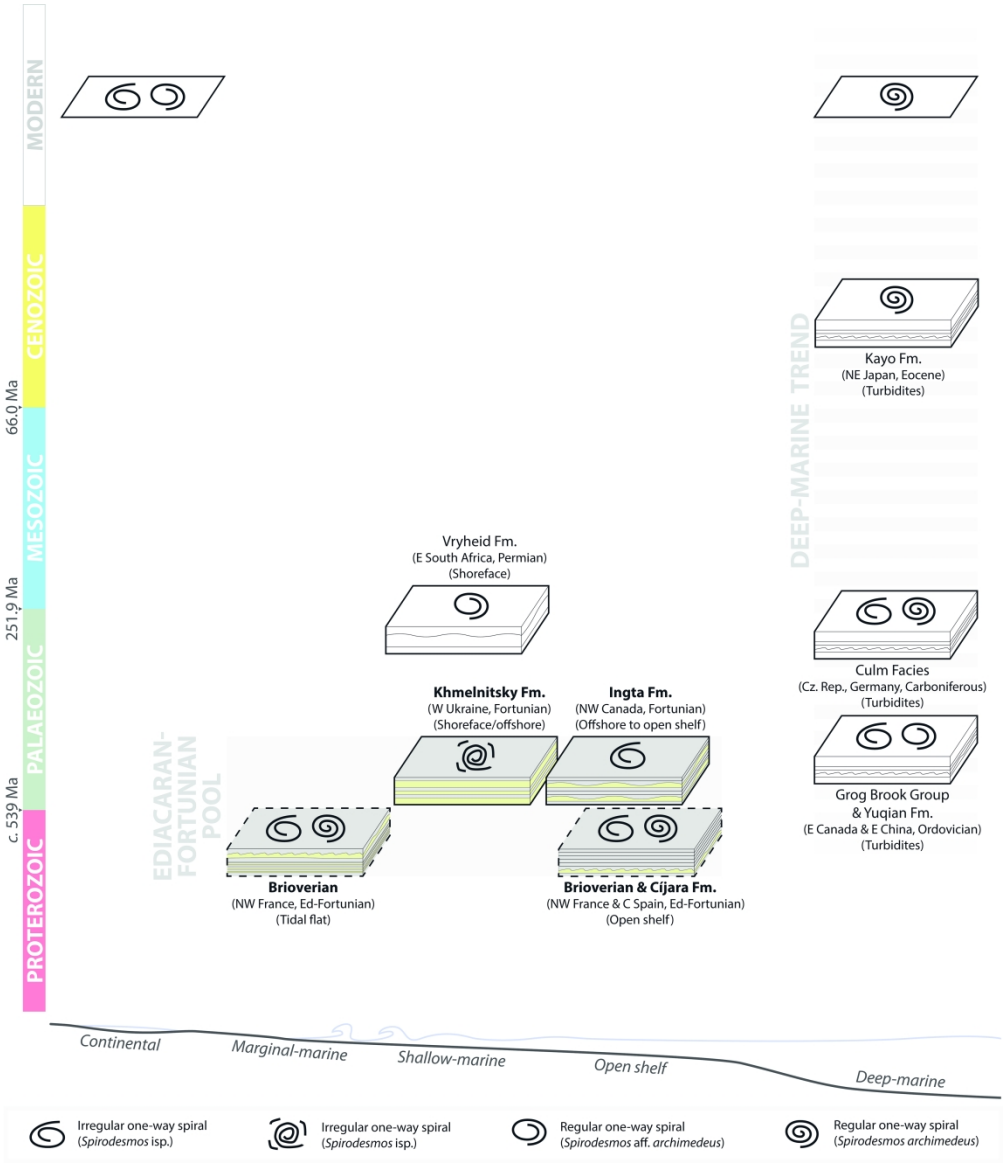

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168x195mm (600 x 600 DPI)

Geological Magazine

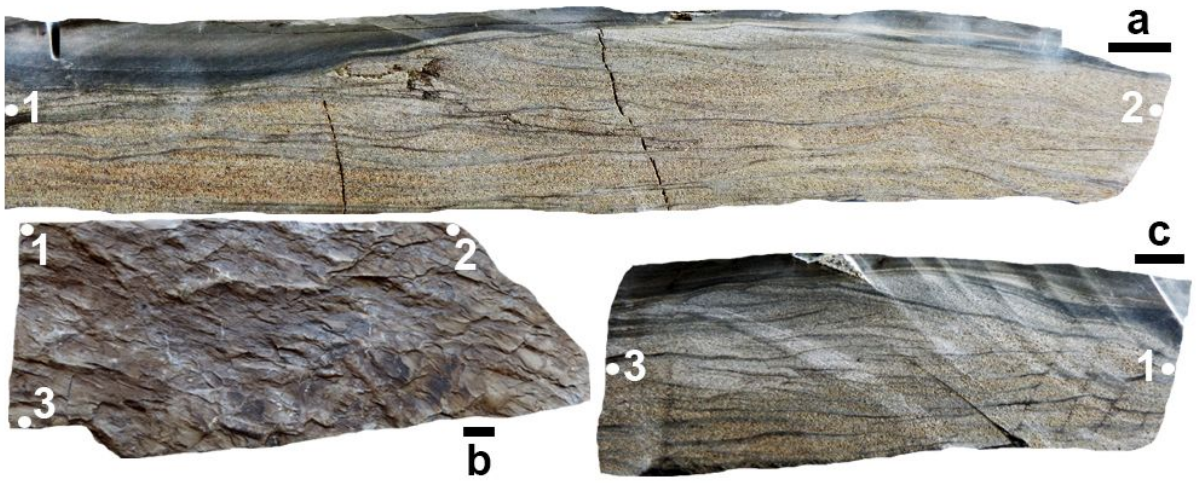
New insights on the early evolution of horizontal spiral trace fossils and the age of the Brioverian (Ediacaran-Cambrian) in Brittany, NW France

Romain Gougeon,, Didier Néraudeau, Alfredo Loi and Marc Poujol

Supplementary Material

Laboratory & Sample Preparation	
Laboratory name	GeOHeLiS Analytical Platform (OSUR, Univ. Rennes 1)
Sample type/mineral	Zircon
Sample preparation	Conventional mineral separation, 1 inch resin mount, 1micron polish to finish
Imaging	RELION CL instrument, Olympus Microscope BX51WI, Leica Color Camera DFC 420C
Laser ablation system	
Make, Model & type	ESI NWR193UC, Excimer
Ablation cell	ESI NWR TwoVol2
Laser wavelength	193 nm
Pulse width	< 5 ns
Fluence	7.4 J/cm^2
Repetition rate	3Hz
Spot size	20 µm
Sampling mode / pattern	Single spot
Carrier gas	100% He, Ar make-up gas and N2 (3 ml/mn) combined using in-house smoothing device
Background collection	20 seconds
Ablation duration	60 seconds
Wash-out delay	15 seconds
Cell carrier gas flow (He)	0.75 l/min
ICP-MS Instrument	
Make, Model & type	Agilent 7700x, Q-ICP-MS
Sample introduction	Via conventional tubing
RF power	1350W
Sampler, skimmer cones	Ni
Extraction lenses	X type
Make-up gas flow (Ar)	0.80 l/min
Detection system	Single collector secondary electron multiplier
Data acquisition protocol	Time-resolved analysis
Scanning mode	Peak hopping, one point per peak
Detector mode	Pulse counting, dead time correction applied, and analog mode when signal intensity > ~ 10^6 cps
Masses measured	^{204}(Hg + Pb), ^{206}Pb, ^{207}Pb, ^{208}Pb, ^{232}Th, ^{238}U
Integration time / peak	10–30 ms (^{207}Pb)
Sensitivity / Efficiency	22000 cps/ppm Pb (50µm, 10Hz)
Data Processing	
Gas blank	20 seconds on-peak
Calibration strategy	GJ1 zircon standard used as primary reference material, Plešovice used as secondary reference material (quality control)
Common-Pb correction	No common-Pb correction.
Reference Material info	GJ1 (Jackson *et al.* 2004), Plešovice (Sláma *et al.* 2008)
Data processing package	Glitter (Van Achterbergh *et al.* 2001)
Uncertainty level and propagation	Ages are quoted at 2 sigma absolute, propagation is by quadratic addition according to Horstwood *et al.* (2016). Reproducibility and age uncertainty of reference material are propagated.
Quality control/ Validation	Plešovice: concordia age = 336.9± 2.0 Ma (N=36; MSWD=1.7)

Supplementary Table S1. Operating conditions for the LA-ICP-MS equipment.



Supplementary Figure 1. A fine-grained sandstone sample from Chanteloup under three different views (a, c: side views; b: surface view) showing abundant and discontinuous mud-drapes (i.e. flaser-lamination; cf. Nichols, 2009, fig. 4.37). The numbers are marker points for a three-dimensional understanding of the sample. Scale bars are 1 cm across.

Supplementary Discussion

1. Review on Phanerozoic planispirals

The Ordovician is marked by the first record of uncontroversial *Spirorhaphe* in turbidites from the Grog Brook Group in eastern Canada (Pickerill, 1980, fig. 2b). This specimen is a regular two-way spiral with 1½ whorls; also associated is a regular *Spirodesmos* with 1¼ whorls (Pickerill, 1980, fig. 2d). Fillion & Pickerill (1990, pl. 17, figs 17, 18) described 'scribbling grazing traces' from the Ordovician Redmans Fm. in eastern Canada; few of these specimens represent distinctive one-way spirals with 1–1½ whorls (i.e. *Spirodesmos* affinity; Fillion & Pickerill, 1990, pl. 17, fig. 18). In eastern China, the Ordovician Yuqian Fm. contains an assemblage of trace fossils with *Spirodesmos kaihuaensis* deposited in deep-water turbidites (Xia *et al.* 1987; Jin & Li, 1998); these are irregular one-way spirals made of 3–5 whorls (Xia *et al.* 1987, pl. 1, fig. 1). Crimes *et al.* (1974, fig. 2) mentioned *Spirophycus* in turbidites from the Ordovician Agüeira Fm. of northwestern Spain, but only a sketch representing an irregular one-way spiral with 1¼ whorls is provided. Interestingly, a spiral burrow was reported from the Ordovician Kermeur Fm. in northwestern France (Vidal *et al.* 2011, fig. 4b), close to the locality where a Brioverian spiral was also found (Fig. 2c). Deposited in proximal settings, the irregular one-way spiral burrow has a variable width, develops 1½ whorls and has a fill clearly different from the host rock. Its closest relatives are *Spirophycus* as described by Chamberlain & Clark (1973, pl. 2, fig. 1) from the Carboniferous of western USA, and by Mikuláš (1993, pl. 2, fig. 1) from the Ordovician of northern Czech Republic. Finally, *Spirodesmos spiralis* from the Ordovician Železný Brod Phyllites of northern Czech Republic (Chlupáč, 1997, pl. 6, fig. 2) is deformed (possibly due to metamorphism), and its ichnotaxonomic affiliation is problematic.

After the Ordovician, abundant *Spirophycus* (e.g. Sacco, 1888; Chamberlain & Clark, 1973; Crimes, 1977; Książkiewicz, 1977; Crimes & McCall, 1995; Buatois *et al.* 2001;

Uchman, 2007) and *Spirorhaphe* (e.g. Abel, 1935, pp. 291, 292; Macsotay, 1967; Książkiewicz, 1977; McCann & Pickerill, 1988; Crimes & McCall, 1995; Uchman, 2001; Monaco & Trecci, 2014) were reported from the deep-sea as part of the *Nereites* ichnofacies. Most of the record of post-Ordovician deep-marine *Spirodesmos* is coming from the Carboniferous Culm Facies of Germany and Czech Republic, represented by *S. archimedeus* (Huckriede, 1952; Zapletal & Pek, 1971; Horn, 1989; Pek & Zapletal, 1990), *S. interruptus* (Andrée, 1920; Horn, 1989), and *S. spiralis* (Geinitz, 1867; Stepanek & Geyer, 1989; Pek & Zapletal, 1990). Other occurrences of *Spirodesmos* in the Phanerozoic are: (1) from the Triassic Al Ayn Fm. of Oman, with only ½ whorl preserved which is problematic (Wetzel *et al.* 2007); and (2) from the Eocene Kayo Fm. of northeastern Japan, with 3½ whorls preserved (Fukuda & Hayasaka, 1978).

Continental occurrences are scarce and only comprise a large *Spirodesmos interruptus* from the Carboniferous Mansfield Fm. of northeastern USA (Archer & Maples, 1984, fig. 5b). This irregular one-way spiral has 1½ whorls, and is made of segments of variable length; Rindsberg & Kopaska-Merkel (2005) argued for a *Treptichnus* affinity instead. Kim *et al.* (2002, fig. 5h) recorded a partially preserved *Spirodesmos* isp. from the Cretaceous Hasandong Fm. of southern Korea; with the absence of at least one fully developed whorl, this continental occurrence remains dubious.

In marginal-marine settings, Minter *et al.* (2006) and Minter & Braddy (2009) reported cf. *Spirorhaphe azteca* from the Permian Robledo Mountains Fm. of southern USA. These are regular one-way spirals with closely spaced, millimetric whorls (up to 19 whorls; Minter *et al.* 2006, fig. 1).

In shallow-marine environments, *Spirodesmos archimedeus* is reported from the Permian Vryheid Fm. of eastern South-Africa (Mason *et al.* 1983). These regular one-way spirals, with 1¼–1½ whorls, are reminiscent of the Ordovician ‘scribbling grazing traces’ of

Fillion & Pickerill (1990, pl. 17, fig. 18). *Macaronichnus segregatis spiriformis* Bromley, Milàn, Uchman & Hansen, 2009 has been reported from the Cretaceous Horseshoe Canyon Fm. of western Canada (Pemberton *et al.* 2001). Although these planispirals are regular with multiple whorls, they differ from other spiral trace fossils by their light-colored infill and their thin, dark mantle (Pemberton *et al.* 2001, fig. 104). Finally, Gierlowski-Kordesch & Ernst (1987) reported a unique assemblage of graphoglyptids with *Spirorhaphe* deposited under storm conditions in the Cretaceous Nangurukuru Fm. of southeastern Tanzania (see also Ernst & Zanders, 1993; Nicholas *et al.* 2006).

2. Review on modern planispirals

From continental settings, Schäfer (1965) reported one-way, tightly coiled spirals from mud banks of the Rhine river in Germany. Although Schäfer (1965) suspected grazing gastropod tracemakers, he failed in observing an animal in action. MacNaughton (2003) found one-way spirals with either irregular tight whorls or regular whorls increasing space outward (i.e. logarithmic spirals) from a lake beach in eastern Canada. MacNaughton (2003) suspected a small infaunal arthropod to be the originator. Muñiz Guinea *et al.* (2014) described regular one-way spirals from a wet orange grove in southwestern Spain. These traces were made by an infaunal fly larvae, and are continuous (incipient *Spirodesmos*) or displaying lateral projections (combination of incipient *Spirodesmos* and *Treptichnus*). Finally, a one-way spiral trace was reported by Metz (1987, fig. 4) from a puddle in eastern USA, made by an epifaunal ground beetle larva.

In tidal settings, *Paraonis* polychaete worms are well-known for constructing infaunal, tightly-coiled regular one-way spirals (Röder, 1971; Schäfer, 1972, p. 296; Risk & Tunnicliffe, 1978; Bromley, 1996, pp. 105-108; Minter *et al.* 2006; Lehane & Ekdale, 2013). The burrow system is made of multiple horizontal spirals occupying different vertical levels, and connected by vertical shafts (Gripp, 1927; Röder, 1971; Gingras *et al.* 1999). In addition,

incipient *Macaronichnus segregatis spiriformis* are made by *Ophelia* and *Thoracophelia* polychaete worms in beach sands (Pemberton *et al.* 2001; Bromley *et al.* 2009; Quiroz *et al.* 2019).

Owing to the development of submarine photography in the middle of the 20th century (Ewing *et al.* 1946; Emery, 1952), the deep ocean exposed two categories of spiral traces: (1) one-way spirals (incipient *Spirodesmos*), and (2) two-way spirals (incipient *Spirorhaphe*). Reports of one-way spirals are prolific in the literature (e.g. Bourne & Heezen, 1965; Hülsemann, 1966; Jacobs *et al.* 1970, pp. 391, 445; Lemche *et al.* 1976; Foell & Pawson, 1986; Holland *et al.* 2005; Durden *et al.* 2019); they are made by acorn worms, a type of giant enteropneust (Bourne & Heezen, 1965; Holland *et al.* 2005), and can be extremely abundant below 2500 m (Heezen & Hollister, 1971, pp. 176, 177; Kitchell *et al.* 1978*a*, *b*; Kitchell, 1979; Bell *et al.* 2013). Two-way spiral traces are more rarely photographed on the deep-sea floor (Ewing & Davis, 1967; Ekdale & Berger, 1978; Berger *et al.* 1979; Ekdale, 1980; Ekdale *et al.* 1984), and their tracemaker has never been identified.

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Isoto

Analysis_#	Pb ppm	Uppm	Th ppm	Th/U	Pb207/U235	PropErr2sigAbs.
Carrière de Lammerais:						
S-230517a-01	49	534	48	0.09	0.947	0.012
S-230517a-02	16	164	60	0.37	0.779	0.010
S-230517a-03	65	151	152	1.00	6.876	0.087
S-230517a-04	27	278	103	0.37	0.770	0.010
S-230517a-05	11	111	53	0.48	0.770	0.011
S-230517a-06	29	300	130	0.43	0.752	0.010
S-230517a-07	27	333	18	0.05	0.748	0.010
S-230517a-08	23	259	75	0.29	0.727	0.010
S-230517a-09	11	114	38	0.33	0.819	0.011
S-230517a-10	61	565	278	0.49	0.838	0.011
S-230517a-11	20	194	83	0.43	0.787	0.011
S-230517a-12	18	178	68	0.38	0.839	0.012
S-230517a-13	34	316	201	0.64	0.791	0.010
S-230517a-14	18	186	92	0.49	0.760	0.010
S-230517a-15	45	504	153	0.30	0.728	0.010
S-230517a-16	30	294	106	0.36	0.810	0.011
S-230517a-17	20	205	63	0.31	0.792	0.011
S-230517a-18	19	189	57	0.30	0.805	0.011
S-230517a-19	18	190	42	0.22	0.811	0.011
S-230517a-20	23	235	69	0.29	0.816	0.012
S-230517a-21	17	179	64	0.36	0.756	0.011
S-230517a-22	31	333	134	0.40	0.749	0.010
S-230517a-23	18	196	56	0.29	0.786	0.012
S-230517a-24	18	193	63	0.33	0.785	0.011
S-230517b-01	36	369	294	0.80	0.826	0.011
S-230517b-02	26	293	105	0.36	0.738	0.010
S-230517b-03	18	178	64	0.36	0.793	0.011
S-230517b-04	33	336	101	0.30	0.809	0.011
S-230517b-05	44	451	118	0.26	0.812	0.011
S-230517b-06	27	275	83	0.30	0.806	0.011
S-230517b-07	25	254	77	0.30	0.851	0.011
S-230517b-08	39	383	229	0.60	0.772	0.010
S-230517b-09	25	263	89	0.34	0.759	0.010
S-230517b-10	36	380	192	0.50	0.743	0.010
S-230517b-11	25	261	54	0.21	0.837	0.011
S-230517b-12	41	446	87	0.20	0.807	0.011
S-230517b-13	21	177	94	0.53	0.948	0.013
S-230517b-15	72	720	289	0.40	0.792	0.010
S-230517b-16	20	192	94	0.49	0.793	0.011
S-230517b-17	40	431	156	0.36	0.751	0.010
S-230517b-18	22	265	48	0.18	0.704	0.009
S-230517b-19	27	311	54	0.17	0.722	0.010
S-230517b-21	60	410	117	0.29	1.439	0.019

S-230517b-22	29	313	102	0.33	0.764	0.010
S-230517b-23	28	284	115	0.40	0.766	0.010
S-230517b-24	24	281	80	0.29	0.710	0.010
S-230517c-01	48	516	128	0.25	0.781	0.010
S-230517c-02	66	813	17	0.02	0.756	0.010
S-230517c-03	29	248	88	0.35	1.008	0.013
S-230517c-04	39	386	165	0.43	0.812	0.011
~~S-230517c-05~~	~~107~~	~~1195~~	~~186~~	~~0.16~~	~~1.278~~	~~0.016~~
S-230517c-06	38	379	129	0.34	0.813	0.011
S-230517c-07	35	355	125	0.35	0.810	0.011
S-230517c-08	18	187	42	0.23	0.800	0.011
S-230517c-09	28	308	85	0.27	0.772	0.010
S-230517c-10	24	264	35	0.13	0.771	0.010
S-230517c-11	29	331	94	0.29	0.712	0.009
S-230517c-12	33	357	147	0.41	0.730	0.010
S-230517c-13	70	813	167	0.21	0.770	0.010
S-230517c-14	33	344	70	0.20	0.808	0.011
S-230517c-15	26	257	59	0.23	0.863	0.011
S-230517c-16	27	253	56	0.22	0.936	0.013
S-230517c-17	10	65	34	0.53	1.333	0.019
S-230517c-18	39	348	90	0.26	0.959	0.013
S-230517c-19	23	110	91	0.83	1.792	0.024
S-230517c-20	31	315	108	0.34	0.804	0.011
S-230517c-21	30	302	114	0.38	0.846	0.011
S-230517c-22	27	281	88	0.31	0.787	0.010
S-230517c-23	28	299	74	0.25	0.780	0.010
S-230517c-24	43	451	45	0.10	0.860	0.011
S-230517d-01	86	897	262	0.29	0.784	0.010
S-230517d-02	493	1011	276	0.27	10.172	0.127
S-230517d-03	161	394	160	0.41	6.604	0.083
S-230517d-04	71	193	86	0.45	5.350	0.067
S-230517d-05	165	425	114	0.27	6.486	0.081
S-230517d-06	253	758	24	0.03	5.792	0.073
S-230517d-07	85	206	100	0.49	6.658	0.084
S-230517d-08	139	230	56	0.24	14.951	0.188
S-230517d-09	192	645	12	0.02	4.876	0.062
S-230517d-10	108	309	179	0.58	6.851	0.087
S-230517d-11	100	184	16	0.09	13.293	0.169
S-230517d-12	65	160	79	0.50	6.183	0.079
S-230517d-13	30	283	165	0.58	0.801	0.011
S-230517d-14	104	809	1084	1.34	0.871	0.011
S-230517d-15	8	86	25	0.29	0.908	0.013
S-230517d-16	24	183	153	0.84	1.174	0.016
S-230517d-17	12	49	51	1.04	2.352	0.037
S-230517d-18	24	249	96	0.39	0.949	0.013
S-230517d-19	21	212	97	0.46	0.807	0.011

S-230517d-20	31	313	111	0.36	0.799	0.011
S-230517d-21	15	148	128	0.86	0.704	0.010
S-230517d-22	39	419	136	0.32	0.770	0.010
S-230517d-23	26	261	114	0.44	0.791	0.011
S-230517d-24	30	238	231	0.97	0.915	0.013
S-230517e-01	6	59	26	0.45	0.785	0.012
S-230517e-02	52	521	319	0.61	0.745	0.010
S-230517e-03	17	186	42	0.23	0.894	0.012
S-230517e-04	16	172	78	0.45	0.724	0.010
S-230517e-05	17	181	59	0.32	0.775	0.010
S-230517e-06	24	257	89	0.35	0.759	0.010
S-230517e-07	41	405	178	0.44	0.794	0.010
S-230517e-08	17	167	71	0.43	1.018	0.013
S-230517e-09	14	140	55	0.39	0.807	0.011
S-230517e-10	21	214	54	0.25	0.803	0.011
S-230517e-11	27	292	31	0.11	0.808	0.011
S-230517e-12	34	359	77	0.21	0.809	0.011
S-230517e-13	34	351	52	0.15	0.949	0.012
S-230517e-14	69	687	235	0.34	0.852	0.011
S-230517e-15	11	104	57	0.54	0.766	0.011
S-230517e-16	28	308	114	0.37	0.730	0.010
S-230517e-17	15	125	45	0.36	1.146	0.016
S-230517e-18	43	476	139	0.29	0.736	0.010
S-230517e-19	21	224	40	0.18	0.792	0.011
S-230517e-20	31	321	81	0.25	0.783	0.010
S-230517e-21	22	233	120	0.52	0.720	0.010
S-230517e-22	26	255	99	0.39	0.805	0.011
S-230517e-23	26	254	175	0.69	0.810	0.011
S-230517e-24	48	481	311	0.65	0.731	0.010
Carrière le Lorinou						
S-140414a-1	25	280	94	0.33	0.741	0.009
S-140414a-2	9	96	35	0.37	0.760	0.010
S-140414a-3	242	631	189	0.30	6.313	0.076
S-140414a-4	12	103	39	0.38	0.977	0.013
S-140414a-5	45	476	79	0.17	0.817	0.010
S-140414a-6	3	27	13	0.50	0.885	0.017
S-140414a-7	36	360	159	0.44	0.772	0.010
S-140414a-8	15	169	54	0.32	0.715	0.009
S-140414a-9	94	144	84	0.59	13.867	0.168
S-140414a-10	30	255	194	0.76	0.909	0.012
S-140414a-11	15	143	67	0.47	0.822	0.011
S-140414a-12	41	101	68	0.67	5.736	0.071
S-140414a-13	22	207	78	0.38	0.840	0.011
S-140414a-14	67	117	124	1.06	10.163	0.125
S-140414a-15	45	356	130	0.37	1.090	0.014

S-140414a-16	214	362	165	0.46	14.056	0.172
S-140414a-17	35	80	54	0.68	6.804	0.085
S-140414a-18	52	113	55	0.49	8.106	0.100
S-140414a-19	133	218	26	0.12	16.275	0.200
S-140414a-20	19	164	56	0.34	0.949	0.012
S-140414a-21	148	545	73	0.13	4.200	0.052
S-140414a-22	20	132	91	0.69	1.268	0.017
S-140414a-23	56	470	213	0.45	1.005	0.014
S-140414a-24	9	90	28	0.31	0.811	0.011
S-140414a-25	16	45	26	0.56	5.017	0.065
S-140414a-26	3	34	15	0.46	0.834	0.014
S-140414a-27	23	176	73	0.41	1.104	0.014
S-140414a-28	195	566	42	0.07	5.907	0.074
S-140414a-29	28	235	134	0.57	0.950	0.012
S-140414a-30	57	124	56	0.45	8.017	0.102
S-140414a-31	14	119	87	0.73	0.935	0.013
S-140414a-32	26	179	106	0.59	1.168	0.015
S-140414a-33	204	726	270	0.37	3.801	0.046
S-140414a-34	191	570	64	0.11	5.336	0.065
S-140414a-35	27	232	120	0.52	0.941	0.012
S-140414a-36	24	241	46	0.19	0.841	0.011
S-140414a-37	18	159	121	0.76	0.797	0.011
S-140414a-38	5	40	42	1.05	0.979	0.015
S-140414a-39	24	129	146	1.13	1.421	0.018
S-140414a-40	30	281	164	0.59	0.807	0.010
S-140414a-41	22	57	73	1.29	4.682	0.059
S-140414a-42	41	414	196	0.47	0.802	0.010
S-140414a-43	13	131	49	0.37	0.845	0.011
S-140414a-44	20	185	127	0.69	0.823	0.011
S-140414a-45	72	127	48	0.37	14.286	0.175
S-140414a-46	32	195	70	0.36	1.617	0.021
S-140414a-47	144	357	122	0.34	6.854	0.084
S-140414a-48	34	367	152	0.41	0.760	0.010
S-140414a-49	12	125	38	0.30	0.783	0.011
S-140414a-50	22	222	61	0.27	0.802	0.010
S-140414a-51	58	343	131	0.38	1.703	0.021
S-140414a-52	9	65	88	1.35	0.882	0.013
S-140414a-53	4	42	13	0.31	0.794	0.013
S-140414a-54	15	160	39	0.25	0.804	0.011
S-140414a-55	27	212	240	1.13	0.838	0.011
S-140414a-56	24	232	102	0.44	0.855	0.012
S-140414a-57	24	246	52	0.21	0.806	0.011
S-140414a-58	2	21	7	0.34	0.912	0.016
S-140414a-59	55	138	58	0.42	6.251	0.079
S-140414a-60	27	264	120	0.46	0.801	0.011
S-140414a-61	124	273	97	0.36	8.212	0.104

S-140414a-62	13	138	44	0.32	0.787	0.011
S-140414a-63	8	78	37	0.48	0.804	0.012
S-140414a-64	20	199	74	0.37	0.814	0.011
S-140414a-65	10	64	53	0.82	1.153	0.016
S-140414a-66	11	101	39	0.39	0.887	0.012
S-140414a-67	69	161	68	0.42	6.961	0.089
S-140414a-68	9	85	44	0.52	0.859	0.013
S-140414a-69	22	147	100	0.68	1.231	0.016
S-140414a-70	6	52	49	0.93	0.874	0.015
S-140414a-71	24	239	131	0.55	0.765	0.010
S-140414a-72	62	622	112	0.18	0.883	0.011
S-140414a-73	44	394	415	1.05	0.776	0.010
S-140414a-74	48	552	126	0.23	0.726	0.009
S-140414a-75	143	245	153	0.63	12.112	0.144
S-140414a-76	19	213	85	0.40	0.727	0.010
S-140414a-77	18	162	102	0.63	0.854	0.014
S-140414a-78	37	57	32	0.56	13.935	0.172
S-140414a-79	60	116	30	0.26	11.560	0.141
S-140414a-80	19	191	53	0.28	0.834	0.012
S-140414a-81	25	267	14	0.05	0.863	0.012
S-140414a-82	58	649	243	0.37	0.711	0.009
S-140414a-83	41	186	206	1.11	1.800	0.023
S-140414a-84	17	39	35	0.88	6.278	0.083
S-140414a-85	43	434	144	0.33	0.824	0.011
S-140414a-86	8	68	71	1.05	0.818	0.014
S-140414a-87	49	284	164	0.58	1.580	0.021
S-140414a-88	12	127	37	0.30	0.769	0.012
S-140414a-89	28	56	80	1.42	6.209	0.083

opic Ratios						***Appar***
Pb206/U238	PropErr2sigAbs.	Rho	Conc.	Pb207/Pb206	PropErr2sigAbs.	Pb206/U238
0.0932	0.0012	0.97	85	1033	21	575
0.0948	0.0012	0.93	100	590	24	584
0.3341	0.0042	0.98	90	2338	18	1858
0.0938	0.0012	0.96	100	586	23	578
0.0945	0.0012	0.90	100	570	25	582
0.0933	0.0012	0.95	101	550	24	575
0.0847	0.0011	0.94	93	741	24	524
0.0901	0.0011	0.94	100	550	24	556
0.0938	0.0012	0.90	95	719	25	578
0.1007	0.0013	0.96	100	616	23	618
0.0965	0.0012	0.93	101	573	25	594
0.0950	0.0012	0.91	95	743	24	585
0.0964	0.0012	0.95	100	588	24	593
0.0936	0.0012	0.93	100	564	25	577
0.0888	0.0011	0.93	99	585	24	548
0.0985	0.0012	0.94	100	593	23	605
0.0974	0.0012	0.92	101	566	25	599
0.0985	0.0012	0.92	101	578	25	606
0.0980	0.0012	0.92	100	604	25	603
0.0978	0.0012	0.90	99	622	26	602
0.0919	0.0012	0.90	99	593	25	567
0.0909	0.0012	0.93	99	595	25	561
0.0936	0.0012	0.87	98	636	27	577
0.0953	0.0012	0.91	100	594	26	587
0.0817	0.0010	0.94	83	1025	23	506
0.0869	0.0011	0.95	96	661	23	537
0.0964	0.0012	0.94	100	592	24	593
0.0976	0.0012	0.95	100	608	24	600
0.0977	0.0012	0.97	100	615	23	601
0.0978	0.0012	0.95	100	595	24	602
0.0982	0.0012	0.94	97	704	23	604
0.0941	0.0012	0.95	100	585	24	580
0.0926	0.0012	0.94	100	582	24	571
0.0901	0.0011	0.96	99	598	23	556
0.0948	0.0012	0.92	95	743	25	584
0.0943	0.0012	0.96	97	676	23	581
0.1075	0.0014	0.93	97	739	24	658
0.0966	0.0012	0.97	100	584	23	595
0.0962	0.0012	0.93	100	595	25	592
0.0913	0.0011	0.95	99	590	24	564
0.0860	0.0011	0.93	98	579	25	532
0.0880	0.0011	0.93	98	587	24	544
0.1438	0.0018	0.95	96	1003	22	866

0.0923	0.0012	0.93	99	607	25	569
0.0937	0.0012	0.93	100	578	25	577
0.0850	0.0011	0.90	97	625	25	526
0.0944	0.0012	0.97	99	605	23	581
0.0889	0.0011	0.95	96	664	23	549
0.1150	0.0014	0.95	99	727	23	702
0.0983	0.0012	0.96	100	601	23	605
~~0.0787~~	~~0.0010~~	~~0.97~~	~~58~~	~~1922~~	~~19~~	~~489~~
0.0980	0.0012	0.95	100	612	23	603
0.0975	0.0012	0.96	100	612	23	600
0.0976	0.0012	0.93	101	584	24	601
0.0922	0.0012	0.93	98	630	24	568
0.0938	0.0012	0.95	100	588	24	578
0.0871	0.0011	0.94	99	576	24	539
0.0880	0.0011	0.93	98	611	24	544
0.0858	0.0011	0.94	92	776	23	531
0.0971	0.0012	0.94	99	617	24	597
0.1008	0.0013	0.94	98	678	24	619
0.1066	0.0013	0.93	97	733	24	653
0.1428	0.0018	0.88	100	860	25	861
0.1122	0.0014	0.94	100	675	24	685
0.1743	0.0022	0.92	99	1056	23	1036
0.0944	0.0012	0.93	97	666	24	581
0.0964	0.0012	0.92	95	731	24	593
0.0958	0.0012	0.92	100	588	25	590
0.0948	0.0012	0.93	100	591	25	584
0.1006	0.0012	0.93	98	675	24	618
0.0949	0.0012	0.98	99	602	22	584
0.4497	0.0056	0.99	98	2498	17	2394
0.3763	0.0047	0.99	100	2061	18	2059
0.3384	0.0042	0.98	100	1875	19	1879
0.3709	0.0046	0.99	99	2055	18	2034
0.3395	0.0042	0.99	97	2011	18	1884
0.3753	0.0047	0.98	99	2080	18	2054
0.5480	0.0068	0.98	100	2809	17	2817
0.3069	0.0038	0.97	95	1884	19	1725
0.3031	0.0038	0.98	84	2497	18	1707
0.5178	0.0064	0.98	100	2709	17	2690
0.3660	0.0045	0.97	100	1994	19	2010
0.0961	0.0012	0.94	99	620	24	592
0.0987	0.0012	0.95	95	742	23	607
0.0910	0.0011	0.85	86	997	26	561
0.1109	0.0014	0.91	86	1117	23	678
0.2064	0.0026	0.82	97	1261	27	1210
0.0908	0.0011	0.92	83	1089	23	560
0.0966	0.0012	0.92	99	625	25	595

0.0968	0.0012	0.93	100	601	25	595
0.0876	0.0011	0.88	100	539	27	541
0.0918	0.0011	0.92	98	634	24	566
0.0966	0.0012	0.91	100	582	25	594
0.1056	0.0013	0.91	98	703	25	647
0.0945	0.0012	0.83	99	613	29	582
0.0914	0.0011	0.97	100	573	23	564
0.0882	0.0011	0.94	84	1029	22	545
0.0895	0.0011	0.93	100	555	25	553
0.0931	0.0012	0.92	98	619	25	574
0.0937	0.0012	0.95	101	557	24	578
0.0972	0.0012	0.96	101	575	23	598
0.0946	0.0012	0.94	82	1148	22	583
0.0964	0.0012	0.91	99	630	25	593
0.0975	0.0012	0.94	100	595	24	600
0.0980	0.0012	0.95	100	595	24	603
0.0979	0.0012	0.96	100	600	24	602
0.0981	0.0012	0.96	89	934	22	603
0.0977	0.0012	0.96	96	717	23	601
0.0940	0.0012	0.88	100	569	26	579
0.0879	0.0011	0.94	98	613	24	543
0.1184	0.0015	0.89	93	935	25	721
0.0896	0.0011	0.95	99	589	24	553
0.0964	0.0012	0.93	100	589	25	594
0.0959	0.0012	0.94	101	576	24	590
0.0895	0.0011	0.91	100	544	26	552
0.0975	0.0012	0.91	100	600	25	600
0.0897	0.0011	0.92	92	790	24	554
0.0894	0.0011	0.93	99	579	24	552
0.0894	0.0011	0.94	91	609	24	552
0.0920	0.0011	0.88	94	602	26	567
0.3623	0.0043	1.00	97	2048	18	1993
0.1104	0.0013	0.91	90	747	25	675
0.0981	0.0012	0.98	98	618	23	603
0.1037	0.0013	0.65	95	671	39	636
0.0952	0.0011	0.96	104	562	23	586
0.0892	0.0011	0.92	103	536	26	551
0.5555	0.0067	0.99	107	2663	17	2848
0.1030	0.0012	0.94	85	741	23	632
0.0987	0.0012	0.90	98	619	25	607
0.3582	0.0043	0.97	104	1898	19	1974
0.1006	0.0012	0.94	99	626	24	618
0.4482	0.0054	0.98	95	2502	18	2387
0.1230	0.0015	0.96	100	750	23	748

0.5105	0.0061	0.98	94	2824	17	2659
0.3770	0.0046	0.97	98	2110	19	2062
0.4146	0.0050	0.97	99	2249	18	2236
0.5637	0.0068	0.98	99	2901	17	2882
0.1118	0.0014	0.92	104	660	24	683
0.2718	0.0033	0.97	85	1834	19	1550
0.1349	0.0016	0.92	93	874	24	816
0.1120	0.0014	0.89	88	779	25	684
0.0943	0.0012	0.88	85	686	26	581
0.3251	0.0039	0.93	99	1832	20	1814
0.0953	0.0012	0.73	81	725	33	587
0.1255	0.0015	0.93	104	734	24	762
0.3486	0.0042	0.96	96	1999	19	1928
0.1099	0.0013	0.92	96	698	24	672
0.4147	0.0050	0.95	100	2230	19	2236
0.1038	0.0013	0.90	81	784	25	637
0.1299	0.0016	0.95	101	781	23	788
0.2606	0.0031	0.99	86	1728	19	1493
0.3359	0.0041	0.99	99	1884	18	1867
0.1104	0.0013	0.95	101	669	23	675
0.1010	0.0012	0.95	101	616	23	620
0.0980	0.0012	0.92	106	566	25	603
0.1136	0.0014	0.81	100	691	29	694
0.1502	0.0018	0.95	101	889	23	902
0.0968	0.0012	0.95	96	621	24	595
0.2947	0.0036	0.96	88	1884	20	1665
0.0946	0.0011	0.96	89	658	23	582
0.0960	0.0012	0.90	80	736	25	591
0.0948	0.0012	0.90	82	708	25	584
0.4958	0.0060	0.98	90	2898	17	2596
0.1590	0.0019	0.94	92	1036	22	951
0.3765	0.0045	0.98	97	2126	18	2060
0.0896	0.0011	0.95	84	659	23	553
0.0947	0.0012	0.88	97	603	27	583
0.0971	0.0012	0.92	100	600	25	597
0.1593	0.0019	0.96	84	1135	21	953
0.1036	0.0013	0.85	95	667	28	635
0.0975	0.0012	0.75	105	569	33	600
0.0949	0.0012	0.91	89	657	25	584
0.1010	0.0012	0.92	102	610	25	620
0.0991	0.0012	0.89	88	695	25	609
0.0985	0.0012	0.93	104	580	25	606
0.1061	0.0013	0.69	95	685	36	650
0.3673	0.0044	0.95	100	2007	19	2017
0.0977	0.0012	0.92	103	585	25	601
0.4180	0.0050	0.95	100	2258	19	2251

0.0958	0.0012	0.89	100	589	26	590
0.0983	0.0012	0.85	104	580	28	604
0.0966	0.0012	0.90	92	644	25	594
0.1292	0.0016	0.86	102	766	27	783
0.1056	0.0013	0.87	101	638	27	647
0.3884	0.0047	0.94	101	2098	20	2115
0.1016	0.0012	0.75	96	649	32	624
0.1317	0.0015	0.87	92	863	25	797
0.1010	0.0012	0.70	88	701	34	620
0.0936	0.0011	0.86	100	577	27	577
0.1027	0.0012	0.91	92	687	24	630
0.0921	0.0011	0.89	88	644	25	568
0.0893	0.0010	0.92	97	566	25	551
0.4940	0.0056	0.96	98	2633	18	2588
0.0871	0.0010	0.84	86	625	27	538
0.0978	0.0012	0.71	83	721	34	601
0.5518	0.0063	0.93	106	2682	19	2833
0.4700	0.0054	0.93	94	2638	18	2483
0.0983	0.0011	0.83	92	658	28	605
0.1001	0.0011	0.84	89	693	27	615
0.0863	0.0010	0.89	89	597	25	533
0.1758	0.0020	0.88	100	1049	24	1044
0.3550	0.0041	0.87	94	2074	22	1959
0.0970	0.0011	0.88	90	662	26	597
0.0986	0.0012	0.68	99	610	36	606
0.1515	0.0017	0.86	84	1086	25	909
0.0928	0.0011	0.76	94	607	31	572
0.3647	0.0042	0.85	100	2007	22	2004

ent Ages

PropErr2sigAbs.	Pb207/U235	PropErr2sigAbs.
7	677	6
7	585	6
20	2096	11
7	580	6
7	580	6
7	570	6
6	567	6
7	555	6
7	607	6
7	618	6
7	589	6
7	618	6
7	592	6
7	574	6
7	555	6
7	603	6
7	592	6
7	600	6
7	603	6
7	606	6
7	572	6
7	568	6
7	589	7
7	588	6
6	612	6
6	561	6
7	593	6
7	602	6
7	604	6
7	600	6
7	625	6
7	581	6
7	573	6
7	564	6
7	618	6
7	601	6
8	677	7
7	592	6
7	593	6
7	569	6
6	541	6
7	552	6
10	905	8

7	577	6
7	577	6
6	545	6
7	586	6
7	572	6
8	708	7
7	604	6
~~6~~	~~836~~	~~7~~
7	604	6
7	602	6
7	597	6
7	581	6
7	580	6
6	546	6
6	557	6
6	580	6
7	601	6
7	632	6
8	671	7
10	860	8
8	683	7
12	1042	9
7	599	6
7	622	6
7	589	6
7	585	6
7	630	6
7	588	6
25	2451	12
22	2060	11
20	1877	11
22	2044	11
20	1945	11
22	2067	11
28	2812	12
19	1798	11
19	2092	11
27	2701	12
21	2002	11
7	598	6
7	636	6
7	656	7
8	789	7
14	1228	11
7	677	7
7	601	6

7	597	6
7	541	6
7	580	6
7	592	6
8	660	7
7	588	7
7	565	6
7	648	6
7	553	6
7	583	6
7	573	6
7	593	6
7	713	7
7	601	6
7	599	6
7	601	6
7	602	6
7	678	6
7	626	6
7	577	6
6	557	6
9	775	8
7	560	6
7	593	6
7	587	6
7	551	6
7	600	6
7	602	6
7	557	6
6	563	5
7	574	6
21	2020	11
8	692	7
7	606	6
8	644	9
7	581	6
6	548	6
28	2741	11
7	656	6
7	609	6
20	1937	11
7	619	6
24	2450	11
9	748	7

26	2754	12
21	2086	11
23	2243	11
28	2893	12
8	678	7
17	1674	10
9	831	7
8	707	7
7	603	6
19	1822	11
7	616	8
9	755	7
20	1962	11
8	678	6
23	2233	11
7	670	7
9	786	7
16	1593	10
20	1875	10
8	674	6
7	620	6
7	595	6
8	693	8
10	898	8
7	601	6
18	1764	11
7	598	6
7	622	6
7	610	6
26	2769	12
11	977	8
21	2093	11
6	574	6
7	587	6
7	598	6
11	1010	8
7	642	7
7	593	7
7	599	6
7	618	6
7	627	6
7	600	6
8	658	9
21	2012	11
7	597	6
23	2255	11

7	590	6
7	599	6
7	605	6
9	779	8
7	645	7
22	2106	11
7	629	7
9	815	7
7	638	8
6	577	6
7	642	6
6	583	6
6	554	5
24	2613	11
6	555	6
7	627	8
26	2745	12
23	2569	11
7	616	6
7	632	6
6	546	5
11	1045	8
19	2015	12
6	610	6
7	607	8
10	963	8
6	579	7
20	2006	12

	Pb207/U235	ErrAbs	Pb206/U238	ErrAbs	rho
Pleso 1	0.3947	0.0054	0.05345	0.00067	0.92
Pleso 2	0.3996	0.0064	0.05317	0.00068	0.79
Pleso 3	0.3966	0.0053	0.05375	0.00067	0.94
Pleso 4	0.3956	0.0053	0.05384	0.00067	0.93
Pleso 5	0.3981	0.0053	0.05342	0.00067	0.94
Pleso 6	0.3966	0.0053	0.05321	0.00066	0.92
Pleso 7	0.3938	0.0053	0.05377	0.00066	0.92
Pleso 8	0.3892	0.0052	0.05379	0.00067	0.93
Pleso 9	0.3924	0.0053	0.05329	0.00066	0.92
Pleso 10	0.3920	0.0054	0.05336	0.00067	0.91
Pleso 11	0.3943	0.0052	0.05371	0.00067	0.94
Pleso 12	0.3889	0.0051	0.05374	0.00067	0.94
Pleso 13	0.3895	0.0053	0.05364	0.00067	0.92
Pleso 14	0.3918	0.0051	0.05378	0.00065	0.93
Pleso 15	0.3905	0.0050	0.05375	0.00065	0.94
Pleso 16	0.3908	0.0052	0.05377	0.00065	0.91
Pleso 17	0.3895	0.0051	0.05379	0.00065	0.93
Pleso 18	0.3924	0.0054	0.05388	0.00065	0.88
Pleso 19	0.3949	0.0049	0.05364	0.00064	0.96
Pleso 20	0.3949	0.0050	0.05370	0.00064	0.94
Pleso 21	0.3916	0.0049	0.05369	0.00064	0.95
Pleso 22	0.3944	0.0050	0.05349	0.00064	0.94
Pleso 23	0.3939	0.0051	0.05383	0.00064	0.92
Pleso 24	0.3962	0.0049	0.05392	0.00065	0.97
Pleso 25	0.3945	0.0049	0.05384	0.00064	0.95
Pleso 26	0.3998	0.0050	0.05351	0.00064	0.95
Pleso 27	0.3941	0.0050	0.05369	0.00064	0.93
Pleso 28	0.3928	0.0050	0.05377	0.00064	0.93
Pleso 29	0.3872	0.0050	0.05365	0.00065	0.95
Pleso 30	0.3927	0.0053	0.05344	0.00065	0.91
Pleso 31	0.3939	0.0051	0.05379	0.00065	0.94
Pleso 32	0.3909	0.0052	0.05369	0.00065	0.90
Pleso 33	0.3932	0.0053	0.05376	0.00065	0.89
Pleso 34	0.3955	0.0050	0.05379	0.00062	0.91
Pleso 35	0.3947	0.0053	0.05377	0.00061	0.85
Pleso 36	0.3945	0.0053	0.05342	0.00061	0.84